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**Instructor's Manual**  
*to accompany*

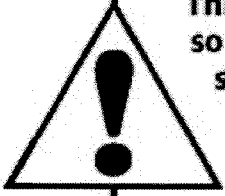
# **APPLIED FLUID MECHANICS**

**Sixth Edition**

**Robert L. Mott**  
University of Dayton



Upper Saddle River, New Jersey  
Columbus, Ohio



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**APPLIED FLUID MECHANICS  
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**Prentice-Hall Publishing Company**

**Description of Spreadsheets Included on the CD in the Book**

**Introduction**

This book includes a CD-ROM that contains ten computational aids that are keyed to the book. The files are written as Microsoft Excel spreadsheets using Version 2002 on Windows XP.

The ten spreadsheets are all included in one workbook called Series Pipe Systems-Master. The names of each spreadsheet described below are on the tabs at the bottom of the workbook when it is opened. You must choose which is appropriate for a given problem. Most names start with either *I*, *II*, or *III* indicating whether the spreadsheet is for a Class *I*, Class *II*, or Class *III* pipe line system as defined in Chapter 11 of the text.

The spreadsheets are designed to facilitate the numerous calculations required to solve the variety of problems in Chapter 11 Series Pipeline Systems. Many of the spreadsheets appear in the text. Others were prepared to produce solutions for the Solutions Manual. The given spreadsheets include data and results from certain figures in the text, from example problems, or in problems from the end of Chapters 8, 11, and 13 containing the analysis and design procedures featured in the programs.

The following sections give brief descriptions of each spreadsheet. Many are discussed in the text in more extensive detail. It is expected that you will verify all of the elements of each spreadsheet before using them for solutions to specific problems.

**Using the Spreadsheets:** *It is recommended that the given spreadsheets be maintained as they initially appear on the CD. To use them for solving other problems, call up the master workbook in Excel and use the "Save as" command to name it something different. That version can then be used for a variety of problems of your own choice. Be careful that you do not modify the contents of critical cells containing complex equations. However, you are encouraged to add additional features to the spreadsheets to enhance their utility.*

The principles involved in the spreadsheets come from Chapters 6 - 11 and you should study the concepts and the solution techniques for each type of problem before using the given spreadsheets. It is highly recommended that you work sample problems by hand first. Then enter the appropriate data into the spreadsheet to verify the solution. In most spreadsheets, the data that need to be entered are identified by gray-shaded areas and by italic type. Results are typically shown in bold type.

**I Power SI:** The objective of problems of this type is to compute the amount of power required to drive a pump to deliver a given amount of fluid through a given system. Energy losses are considered. All data must be in the listed SI units. The solution procedure is for a Class I series pipe line system. The following is a summary of the steps you must complete.

1. Enter the problem identification information first. The given data in the spreadsheet are for example Problem 11.1 for the system shown in Figure 11.2.
2. Describe two appropriate reference points for completing the analysis of the general energy equation.
3. Specify the required volume flow rate,  $Q$ , in  $\text{m}^3/\text{s}$ .
4. Enter the pressures (in kPa), velocities (in  $\text{m}/\text{s}$ ), and elevations (in m) at the reference points in the **System Data:** at the top of the sheet. If the velocity at either reference point is in a pipe, you may use a computed velocity from  $v = Q/A$  that is included in the data cells for the two pipes. In such cases, you enter the Excel command "=B20" for the velocity in pipe 1 and "=E20" for the velocity in pipe 2.
5. Enter the fluid properties of specific weight (in  $\text{kN}/\text{m}^3$ ) and kinematic viscosity (in  $\text{m}^2/\text{s}$ ).
6. Enter pipe data, including flow diameter  $D$  (in m), pipe wall roughness  $a$  (in m from Table 8.2), and length  $L$  (in m). Other pipe-related data are computed by the spreadsheet. Equation 8-7 is used to compute the friction factor.
7. Enter energy loss coefficients,  $K$ , for all loss-producing elements in both pipes. See Chapters 8, 10, and 11 for the proper form for  $K$  for each element and for necessary data. The value for  $K$  for pipe friction is computed automatically from known data in the "Pipe" section. Specify the number of like elements in the "Qty." column. Enter brief descriptions of each element so your printout is keyed to the given problem and so you can observe the energy loss contribution of each element. Space is given for up to eight different kinds of energy loss elements. Enter zero for the value of the  $K$  factor for those not needed.
8. The **Results:** section at the bottom of the spreadsheet includes the total energy loss  $h_L$ , the total head on the pump  $h_p$ , and the power added to the fluid by the pump  $P_p$ . If you enter an efficiency for the pump, the power input to the pump  $P$ , is computed.

**I Power US:** Same as **Power SI**; except U.S. Customary units are used. The given solution is for Problem 11.29 for the system shown in Figure 11.26. The first reference point is taken just before the pump inlet. Therefore there are no friction losses or minor losses considered in the suction pipe. The length is given to be zero and all  $K$  factors are zero for Pipe 1. In Pipe 2, pipe friction, the loss in the elbow, and the loss in the nozzle are included.

**I Pressure SI:** Most of the layout and data entry for this spreadsheet are the same as those in the first two spreadsheets, **I Power SI**, and **I Power US**. The difference here is that the analysis determines the pressure at one point in the system when the pressure at some other point is known. Class I systems with one or two pipe sizes including minor losses can be analyzed. This spreadsheet uses the known pressure at some starting point and computes the pressure at a downstream point, considering changes in elevation, velocity head, pipe friction and minor losses. The example is the solution of Problem 11.7 for the

system shown in Figure 11.17.  $p_2$  is assumed to be 100 kPa.  $p_2$  is computed to be 78.21 kPa. Then  $\Delta p = -21.79$  kPa.

**I Pressure US:** This spreadsheet is virtually identical to **I Pressure SI:** except for the different unit system used. The example is the solution for Problem 11.3 using the system shown in Figure 11.13. An important difference occurs here because the objective of the problem is to compute the upstream pressure at the outlet of a pump when the desired downstream pressure at the inlet to the hydraulic cylinder is specified. You should examine the contents of cells B7 and B8 where the pressures are listed and E43 and E44 where the actual calculations for pressure change are performed. The changes demonstrated here between **I Pressure SI:** and **I Pressure US:** show how the spreadsheets can be adapted to specific types of problems. Knowledge of the fluid mechanics of the problems and familiarity with the design of the spreadsheet are required to make such adjustments accurately.

**II-A & II-B SI:** This spreadsheet solves Class II series pipe line problems using either Method II-A or Method II-B as described in Chapter 11 of the text. SI Metric units are used. Example Problem 11.3 using the system shown in Figure 11.7 is solved in the given sheet.

You should review the details of these sheets from the discussions in the book. In summary, Method II-A is used for finding the maximum velocity of flow and volume flow rate that a given pipe can deliver while limiting the pressure drop to a specified value, without any minor losses. This is accomplished by the upper part of the spreadsheet only. Enter the pressures at two system reference points in the **System Data:** near the top of the sheet. Enter other data called for in the gray shaded cells. Refer to Example Problem 11.2 in the text for an illustration of the use of just the upper part of this sheet to solve Class II problems without minor losses.

The lower part of the spreadsheet implements Method II-B for which minor losses are considered in addition to the friction losses in the pipe. The solution procedure is iterative, requiring you to assume a volume flow rate in the upper part of the lower section of the spreadsheet that is somewhat lower than the result of the Method II-A solution directly above. Enter the minor loss coefficients in the lower part of the spreadsheet. As each estimate for flow rate is entered, the pressure at a target point, called  $p_2$ , is computed. You must compare this pressure with the desired pressure. Successive changes in the estimate can be made very rapidly until the desired pressure is acceptable within a small tolerance that you decide.

**II-A & II-B US:** This spreadsheet is identical to **II-A & II-B:** except for using the U.S. Customary unit system. Problem 11.10 is solved in the example. The system in this problem has no minor losses so the upper part of the spreadsheet shows the most pertinent data and results. The lower part has been adjusted to use the same volume flow rate as the result from the upper part and all minor losses have been set to zero. The result is that the pressure at the target point,  $p_2$ , is very near the desired pressure. The small difference is due to rounding and a possible difference between the result from Equation 11.3 used to solve for Q in Method II-A and the calculation of friction factor and other terms in Method II-B.

**III-A & III-B SI:** Class III series pipe line problems require the determination of the minimum required size of pipe to carry a given volume flow rate of fluid with a limiting pressure drop. Both Method III-A and Method III-B as described in the text are shown on this spreadsheet. If only pipe friction loss is considered, then only the upper part using Method III-A is pertinent.

Problem 11.18 is solved by the given spreadsheet data. Only pipe friction losses are included and the solution computes that the minimum acceptable pipe flow diameter is 0.0908 m (90.8 mm). But the problem statement calls for the specification of the smallest standard Type K copper tube. So the lower part of the spreadsheet shows the application of a 4-in Type K copper tube having a flow diameter of 0.09797 m (97.97 mm). The spreadsheet then computes the predicted pressure at the end of the system for the given volume flow rate, 0.06 m<sup>3</sup>/s. Note that the result predicts that the pressure at the end of the tube would be 48.13 kPa. In reality, the pressure there is zero as the problem states that the flow exits into the atmosphere from the end of the tube. Actually, then, the 4-in tube will permit a higher flow rate for the same pressure drop. You could use the spreadsheet *II-A 4 II-B SI*: to compute the actual expected volume flow rate when using the 4-in Type K copper tube.

Class III systems with minor losses are demonstrated in the next spreadsheet.

**III-A & III-B US:** This spreadsheet is identical to *III-A & III-B SI*: described above except for the use of U.S. Customary units instead of SI Metric units. The solution to Example Problem 11.6 from the text is shown and this spreadsheet is included in the text with extensive description of how it is used. Please refer to the text.

The problem includes some minor losses so that both the upper part (Method III-A) and the lower part (Method III-B) are used. The result from Method III-A predicts that the minimum acceptable pipe flow diameter is 0.3090 ft if no minor losses are considered. Using a standard 4-in schedule 40 steel pipe ( $D = 0.3355$  ft) with the minor losses included in Method III-B shows that the pressure at the target point,  $p_2$ , is greater than the minimum acceptable pressure. Therefore, that pipe size is satisfactory.

**System Curve US:** This spreadsheet is the same as that shown in Figure 13.41 in Chapter 13 of the text. It is used to determine the operating point of a pump selected for the system shown in Figure 13.40 and described in Example Problem 13.4. Refer to the extensive discussion of system curves and this spreadsheet in Sections 13.10 and 13.14.

The spreadsheet includes two pages. The first page is an analysis of the total head on the pump when the desired volume flow rate, 0.5011 ft<sup>3</sup>/s (225 gal/min), flows in the system. This sheet is basically the same as that in the spreadsheet called *I Power US*:, discussed earlier. But the final calculation of the power delivered by the pump to the fluid has been deleted.

After seeing the required total head on the pump for the desired flow rate, the user has selected a centrifugal pump, model 2x3-10 with a 9-in impeller, using the pump performance curves from Figure 13.27. This pump will actually deliver somewhat more flow at this head. The spreadsheet was used to compute data for the system curve that is a plot of the total head versus the volume flow rate (capacity) delivered. Several data points for the resulting total head for different flow rates from zero to 275 gal/min were computed. These were entered on page 2 of the spreadsheet and the system curve was plotted on the graph shown there. Simultaneously, data from the actual performance curve for the selected pump were entered and plotted on the same graph. Where the two curves intersect is the operating point, predicting that the pump will deliver approximately 240 gal/min. Then you must go back to Figure 13.27 to determine the other performance parameters at this operating point, efficiency, power required, and  $NPSH_R$  (net positive suction head required).

Note that no spreadsheet system using SI Metric units for operating point is included in this set. It would be good practice for you to copy this given spreadsheet and convert it to SI Metric units. You should examine the contents of each cell to determine if the equations must be modified with different conversion factors to achieve an accurate result.

**Friction Factor:** This is a simple spreadsheet whose sole purpose is to compute the friction factor using Equation 8-7 from Section 8.8 of the text. We refer to this equation as the *Swamee-Jain Equation* for its developers. See Reference 3 in Chapter 8.

The spreadsheet shows the computation of the friction factor for the data from Problem 8.28. Data entry is similar to that used in the other spreadsheets described above. Either SI Metric or U.S. Customary units can be used because only dimensionless quantities are used in the equation. But units must be consistent within a given problem. You might want to use this spreadsheet to test your ability to read accurately the Moody Diagram, Figure 8.6.

**HYDROFLO 2, HCALC, and PumpBase Software  
by TAHOE DESIGN SOFTWARE  
Included on the CD with this book**

**APPLIED FLUID MECHANICS  
Sixth Edition  
Robert L. Mott**

This book includes a CD that contains student versions of three powerful software programs for the solution of a variety of pipeline design and analysis problems. Created by Tahoe Design Software of Nevada City, CA, **HYDROFLO 2**, **HCALC**, and **PumpBase** can be used for problem solutions in Chapters 8 and 10 -13 of the book. More information about Tahoe Design Software and the professional versions of these programs can be found on their website [www.tahoessoft.com](http://www.tahoessoft.com).

**HYDROFLO 2** is a unique fluid conveyance system design tool for full pipe incompressible flow conditions. It makes it easy to model and analyze fluid transport systems found in industrial process, water supply, petroleum transport, mining de-watering and HVAC systems. During the design process, you view a vertical elevation-scaled representation of your fluid conveyance system in **HYDROFLO**'s workspace. Elements (such as pipes, valves, etc.) can be added to your design with drag-and-drop and cut-and-paste ease. **HYDROFLO**'s clipboard enables near instant creation of duplicate parallel lines. Element data and analysis results can be viewed simply by placing the cursor over an element. **HYDROFLO**'s Group Editor eliminates repetitive and tedious editing tasks.

The academic version of **HYDROFLO** can model liquid conveyance systems with single sources and single discharges and up to 20 pipes, 20 fittings and valves, 3 pumps, and up to nine parallels. Gauges can be placed anywhere in a line to determine the pressure head at a point of interest, to start or end parallels, or to depict elevation changes or vertical bends in a line. Many conveyance systems include pumps in series or parallel and **HYDROFLO** can easily analyze these systems. See Section 13.15 in the book.

Many types of fluid flow problems can be solved, such as

- Validation/calibration of existing pipeline systems.
- Modeling a proposed system's operation.
- Determination of line head losses at a specific flow rate. (termed a forced-flow system).
- Analysis of cavitation and net positive suction head (NPSH) problems.
- Comparison of equivalent SI unit to English unit designs.
- Modeling of recirculating and gravity (non-pumped) flow systems.

Pipe head losses can be calculated using the Hazen-Williams equation for water flow (Section 8.9 in the book) or the Darcy-Weisbach equation for other types of incompressible fluids. We use the term *Darcy's equation* in the book. See Section 8.5.

**HYDROFLO**'s extensive liquid property database can be accessed to obtain hundreds of liquid properties. Accurate analyses of liquid transport systems require use of precise liquid property data. Your custom liquid property descriptions can be saved in **HYDROFLO**'s

database for later use. System data can be entered and displayed in standard English, SI or a mix of units.

HYDROFLO also performs  $NPSH_A$  (net positive suction head available) calculations to determine possible cavitation situations. Once a pump's operating conditions are found, PumpBase can be used to find the best pumps for the application.

*PumpBase* provides an extensive searchable database for commercially available pumps that meet the requirements for a given system. Only a few data values must be input for basic operation of the program; the operating point for a desired volume flow rate at the corresponding total dynamic head  $TDH$  and the total static head  $h_o$ , as found from Eq. (13-11). The program fits a second degree equation between those two points and plots that as the system curve. See Section 13.10 in the book. The program will search its database, select several candidate pumps that meet the specifications, and report a list that is ordered by pump efficiency. You may select any candidate pump and call for its performance curve to be displayed along with the system curve and listing of such operating parameters as the impeller diameter, actual flow rate, power required efficiency, and  $NPSH_R$ . You are advised to verify that the selected pump meets all requirements.

More input data are required if the fluid is not cool water, a limit for  $NPSH_R$  is to be specified, or a certain type of pump is desired.

**HCALC** is a handy calculator tool that resides in the system tray for easy access. It performs the calculations for any variable in the flow rate equation,  $Q = Av$ , or the Darcy-Weisbach equation,  $h_L = f(L/D)(v^2/2g)$ , when sufficient data are entered for fluid properties, pipe dimensions, roughness, and so forth. Reynolds number and friction factor are also calculated. You may select either SI or U.S. Customary units.

### **Suggestions for use of these programs:**

***As with any software, it is essential that the user have a solid understanding of the principles involved in the analyses performed by the software as well as the details of data entry and interpretation of results. It is advised that practice with hand calculations for representative problems be completed before using the software, Then use the results of known, accurately-solved problems with the software to verify that it is being used correctly and to gain confidence in its capabilities.***

The following types of problems and projects can be solved with these programs:

- Energy losses due to friction in straight pipes and tubes (Chapter 8)
- Energy losses due to valves and fittings (Chapter 10)
- Analysis of series pipeline systems (Chapter 11)
- Analysis of parallel pipeline systems (Chapter 12)
- Analysis of pumped pipeline systems (Chapters 11-13)
- Selection of a suitable pump for a given system (Chapter 13)
- Design aid for design problems such as those outlined at the end of Chapter 13.
- Extensive system design as a senior design project.

In the author's own teaching of a first course in fluid mechanics, a design project is assigned after class coverage of Chapter 11 on Series Pipeline Systems. Each student is given a project description and data adapted from the design problems listed at the end of Chapter 13 after the Problems. They are expected to produce the design of a pumped fluid flow system,

Given the need to pump a give volume flow rate of a specified fluid from a particular source to a destination, completely define the configuration of the system, including:

- Pipe types and sizes
- Length of pipe for all parts of the system
- Layout of the piping system
- Location of the pump
- Types and sizes of all valves and fittings and their placement
- List of materials required for the system
- Analysis of the pressure at pertinent points
- Determination of the total dynamic head on the pump
- Specification of a suitable pump having good efficiency and able to deliver the required volume flow rate in the system as designed
- Assurance that the specified pump has a satisfactory  $NPSH_R$  to prevent cavitation over the entire range of expected system operation
- Written report documenting the design and analyses performed using good report writing practice

The use of the Tahoe Design Software programs after learning the fundamentals of fluid system design analysis allows more comprehensive exploration of possible designs and the completion of a more optimum design. The experience is also useful for students as they move into career positions where the use of such software is frequently expected.

# CHAPTER ONE

## THE NATURE OF FLUIDS AND THE STUDY OF FLUID MECHANICS

### *Conversion factors*

- 1.1  $1250 \text{ mm}(1 \text{ m}/10^3 \text{ mm}) = 1.25 \text{ m}$
- 1.2  $1600 \text{ mm}^2[1 \text{ m}^2/(10^3 \text{ mm})^2] = 1.6 \times 10^{-3} \text{ m}^2$
- 1.3  $3.65 \times 10^3 \text{ mm}^3[1 \text{ m}^3/(10^3 \text{ mm})^3] = 3.65 \times 10^{-6} \text{ m}^3$
- 1.4  $2.05 \text{ m}^2[(10^3 \text{ mm})^2/\text{m}^2] = 2.05 \times 10^6 \text{ mm}^2$
- 1.5  $0.391 \text{ m}^3[(10^3 \text{ mm})^3/\text{m}^3] = 391 \times 10^6 \text{ mm}^3$
- 1.6  $55.0 \text{ gal}(0.00379 \text{ m}^3/\text{gal}) = 0.208 \text{ m}^3$
- 1.7  $\frac{80 \text{ km}}{\text{h}} \times \frac{10^3 \text{ m}}{\text{km}} \times \frac{1 \text{ h}}{3600 \text{ s}} = 22.2 \text{ m/s}$
- 1.8  $25.3 \text{ ft}(0.3048 \text{ m}/\text{ft}) = 7.71 \text{ m}$
- 1.9  $1.86 \text{ mi}(1.609 \text{ km}/\text{mi})(10^3 \text{ m}/\text{km}) = 2993 \text{ m}$
- 1.10  $8.65 \text{ in}(25.4 \text{ mm}/\text{in}) = 220 \text{ mm}$
- 1.11  $2580 \text{ ft}(0.3048 \text{ m}/\text{ft}) = 786 \text{ m}$
- 1.12  $480 \text{ ft}^3(0.0283 \text{ m}^3/\text{ft}^3) = 13.6 \text{ m}^3$
- 1.13  $7390 \text{ cm}^3[1 \text{ m}^3/(100 \text{ cm})^3] = 7.39 \times 10^{-3} \text{ m}^3$
- 1.14  $6.35 \text{ L}(1 \text{ m}^3/1000 \text{ L}) = 6.35 \times 10^{-3} \text{ m}^3$
- 1.15  $6.0 \text{ ft/s}(0.3048 \text{ m}/\text{ft}) = 1.83 \text{ m/s}$
- 1.16  $\frac{2500 \text{ ft}^3}{\text{min}} \times \frac{0.0283 \text{ m}^3}{\text{ft}^3} \times \frac{1 \text{ min}}{60 \text{ s}} = 1.18 \text{ m}^3/\text{s}$

### *Consistent units in an equation*

1.17  $v = \frac{s}{t} = \frac{0.50 \text{ km}}{10.6 \text{ s}} \times \frac{10^3 \text{ m}}{\text{km}} = 47.2 \text{ m/s}$

$$1.18 \quad v = \frac{s}{t} = \frac{1.50 \text{ km}}{5.2 \text{ s}} \times \frac{3600 \text{ s}}{\text{h}} = \mathbf{1038 \text{ km/h}}$$

$$1.19 \quad v = \frac{s}{t} = \frac{1000 \text{ ft}}{14 \text{ s}} \times \frac{1 \text{ mi}}{5280 \text{ ft}} \times \frac{3600 \text{ s}}{\text{h}} = \mathbf{48.7 \text{ mi/h}}$$

$$1.20 \quad v = \frac{s}{t} = \frac{1.0 \text{ mi}}{5.7 \text{ s}} \times \frac{3600 \text{ s}}{\text{h}} = \mathbf{632 \text{ mi/h}}$$

$$1.21 \quad a = \frac{2s}{t^2} = \frac{(2)(3.2 \text{ km})}{(4.7 \text{ min})^2} \times \frac{10^3 \text{ m}}{\text{km}} \times \frac{1 \text{ min}^2}{(60 \text{ s})^2} = \mathbf{8.05 \times 10^{-2} \text{ m/s}^2}$$

$$1.22 \quad t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{(2)(13 \text{ m})}{9.81 \text{ m/s}^2}} = \mathbf{1.63 \text{ s}}$$

$$1.23 \quad a = \frac{2s}{t^2} = \frac{(2)(3.2 \text{ km})}{(4.7 \text{ min})^2} \times \frac{10^3 \text{ m}}{\text{km}} \times \frac{1 \text{ ft}}{0.3048 \text{ m}} \times \frac{1 \text{ min}^2}{(60 \text{ s})^2} = \mathbf{0.264 \frac{\text{ft}}{\text{s}^2}}$$

$$1.24 \quad t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{(2)(53 \text{ in})}{32.2 \text{ ft/s}^2} \times \frac{1 \text{ ft}}{12 \text{ in}}} = \mathbf{0.524 \text{ s}}$$

$$1.25 \quad KE = \frac{mv^2}{2} = \frac{(15 \text{ kg})(1.2 \text{ m/s})^2}{2} = 10.8 \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2} = \mathbf{10.8 \text{ N} \cdot \text{m}}$$

$$1.26 \quad KE = \frac{mv^2}{2} = \frac{(3600 \text{ kg})}{2} \times \left(\frac{16 \text{ km}}{\text{h}}\right)^2 \times \frac{(10^3 \text{ m})^2}{\text{km}^2} \times \frac{1 \text{ h}^2}{(3600 \text{ s})^2} = \mathbf{35.6 \times 10^3 \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2}}$$

$$KE = \mathbf{35.6 \text{ kN} \cdot \text{m}}$$

$$1.27 \quad KE = \frac{mv^2}{2} = \frac{75 \text{ kg}}{2} \times \left(\frac{6.85 \text{ m}}{\text{s}}\right)^2 = 1.76 \times 10^3 \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2} = \mathbf{1.76 \text{ kN} \cdot \text{m}}$$

$$1.28 \quad m = \frac{2(KE)}{v^2} = \frac{(2)(38.6 \text{ N} \cdot \text{m})}{1} \times \left(\frac{\text{h}}{31.5 \text{ km}}\right)^2 \times \frac{1 \text{ kg} \cdot \text{m}}{\text{s}^2 \cdot \text{N}} \times \frac{(3600 \text{ s})^2}{\text{h}^2} \times \frac{1 \text{ km}^2}{(10^3 \text{ m})^2}$$

$$m = \frac{(2)(38.6)(3600)^2}{(31.5)^2(10^3)^2} \text{ kg} = \mathbf{1.008 \text{ kg}}$$

$$1.29 \quad m = \frac{2(KE)}{v^2} = \frac{(2)(94.6 \text{ mN} \cdot \text{m})}{(2.25 \text{ m/s})^2} \times \frac{10^{-3} \text{ N}}{\text{mN}} \times \frac{1 \text{ kg} \cdot \text{m}}{\text{s}^2 \cdot \text{N}} \times \frac{10^3 \text{ g}}{\text{kg}} = \mathbf{37.4 \text{ g}}$$

$$1.30 \quad v = \sqrt{\frac{2(KE)}{m}} = \sqrt{\frac{2(15 \text{ N} \cdot \text{m})}{12 \text{ kg}} \times \frac{1 \text{ kg} \cdot \text{m/s}^2}{\text{N}}} = \mathbf{1.58 \text{ m/s}}$$

$$1.31 \quad v = \sqrt{\frac{2(KE)}{m}} = \sqrt{\frac{2(212 \text{ mN} \cdot \text{m})}{175 \text{ g}} \times \frac{10^{-3} \text{ N}}{\text{mN}} \times \frac{10^3 \text{ g}}{\text{kg}} \times \frac{1 \text{ kg} \cdot \text{m}}{\text{s}^2 \cdot \text{N}}} = \mathbf{1.56 \text{ m/s}}$$

$$1.32 \quad KE = \frac{mv^2}{2} = \frac{(1 \text{ slug})(4 \text{ ft/s})^2}{2} \times \frac{1 \text{ lb} \cdot \text{s}^2/\text{ft}}{\text{slug}} = \mathbf{8.00 \text{ lb} \cdot \text{ft}}$$

$$1.33 \quad KE = \frac{mv^2}{2} = \frac{wv^2}{2g} = \frac{(8000 \text{ lb})(10 \text{ mi})^2}{(2)(32.2 \text{ ft/s}^2)(\text{h})^2} \times \frac{1 \text{ h}^2}{(3600 \text{ s})^2} \times \frac{(5280 \text{ ft})^2}{\text{mi}^2}$$

$$KE = \frac{(8000)(10)^2(5280)^2}{(2)(32.2)(3600)^2} \text{ lb} \cdot \text{ft} = \mathbf{26700 \text{ lb} \cdot \text{ft}}$$

$$1.34 \quad KE = \frac{mv^2}{2} = \frac{wv^2}{2g} = \frac{(150 \text{ lb})(20 \text{ ft/s})^2}{(2)(32.2 \text{ ft/s}^2)} = \mathbf{932 \text{ lb} \cdot \text{ft}}$$

$$1.35 \quad m = \frac{2(KE)}{v^2} = \frac{2(15 \text{ lb} \cdot \text{ft})}{(2.2 \text{ ft/s}^2)^2} = 6.20 \frac{\text{lb} \cdot \text{s}^2}{\text{ft}} = \mathbf{6.20 \text{ slugs}}$$

$$1.36 \quad w = \frac{2g(KE)}{v^2} = \frac{2(32.2 \text{ ft})(38.6 \text{ lb} \cdot \text{ft})(\text{h}^2)}{\text{s}^2(19.5 \text{ mi})^2} \times \frac{1 \text{ mi}^2}{(5280 \text{ ft})^2} \times \frac{(3600 \text{ s})^2}{\text{h}^2}$$

$$w = \frac{(2)(32.2)(38.6)(3600)^2}{(19.5)^2(5280)^2} \text{ lb} = \mathbf{3.04 \text{ lb}}$$

$$1.37 \quad v = \sqrt{\frac{2g(KE)}{w}} = \sqrt{\frac{2(32.2 \text{ ft/s}^2)(10 \text{ lb} \cdot \text{ft})}{30 \text{ lb}}} = \mathbf{4.63 \text{ ft/s}}$$

$$1.38 \quad v = \sqrt{\frac{2g(KE)}{w}} = \sqrt{\frac{2(32.2 \text{ ft/s}^2)(30 \text{ oz} \cdot \text{in})}{6.0 \text{ oz}} \times \frac{1 \text{ ft}}{12 \text{ in}}} = \mathbf{5.18 \text{ ft/s}}$$

$$1.39 \quad \text{ERA} = \frac{39 \text{ runs}}{141 \text{ innings}} \times \frac{9 \text{ innings}}{\text{game}} = \mathbf{2.49 \text{ runs/game}}$$

$$1.40 \quad \frac{3.12 \text{ runs}}{\text{game}} \times \frac{1 \text{ game}}{9 \text{ innings}} \times 150 \text{ innings} = \mathbf{52 \text{ runs}}$$

$$1.41 \quad 40 \text{ runs} \times \frac{1 \text{ game}}{2.79 \text{ runs}} \times \frac{9 \text{ innings}}{\text{game}} = \mathbf{129 \text{ innings}}$$

$$1.42 \quad \text{ERA} = \frac{49 \text{ runs}}{123 \text{ innings}} \times \frac{9 \text{ innings}}{\text{game}} = \mathbf{3.59 \text{ runs/game}}$$

***The definition of pressure***

$$1.43 \quad p = F/A = 2500 \text{ lb}/[\pi(3.00 \text{ in})^2/4] = \mathbf{354 \text{ lb/in}^2} = \mathbf{354 \text{ psi}}$$

$$1.44 \quad p = F/A = 8700 \text{ lb}/[\pi(1.50 \text{ in})^2/4] = \mathbf{4923 \text{ psi}}$$

$$1.45 \quad p = \frac{F}{A} = \frac{12.0 \text{ kN}}{\pi(75 \text{ mm})^2/4} \times \frac{10^3 \text{ N}}{\text{kN}} \times \frac{(10^3 \text{ mm})^2}{\text{m}^2} = 2.72 \times 10^6 \frac{\text{N}}{\text{m}^2} = \mathbf{2.72 \text{ MPa}}$$

$$1.46 \quad p = \frac{F}{A} = \frac{38.8 \times 10^3 \text{ N}}{\pi(40 \text{ mm})^2/4} \times \frac{(10^3 \text{ mm})^2}{\text{m}^2} = 30.9 \times 10^6 \frac{\text{N}}{\text{m}^2} = \mathbf{30.9 \text{ MPa}}$$

$$1.47 \quad p = \frac{F}{A} = \frac{6000 \text{ lb}}{\pi(8.0 \text{ in})^2/4} = \mathbf{119 \text{ psi}}$$

$$1.48 \quad p = \frac{F}{A} = \frac{18000 \text{ lb}}{\pi(2.50 \text{ in})^2/4} = \mathbf{3667 \text{ psi}}$$

$$1.49 \quad F = pA = \frac{20.5 \times 10^6 \text{ N}}{\text{m}^2} \times \frac{\pi(50 \text{ mm})^2}{4} \times \frac{1 \text{ m}^2}{(10^3 \text{ mm})^2} = \mathbf{40.25 \text{ kN}}$$

$$1.50 \quad F = pA = (6000 \text{ lb/in}^2)(\pi[2.00 \text{ in}]^2/4) = \mathbf{18850 \text{ lb}}$$

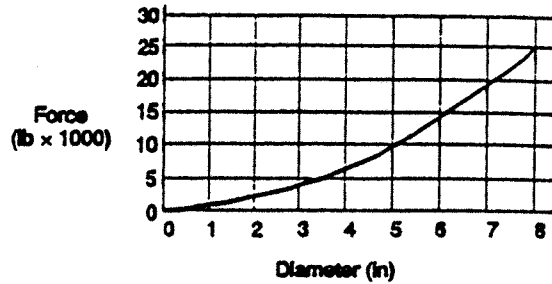
$$1.51 \quad p = \frac{F}{A} = \frac{F}{\pi D^2/4} = \frac{4F}{\pi D^2}: \text{ Then } D = \sqrt{\frac{4F}{\pi p}}$$

$$D = \sqrt{\frac{4(20000 \text{ lb})}{\pi(5000 \text{ lb/in}^2)}} = \mathbf{2.26 \text{ in}}$$

$$1.52 \quad D = \sqrt{\frac{4F}{\pi p}} = \sqrt{\frac{4(30 \times 10^3 \text{ N})}{\pi(15.0 \times 10^6 \text{ N/m}^2)}} = 50.5 \times 10^{-3} \text{ m} = \mathbf{50.5 \text{ mm}}$$

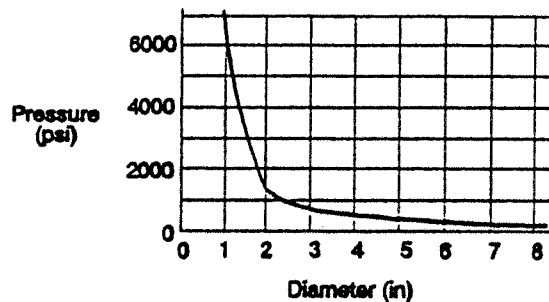
$$1.53 \quad F = pA = \frac{p[\pi D^2]}{4} = \frac{500 \text{ lb}(\pi)(D \text{ in})^2}{\text{in}^2 4} = 392.7 D^2 \text{ lb}$$

$D(\text{in})$	$D^2(\text{in}^2)$	$F(\text{lb})$
1.00	1.00	393
2.00	4.00	1571
3.00	9.00	3534
4.00	16.00	6283
5.00	25.00	9817
6.00	36.00	14137
7.00	49.00	19242
8.00	64.00	25133



$$1.54 \quad p = \frac{F}{A} = \frac{F}{\pi D^2/4} = \frac{4F}{\pi D^2} = \frac{4(5000 \text{ lb})}{\pi(D \text{ in})^2} = \frac{6366}{D^2} \text{ psi}$$

$D(\text{in})$	$D^2(\text{in}^2)$	$p(\text{psi})$
1.00	1.00	6366
2.00	4.00	1592
3.00	9.00	707
4.00	16.00	398
5.00	25.00	255
6.00	36.00	177
7.00	49.00	130
8.00	64.00	99



1.55 (Variable Answers) Example:  $w = 160 \text{ lb} (4.448 \text{ N/lb}) = 712 \text{ N}$

$$p = \frac{F}{A} = \frac{712 \text{ N}}{\pi(20 \text{ mm})^2/4} \times \frac{(10^3 \text{ mm})^2}{\text{m}^2} = 2.77 \times 10^6 \text{ Pa} = 2.27 \text{ MPa}$$

$$p = 2.27 \times 10^6 \text{ Pa} (1 \text{ psi}/6895 \text{ Pa}) = 329 \text{ psi}$$

1.56 (Variable Answers) using  $p = 2.27 \text{ MPa}$

$$F = pA = (2.27 \times 10^6 \text{ N/m}^2)(\pi(0.250 \text{ m})^2/4) = 111 \times 10^3 \text{ N} = 111 \text{ kN}$$

$$F = 111 \text{ kN} (1 \text{ lb}/4.448 \text{ N}) = 25050 \text{ lb}$$

### **Bulk modulus**

$$1.57 \quad \Delta p = -E(\Delta V/V) = -130000 \text{ psi}(-0.01) = \mathbf{1300 \text{ psi}}$$
$$\Delta p = -896 \text{ MPa}(-0.01) = \mathbf{8.96 \text{ MPa}}$$

$$1.58 \quad \Delta p = -E(\Delta V/V) = -3.59 \times 10^6 \text{ psi}(-0.01) = \mathbf{35900 \text{ psi}}$$
$$\Delta p = -24750 \text{ MPa}(-0.01) = \mathbf{247.5 \text{ MPa}}$$

$$1.59 \quad \Delta p = -E(\Delta V/V) = -189000 \text{ psi}(-0.01) = \mathbf{1890 \text{ psi}}$$
$$\Delta p = -1303 \text{ MPa}(-0.01) = \mathbf{13.03 \text{ MPa}}$$

$$1.60 \quad \Delta V/V = -0.01; \Delta V = 0.01V = 0.01 AL$$

Assume area of cylinder does not change.

$$\Delta V = A(\Delta L) = 0.01 AL$$

Then  $\Delta L = 0.01 L = 0.01(12.00 \text{ in}) = \mathbf{0.120 \text{ in}}$

$$1.61 \quad \frac{\Delta V}{V} = \frac{-p}{E} = \frac{-3000 \text{ psi}}{189000 \text{ psi}} = -0.0159 = \mathbf{-1.59\%}$$

$$1.62 \quad \frac{\Delta V}{V} = \frac{-20.0 \text{ MPa}}{1303 \text{ MPa}} = -0.0153 = \mathbf{-1.53\%}$$

$$1.63 \quad \text{Stiffness} = \text{Force/Change in Length} = F/\Delta L$$

$$\text{Bulk Modulus} = E = \frac{-p}{\Delta V/V} = \frac{-pV}{\Delta V}$$

$$\text{But } p = F/A; V = AL; \Delta V = -A(\Delta L)$$

$$E = \frac{-F}{A} \times \frac{AL}{-A(\Delta L)} = \frac{FL}{A(\Delta L)}$$

$$\frac{F}{(\Delta L)} = \frac{EA}{L} = \frac{189000 \text{ lb} \pi (0.5 \text{ in})^2}{\text{in}^2 (42 \text{ in})} = \mathbf{884 \text{ lb/in}}$$

$$1.64 \quad \frac{F}{(\Delta L)} = \frac{EA}{L} = \frac{189000 \text{ lb} \pi (0.5 \text{ in})^2}{\text{in}^2 (10.0 \text{ in})} = \mathbf{3711 \text{ lb/in}} \quad \mathbf{4.2 \text{ times higher}}$$

$$1.65 \quad \frac{F}{(\Delta L)} = \frac{EA}{L} = \frac{189000 \text{ lb} \pi (2.00 \text{ in})^2}{\text{in}^2 (42.0 \text{ in})} = \mathbf{14137 \text{ lb/in}} \quad \mathbf{16 \text{ times higher}}$$

1.66 Use large diameter cylinders and short strokes.

### **Force and mass**

$$1.67 \quad m = \frac{w}{g} = \frac{610 \text{ N}}{9.81 \text{ m/s}^2} \times \frac{1 \text{ kg} \cdot \text{m/s}^2}{\text{N}} = \mathbf{62.2 \text{ kg}}$$

- 1.68  $m = \frac{w}{g} = \frac{1.35 \times 10^3 \text{ N}}{9.81 \text{ m/s}^2} \times \frac{1 \text{ kg} \cdot \text{m/s}^2}{\text{N}} = \mathbf{138 \text{ kg}}$
- 1.69  $w = mg = 825 \text{ kg} \times 9.81 \text{ m/s}^2 = 8093 \text{ kg} \cdot \text{m/s}^2 = \mathbf{8093 \text{ N}}$
- 1.70  $w = mg = 450 \text{ g} \times \frac{1 \text{ kg}}{10^3 \text{ g}} \times 9.81 \text{ m/s}^2 = 4.41 \text{ kg} \cdot \text{m/s}^2 = \mathbf{4.41 \text{ N}}$
- 1.71  $m = \frac{w}{g} = \frac{7.8 \text{ lb}}{32.2 \text{ ft/s}^2} = 0.242 \frac{\text{lb} \cdot \text{s}^2}{\text{ft}} = \mathbf{0.242 \text{ slugs}}$
- 1.72  $m = \frac{w}{g} = \frac{42.0 \text{ lb}}{32.2 \text{ ft/s}^2} = \mathbf{1.304 \text{ slugs}}$
- 1.73  $w = mg = 1.58 \text{ slugs} \times 32.2 \text{ ft/s}^2 \times \frac{1 \text{ lb} \cdot \text{s}^2/\text{ft}}{\text{slug}} = \mathbf{50.9 \text{ lb}}$
- 1.74  $w = mg = 0.258 \text{ slugs} \times 32.2 \text{ ft/s}^2 \times \frac{1 \text{ lb} \cdot \text{s}^2/\text{ft}}{\text{slug}} = \mathbf{8.31 \text{ lb}}$
- 1.75  $m = \frac{w}{g} = \frac{160 \text{ lb}}{32.2 \text{ ft/s}^2} = \mathbf{4.97 \text{ slugs}}$   
 $w = 160 \text{ lb} \times 4.448 \text{ N/lb} = \mathbf{712 \text{ N}}$   
 $m = 4.97 \text{ slugs} \times 14.59 \text{ kg/slug} = \mathbf{72.5 \text{ kg}}$
- 1.76  $m = \frac{w}{g} = \frac{1.00 \text{ lb}}{32.2 \text{ ft/s}^2} = \mathbf{0.0311 \text{ slugs}}$   
 $m = 0.0311 \text{ slugs} \times 14.59 \text{ kg/slug} = \mathbf{0.453 \text{ kg}}$   
 $w = 1.00 \text{ lb} \times 4.448 \text{ N/lb} = \mathbf{4.448 \text{ N}}$
- 1.77  $F = w = mg = 1000 \text{ kg} \times 9.81 \text{ m/s}^2 = 9810 \text{ kg} \cdot \text{m/s}^2 = \mathbf{9810 \text{ N}}$
- 1.78  $F = 9810 \text{ N} \times 1.0 \text{ lb}/4.448 \text{ N} = \mathbf{2205 \text{ lb}}$
- 1.79 (Variable Answers) See problem 1.75 for method.

***Density, specific weight, and specific gravity***

- 1.80  $\gamma_B = (\text{sg})_B \gamma_w = (0.876)(9.81 \text{ kN/m}^3) = \mathbf{8.59 \text{ kN/m}^3}$   
 $\rho_B = (\text{sg})_B \rho_w = (0.876)(1000 \text{ kg/m}^3) = \mathbf{876 \text{ kg/m}^3}$
- 1.81  $\rho = \frac{\gamma}{g} = \frac{12.02 \text{ N}}{\text{m}^3} \times \frac{\text{s}^2}{9.81 \text{ m}} \times \frac{1 \text{ kg} \cdot \text{m/s}^2}{\text{N}} = \mathbf{1.225 \text{ kg/m}^3}$

$$1.82 \quad \gamma = \rho g = 1.964 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 \times \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} = \mathbf{19.27 \text{ N/m}^3}$$

$$1.83 \quad \text{sg} = \frac{\gamma_o}{\gamma_w @ 4^\circ\text{C}} = \frac{8.860 \text{ kN/m}^3}{9.81 \text{ kN/m}^3} = \mathbf{0.903 \text{ at } 5^\circ\text{C}}$$

$$\text{sg} = \frac{\gamma_o}{\gamma_w @ 4^\circ\text{C}} = \frac{8.483 \text{ kN/m}^3}{9.81 \text{ kN/m}^3} = \mathbf{0.865 \text{ at } 50^\circ\text{C}}$$

$$1.84 \quad \gamma = \frac{w}{V}; V = \frac{w}{\gamma} = \frac{2.25 \text{ kN}}{130.4 \text{ kN/m}^3} = \mathbf{0.0173 \text{ m}^3}$$

$$1.85 \quad V = AL = \pi D^2 L / 4 = \pi (0.150 \text{ m})^2 (0.100 \text{ m}) / 4 = 1.767 \times 10^{-3} \text{ m}^3$$

$$\rho_o = \frac{m}{V} = \frac{1.56 \text{ kg}}{1.767 \times 10^{-3} \text{ m}^3} = \mathbf{883 \text{ kg/m}^3}$$

$$\gamma_o = \rho_o g = 883 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 \times \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} = 8.66 \times \frac{10^3 \text{ N}}{\text{m}^3} = \mathbf{8.66 \frac{\text{kg}}{\text{m}^3}}$$

$$\text{sg} = \rho_o / \rho_w @ 4^\circ\text{C} = 883 \text{ kg/m}^3 / 1000 \text{ kg/m}^3 = \mathbf{0.883}$$

$$1.86 \quad \gamma = (\text{sg})(\gamma_w @ 4^\circ\text{C}) = 1.258(9.81 \text{ kN/m}^3) = 12.34 \text{ kN/m}^3 = w/V$$

$$w = \gamma V = (12.34 \text{ kN/m}^3)(0.50 \text{ m}^3) = \mathbf{6.17 \text{ kN}}$$

$$m = \frac{w}{g} = \frac{6.17 \text{ kN}}{9.81 \text{ m/s}^2} \times \frac{10^3 \text{ N}}{\text{kN}} \times \frac{1 \text{ kg} \cdot \text{m/s}^2}{\text{N}} = \mathbf{629 \text{ kg}}$$

$$1.87 \quad w = \gamma V = (\text{sg})(\gamma_w)(V) = (0.68)(9.81 \text{ kN/m}^3)(0.095 \text{ m}^3) = 0.634 \text{ kN} = \mathbf{634 \text{ N}}$$

$$1.88 \quad \gamma = \rho g = (1200 \text{ kg/m}^3)(9.81 \text{ m/s}^2) \left( \frac{1 \text{ N}}{\text{kg} \cdot \text{m/s}^2} \right) = \mathbf{11.77 \text{ kN/m}^3}$$

$$\text{sg} = \frac{\rho}{\rho_w @ 4^\circ\text{C}} = \frac{1200 \text{ kg/m}^3}{1000 \text{ kg/m}^3} = \mathbf{1.20}$$

$$1.89 \quad V = \frac{w}{\gamma} = \frac{22.0 \text{ N}}{(0.826)(9.81 \text{ kN/m}^3)} \times \frac{1 \text{ kN}}{10^3 \text{ N}} = \mathbf{2.72 \times 10^{-3} \text{ m}^3}$$

$$1.90 \quad \gamma = \rho g = \frac{1080 \text{ kg}}{\text{m}^3} \times \frac{9.81 \text{ m}}{\text{s}^2} \times \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \times \frac{1 \text{ kN}}{10^3 \text{ N}} = \mathbf{10.59 \text{ kN/m}^3}$$

$$\text{sg} = \rho / \rho_w = \frac{1080 \text{ kg/m}^3}{1000 \text{ kg/m}^3} = \mathbf{1.08}$$

$$1.91 \quad \rho = (\text{sg})(\rho_w) = (0.789)(1000 \text{ kg/m}^3) = \mathbf{789 \text{ kg/m}^3}$$

$$\gamma = (\text{sg})(\gamma_w) = (0.789)(9.81 \text{ kN/m}^3) = \mathbf{7.74 \text{ kN/m}^3}$$

1.92  $w_o = 35.4 \text{ N} - 2.25 \text{ N} = 33.15 \text{ N}$   
 $V_o = Ad = (\pi D^2/4)(d) = \pi(.150 \text{ m})^2(.20 \text{ m})/4 = 3.53 \times 10^{-3} \text{ m}^3$   
 $\gamma_o = \frac{w}{V} = \frac{33.15 \text{ N}}{3.53 \times 10^{-3} \text{ m}^3} = 9.38 \times 10^3 \text{ N/m}^3 = \mathbf{9.38 \text{ kN/m}^3}$   
 $\text{sg} = \frac{\gamma_o}{\gamma_w} = \frac{9.38 \text{ kN/m}^3}{9.81 \text{ kN/m}^3} = \mathbf{0.956}$

1.93  $V = Ad = (\pi D^2/4)(d) = \pi(10 \text{ m})^2(6.75 \text{ m})/4 = 530.1 \text{ m}^3$   
 $w = \gamma V = (0.68)(9.81 \text{ kN/m}^3)(530.1 \text{ m}^3) = 3.536 \times 10^3 \text{ kN} = \mathbf{3.536 \text{ MN}}$   
 $m = \rho V = (0.68)(1000 \text{ kg/m}^3)(530.1 \text{ m}^3) = 360.5 \times 10^3 \text{ kg} = \mathbf{360.5 \text{ Mg}}$

1.94  $w_{\text{castor oil}} = \gamma_{co} \cdot V_{co} = (9.42 \text{ kN/m}^3)(0.02 \text{ m}^3) = 0.1884 \text{ kN}$   
 $V_m = \frac{w}{\gamma_m} = \frac{0.1884 \text{ kN}}{(13.54)(9.81 \text{ kN/m}^3)} = \mathbf{1.42 \times 10^{-3} \text{ m}^3}$

1.95  $w = \gamma V = (2.32)(9.81 \text{ kN/m}^3)(1.42 \times 10^{-4} \text{ m}^3) = 3.23 \times 10^{-3} \text{ kN} = \mathbf{3.23 \text{ N}}$

1.96  $\gamma = (\text{sg})(\gamma_w) = 0.876(62.4 \text{ lb/ft}^3) = \mathbf{54.7 \text{ lb/ft}^3}$   
 $\rho = (\text{sg})(\rho_w) = 0.876(1.94 \text{ slugs/ft}^3) = \mathbf{1.70 \text{ slugs/ft}^3}$

1.97  $\rho = \frac{\gamma}{g} = \frac{0.0765 \text{ lb/ft}^3}{32.2 \text{ ft/s}^2} \times \frac{1 \text{ slug}}{1 \text{ lb} \cdot \text{s}^2/\text{ft}} = \mathbf{2.38 \times 10^{-3} \text{ slugs/ft}^3}$

1.98  $\gamma = \rho g = 0.00381 \text{ slug/ft}^3 (32.2 \text{ ft/s}^2) \frac{1 \text{ lb} \cdot \text{s}^2/\text{ft}}{\text{slug}} = \mathbf{0.1227 \text{ lb/ft}^3}$

1.99  $\text{sg} = \gamma_o/(\gamma_w @ 4^\circ\text{C}) = 56.4 \text{ lb/ft}^3/62.4 \text{ lb/ft}^3 = \mathbf{0.904 \text{ at } 40^\circ\text{F}}$   
 $\text{sg} = \gamma_o/(\gamma_w @ 4^\circ\text{C}) = 54.0 \text{ lb/ft}^3/62.4 \text{ lb/ft}^3 = \mathbf{0.865 \text{ at } 120^\circ\text{F}}$

1.100  $V = w/\gamma = 500 \text{ lb}/834 \text{ lb/ft}^3 = \mathbf{0.600 \text{ ft}^3}$

1.101  $\gamma = \frac{w}{V} = \frac{7.50 \text{ lb}}{1 \text{ gal}} \times \frac{7.48 \text{ gal}}{\text{ft}^3} = \mathbf{56.1 \text{ lb/ft}^3}$   
 $\rho = \frac{\gamma}{g} = \frac{56.1 \text{ lb/ft}^3}{32.2 \text{ ft/s}^2} = 1.74 \frac{\text{lb} \cdot \text{s}^2}{\text{ft}^4} = \mathbf{1.74 \text{ slugs/ft}^3}$   
 $\text{sg} = \frac{\gamma_o}{\gamma_w @ 4^\circ\text{C}} = \frac{5.61 \text{ lb/ft}^3}{62.4 \text{ lb/ft}^3} = \mathbf{0.899}$

1.102  $w = \gamma V = (1.258) \frac{(62.4 \text{ lb})}{\text{ft}^3} (50 \text{ gal}) \frac{(1 \text{ ft}^3)}{7.48 \text{ gal}} = \mathbf{525 \text{ lb}}$

1.103  $w = \gamma V = \rho g V = \frac{1.32 \text{ lb} \cdot \text{s}^2}{\text{ft}^4} \times \frac{32.2 \text{ ft}}{\text{s}^2} \times 25.0 \text{ gal} \times \frac{1 \text{ ft}^3}{7.48 \text{ gal}} = \mathbf{142 \text{ lb}}$

$$1.104 \quad \text{sg} = \frac{\rho}{\rho_w} = \frac{1.20 \text{ g}}{\text{cm}^3} \times \frac{\text{m}^3}{1000 \text{ kg}} \times \frac{1 \text{ kg}}{10^3 \text{ g}} \times \frac{(10^2 \text{ cm})^3}{\text{m}^3} = \mathbf{1.20}$$

$$\rho = (\text{sg})(\rho_w) = 1.20(1.94 \text{ slugs/ft}^3) = \mathbf{2.33 \text{ slugs/ft}^3}$$

$$\gamma = (\text{sg})(\gamma_w) = (1.20)(62.4 \text{ lb/ft}^3) = \mathbf{74.9 \text{ lb/ft}^3}$$

$$1.105 \quad V = \frac{w}{\gamma} = \frac{5.0 \text{ lb ft}^3}{(0.826)62.4 \text{ lb}} \times \frac{0.0283 \text{ m}^3}{\text{ft}^3} \times \frac{(10^2 \text{ cm})^3}{\text{m}^3} = \mathbf{2745 \text{ cm}^3}$$

$$1.106 \quad \gamma = (\text{sg})(\gamma_w) = (1.08)(62.4 \text{ lb/ft}^3) = \mathbf{67.4 \text{ lb/ft}^3}$$

$$1.107 \quad \rho = (0.79)(1.94 \text{ slugs/ft}^3) = \mathbf{1.53 \text{ slugs/ft}^3}; \quad \rho = \mathbf{0.79 \text{ g/cm}^3}$$

$$1.108 \quad \gamma_o = \frac{w}{V} = \frac{(7.95 - 0.50) \text{ lb}}{(\pi(6.0 \text{ in})^2/4)(8.0 \text{ in})} \times \frac{1728 \text{ in}^3}{\text{ft}^3} = \mathbf{56.9 \text{ lb/ft}^3}$$

$$\text{sg} = \gamma_o/\gamma_w = 56.9 \text{ lb/ft}^3/62.4 \text{ lb/ft}^3 = \mathbf{0.912}$$

$$1.109 \quad V = A \cdot d = \frac{\pi D^2}{4} \cdot d = \frac{\pi(30 \text{ ft})^2}{4} \times 22 \text{ ft} = 15550 \text{ ft}^3 \times 7.48 \text{ gal/ft}^3 = \mathbf{1.16 \times 10^5 \text{ gal}}$$

$$w = \gamma V = (0.68)(62.4 \text{ lb/ft}^3)(15550 \text{ ft}^3) = \mathbf{6.60 \times 10^5 \text{ lb}}$$

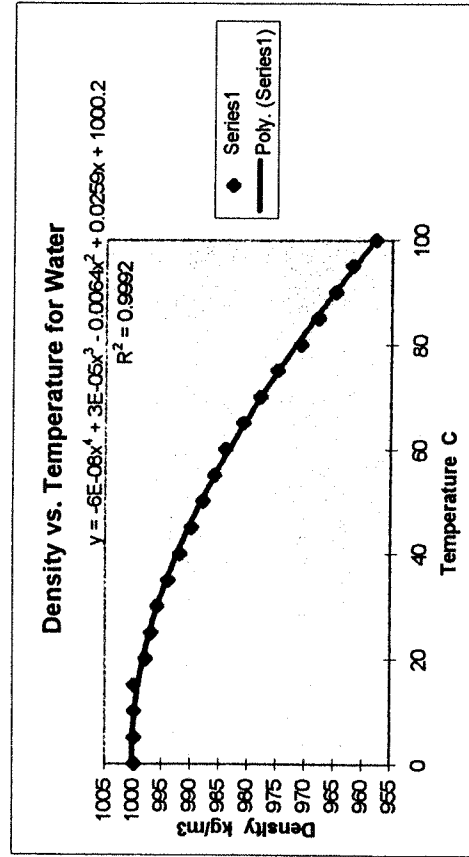
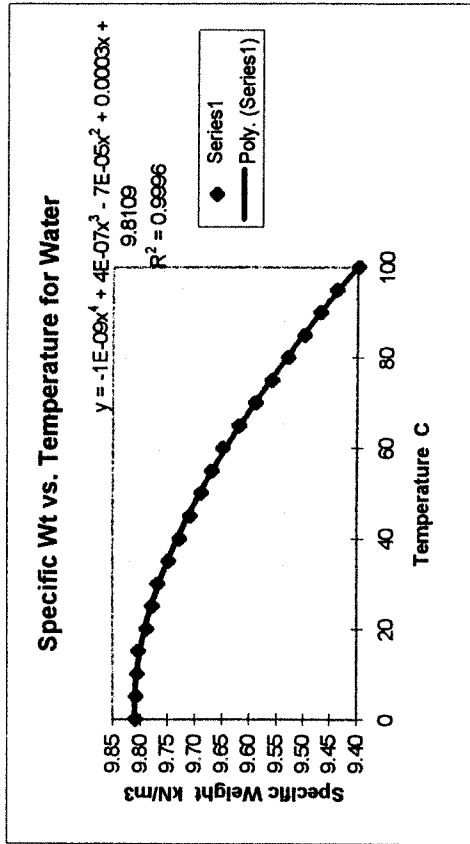
$$1.110 \quad w_{co} = \gamma_{co} V = (59.69 \text{ lb/ft}^3)(5 \text{ gal})(1 \text{ ft}^3/7.48 \text{ gal}) = \mathbf{39.90 \text{ lb}}$$

$$V_m = \frac{w}{\gamma_m} = \frac{39.90 \text{ lb ft}^3}{13.54(62.4 \text{ lb})} \times \frac{7.48 \text{ gal}}{\text{ft}^3} = \mathbf{0.353 \text{ gal}}$$

$$1.111 \quad w = \gamma V = (2.32) \frac{(62.4 \text{ lb})}{\text{ft}^3} (8.64 \text{ in}^3) \frac{(1 \text{ ft}^3)}{1728 \text{ in}^3} = \mathbf{0.724 \text{ lb}}$$

CURVE FIT FOR THE PROPERTIES OF WATER VS. TEMPERATURE  
TABLE A.1

Temp.	Sp Wt	Density	Computed Sp Wt	% Diff	Computed Density	%Diff
0	9.81	1000	9.811	0.002	1000.2	0.020
5	9.81	1000	9.812	0.018	1000.2	0.017
10	9.81	1000	9.809	0.012	999.8	-0.015
15	9.81	1000	9.803	-0.017	999.2	-0.075
20	9.79	998	9.794	0.045	998.4	0.039
25	9.78	997	9.783	0.028	997.3	0.029
30	9.77	996	9.769	-0.015	996.0	-0.002
35	9.75	994	9.752	0.022	994.5	0.047
40	9.73	992	9.734	0.037	992.8	0.077
45	9.71	990	9.713	0.032	990.9	0.090
50	9.69	988	9.691	0.007	988.9	0.088
55	9.67	986	9.667	-0.035	986.7	0.072
60	9.65	984	9.641	-0.096	984.4	0.042
65	9.62	981	9.613	-0.070	982.0	0.103
70	9.59	978	9.584	-0.061	979.5	0.154
75	9.56	975	9.553	-0.069	976.9	0.195
80	9.53	971	9.521	-0.097	974.2	0.331
85	9.50	968	9.486	-0.144	971.5	0.357
90	9.47	965	9.450	-0.211	968.6	0.376
95	9.44	962	9.411	-0.302	965.7	0.388
100	9.40	958	9.371	-0.312	962.8	0.500



Computer Assignment 2: Sample Output - Equations for Specific Weight and Density versus Temperature are shown within the plots of the output.

## CHAPTER TWO

# VISCOSITY OF FLUIDS

- 2.1 Shearing stress is the force required to slide one unit area layer of a substance over another.
- 2.2 Velocity gradient is a measure of the velocity change with position within a fluid.
- 2.3 Dynamic viscosity = shearing stress/velocity gradient.
- 2.4 Oil. It pours very slowly compared with water. It takes a greater force to stir the oil, indicating a higher shearing stress for a given velocity gradient.
- 2.5  $\text{N}\cdot\text{s}/\text{m}^2$  or  $\text{Pa}\cdot\text{s}$
- 2.6  $\text{lb}\cdot\text{s}/\text{ft}^2$
- 2.7  $1 \text{ poise} = 1 \text{ dyne}\cdot\text{s}/\text{cm}^2 = 1 \text{ g}/(\text{cm}\cdot\text{s})$
- 2.8 It does not conform to the standard SI system. It uses obsolete basic units of dynes and cm.
- 2.9 Kinematic viscosity = dynamic viscosity/density of the fluid.
- 2.10  $\text{m}^2/\text{s}$
- 2.11  $\text{ft}^2/\text{s}$
- 2.12  $1 \text{ stoke} = 1 \text{ cm}^2/\text{s}$
- 2.13 It does not conform to the standard SI system. It uses obsolete basic unit of cm.
- 2.14 A newtonian fluid is one for which the dynamic viscosity is independent of the velocity gradient.
- 2.15 A nonnewtonian fluid is one for which the dynamic viscosity is dependent on the velocity gradient.
- 2.16 Water, oil, gasoline, alcohol, kerosene, benzene, and others.
- 2.17 Blood plasma, molten plastics, catsup, paint, and others.
- 2.18  $6.5 \times 10^{-4} \text{ Pa}\cdot\text{s}$
- 2.19  $1.5 \times 10^{-3} \text{ Pa}\cdot\text{s}$
- 2.20  $2.0 \times 10^{-5} \text{ Pa}\cdot\text{s}$

- 2.21  $1.1 \times 10^{-5} \text{ Pa}\cdot\text{s}$
- 2.22  $3.0 \times 10^{-1} \text{ Pa}\cdot\text{s}$
- 2.23  $1.90 \text{ Pa}\cdot\text{s}$
- 2.24  $3.2 \times 10^{-5} \text{ lb}\cdot\text{s}/\text{ft}^2$
- 2.25  $8.9 \times 10^{-6} \text{ lb}\cdot\text{s}/\text{ft}^2$
- 2.26  $3.6 \times 10^{-7} \text{ lb}\cdot\text{s}/\text{ft}^2$
- 2.27  $1.9 \times 10^{-7} \text{ lb}\cdot\text{s}/\text{ft}^2$
- 2.28  $5.0 \times 10^{-2} \text{ lb}\cdot\text{s}/\text{ft}^2$
- 2.29  $4.1 \times 10^{-3} \text{ lb}\cdot\text{s}/\text{ft}^2$
- 2.30  $3.3 \times 10^{-5} \text{ lb}\cdot\text{s}/\text{ft}^2$
- 2.31  $2.8 \times 10^{-5} \text{ lb}\cdot\text{s}/\text{ft}^2$
- 2.32  $2.1 \times 10^{-3} \text{ lb}\cdot\text{s}/\text{ft}^2$
- 2.33  $9.5 \times 10^{-5} \text{ lb}\cdot\text{s}/\text{ft}^2$
- 2.34  $1.3 \times 10^{-2} \text{ lb}\cdot\text{s}/\text{ft}^2$
- 2.35  $2.2 \times 10^{-4} \text{ lb}\cdot\text{s}/\text{ft}^2$
- 2.36 Viscosity index is a measure of how greatly the viscosity of a fluid changes with temperature.
- 2.37 High viscosity index (VI).
- 2.38 Rotating drum viscometer.
- 2.39 The fluid occupies the small radial space between the stationary cup and the rotating drum. Therefore, the fluid in contact with the cup has a zero velocity while that in contact with the drum has a velocity equal to the surface speed of the drum.
- 2.40 A meter measures the torque required to drive the rotating drum. The torque is a function of the drag force on the surface of the drum which is a function of the shear stress in the fluid. Knowing the shear stress and the velocity gradient, Equation 2-2 is used to compute the dynamic viscosity.
- 2.41 The inside diameter of the capillary tube; the velocity of fluid flow; the length between pressure taps; the pressure difference between the two points a distance L apart. See Eq. (2-4).

- 2.42 Terminal velocity is that velocity achieved by the sphere when falling through the fluid when the downward force due to gravity is exactly balanced by the buoyant force and the drag force on the sphere. The drag force is a function of the dynamic viscosity.
- 2.43 The diameter of the ball; the terminal velocity (usually by noting distance traveled in a given time); the specific weight of the fluid; the specific weight of the ball.
- 2.44 The Saybolt viscometer employs a container in which the fluid can be brought to a known, controlled temperature, a small standard orifice in the bottom of the container and a calibrated vessel for collecting a 60 mL sample of the fluid. A stopwatch or timer is required to measure the time required to collect the 60 mL sample.
- 2.45 No. The time is reported as Saybolt Universal Seconds and is a relative measure of viscosity.
- 2.46 Kinematic viscosity.
- 2.47 Standard calibrated glass capillary viscometer.
- 2.48 See Table 2.4. The kinematic viscosity of SAE 20 oil must be between 5.6 and 9.3 cSt at 100°C using ASTM D 445. Its dynamic viscosity must be over 2.6 cP at 150°C using ASTM D 4683, D 4741, or D 5481. The kinematic viscosity of SAE 20W oil must be over 5.6 cSt at 100°C using ASTM D 445. Its dynamic viscosity for cranking must be below 9500 cP at -15°C using ASTM D 5293. For pumping it must be below 60,000 cP at -20°C using ASTM D 4684.
- 2.49 SAE 0W through SAE 250 depending on the operating environment. See Table 2.4.
- 2.50 SAE 70W through SAE 60 depending on the operating environment and loads. See Table 2.5.
- 2.51 100°C using ASTM D 445 testing method and at 150° C using ASTM D 4683, D 4741, or D 5481.
- 2.52 At -25°C using ASTM D 5293; at -30°C using ASTM D 4684; at 100°C using ASTM D 445.
- 2.53 See Table 2.4. The kinematic viscosity of SAE 5W-40 oil must be between 12.5 and 16.3 cSt at 100°C using ASTM D 445. Its dynamic viscosity must be over 2.9 cP at 150°C using ASTM D 4683, D 4741, or D 5481. The kinematic viscosity must be over 3.8 cSt at 100°C using ASTM D 445. Its dynamic viscosity for cranking must be below 6600 cP at -30°C using ASTM D 5293. For pumping it must be below 60 000 cP at -35°C using ASTM D 4684.
- 2.54  $\nu = \text{SUS}/4.632 = 500/4.632 = 107.9 \text{ mm}^2/\text{s} = 107.9 \times 10^{-6} \text{ m}^2/\text{s}$   
 $\nu = 107.9 \times 10^{-6} \text{ m}^2/\text{s} [(10.764 \text{ ft}^2/\text{s})/(\text{m}^2/\text{s})] = 1.162 \times 10^{-3} \text{ ft}^2/\text{s}$
- 2.55 SAE 10W-30 engine oil:  
 Low temperature cranking viscosity at -25°C: 7000 cP = 7000 mPa s = **7.0 Pa·s maximum**  
 Low temperature pumping viscosity at -30°C: 60 000 cP = 60 000 mPa s = **60 Pa·s maximum**  
 Low shear rate kinematic viscosity at 100°C: 9.3 cSt = 9.3 mm<sup>2</sup>/s = **9.3 × 10<sup>-6</sup> m<sup>2</sup>/2 minimum**  
 Low shear rate kinematic viscosity at 100°C: 12.5 cSt = 12.5 mm<sup>2</sup>/s = **12.5 × 10<sup>-6</sup> m<sup>2</sup>/2 maximum**  
 High shear rate dynamic viscosity at 150°C: 2.9 cP = 2.9 mPa s = **0.0029 Pa·s minimum**

$$2.56 \quad \eta = 4500 \text{ cP} [(1 \text{ Pa}\cdot\text{s})/(1000 \text{ cP})] = \mathbf{4.50 \text{ Pa}\cdot\text{s}}$$

$$\eta = 4.50 \text{ Pa}\cdot\text{s} [(1 \text{ lb}\cdot\text{s}/\text{ft}^2)/(47.88 \text{ Pa}\cdot\text{s})] = \mathbf{0.0940 \text{ lb}\cdot\text{s}/\text{ft}^2}$$

$$2.57 \quad \nu = 5.6 \text{ cSt} [(1 \text{ m}^2/\text{s})/(10^6 \text{ cSt})] = \mathbf{5.60 \times 10^{-6} \text{ m}^2/\text{s}}$$

$$\nu = 5.60 \times 10^{-6} \text{ m}^2/\text{s} [(10.764 \text{ ft}^2/\text{s})/(\text{m}^2/\text{s})] = \mathbf{6.03 \times 10^{-5} \text{ ft}^2/\text{s}}$$

$$2.58 \quad \text{From Figure 2.12: } \nu = 15.5 \text{ mm}^2/\text{s} = 15.5 \times 10^{-6} \text{ m}^2/\text{s}$$

$$2.59 \quad \eta = 6.5 \times 10^{-3} \text{ Pa}\cdot\text{s} [(1 \text{ lb}\cdot\text{s}/\text{ft}^2)/(47.88 \text{ Pa}\cdot\text{s})] = \mathbf{1.36 \times 10^{-4} \text{ lb}\cdot\text{s}/\text{ft}^2}$$

$$2.60 \quad \eta = 0.12 \text{ poise} [(1 \text{ Pa}\cdot\text{s})/(10 \text{ poise})] = 0.012 \text{ Pa}\cdot\text{s} = 1.2 \times 10^{-2} \text{ Pa}\cdot\text{s}. \quad \mathbf{\text{SAE 10 oil}}$$

2.61

$$\eta = \frac{(\gamma_s - \gamma_f)D^2}{18\nu} \quad (\text{Eq. 2-9}) \quad \left| \begin{array}{l} \gamma_f = 0.94(9.81 \text{ kN}/\text{m}^3) = 9.22 \text{ kN}/\text{m}^3 \\ D = 1.6 \text{ mm} = 1.6 \times 10^{-3} \text{ m} \end{array} \right.$$

$$\nu = s/t = .250 \text{ m}/10.4 \text{ s} = 2.40 \times 10^{-2} \text{ m}/\text{s}$$

$$\mu = \frac{(77.0 - 9.22) \text{ kN}(1.6 \times 10^{-3} \text{ m})^2}{18 \text{ m}^3(2.40 \times 10^{-2} \text{ m}/\text{s})} \times \frac{10^3 \text{ N}}{\text{kN}} = 0.402 \frac{\text{N}\cdot\text{s}}{\text{m}^2} = \mathbf{0.402 \text{ Pa}\cdot\text{s}}$$

2.62

$$\eta = \frac{(p_1 - p_2)D^2}{32\nu L} \quad (\text{Eq. 2-4}) \quad \left| \begin{array}{l} \text{Use } \gamma_{\text{Mercury}} = 132.8 \text{ kN}/\text{m}^3 \text{ (App. B)} \\ \gamma_o = 0.90(9.81 \text{ kN}/\text{m}^3) = 8.83 \text{ kN}/\text{m}^3 \end{array} \right.$$

Manometer Eq. using principles of Chapter 3:

$$p_1 + \gamma_o y + \gamma_o h - \gamma_m h - \gamma_o y = p_2$$

$$p_1 - p_2 = \gamma_m h - \gamma_o h = h(\gamma_m - \gamma_o) = 0.177 \text{ m}(132.8 - 8.83) \frac{\text{kN}}{\text{m}^3} = 21.94 \frac{\text{kN}}{\text{m}^2}$$

$$\eta = \frac{(21.94 \text{ kN}/\text{m}^2)(0.0025 \text{ m})^2}{32(1.58 \text{ m}/\text{s})(0.300 \text{ m})} = 9.04 \times 10^{-6} \frac{\text{kN}\cdot\text{s}}{\text{m}^2} \times \frac{10^3 \text{ N}}{\text{kN}} = \mathbf{9.04 \times 10^{-3} \text{ Pa}\cdot\text{s}}$$

$$2.63 \quad \text{See Prob. 2.61. } \gamma_f = 0.94(62.4 \text{ lb}/\text{ft}^3) = 58.7 \text{ lb}/\text{ft}^3: D = (0.063 \text{ in})(1 \text{ ft}/12 \text{ in}) = 0.00525 \text{ ft}$$

$$\nu = s/t = (10.0 \text{ in}/10.4 \text{ s})(1 \text{ ft}/12 \text{ in}) = 0.0801 \text{ ft}/\text{s}: \gamma_s = (0.283 \text{ lb}/\text{in}^3)(1728 \text{ in}^3/\text{ft}^3) = 489 \text{ lb}/\text{ft}^3$$

$$\eta = \frac{(\gamma_s - \gamma_f)D^2}{18\nu} = \frac{(489 - 58.7) \text{ lb}/\text{ft}^3 (0.00525 \text{ ft})^2}{32(4.82 \text{ ft}/\text{s})} = 0.00207 \text{ lb s}/\text{ft}^2 = 2.07 \times 10^{-4} \text{ lb}\cdot\text{s}/\text{ft}^2$$

$$2.64 \quad \text{See Problem 2.62. Use } \gamma_m = 844.9 \text{ lb}/\text{ft}^3 \text{ (App. B): } \gamma_o = (0.90)(62.4 \text{ lb}/\text{ft}^3) = 56.16 \text{ lb}/\text{ft}^3$$

$$h = (7.00 \text{ in})(1 \text{ ft}/12 \text{ in}) = 0.5833 \text{ ft}: D = (0.100 \text{ in})(1 \text{ ft}/12 \text{ in}) = 0.00833 \text{ ft}$$

$$p_1 - p_2 = h(\gamma_m - \gamma_o) = (0.5833 \text{ ft})(844.9 - 56.16) \text{ lb}/\text{ft}^3 = 460.1 \text{ lb}/\text{ft}^2$$

$$\eta = \frac{(p_1 - p_2)D^2}{32\nu L} = \frac{(460.1 \text{ lb}/\text{ft}^2)(0.00833 \text{ ft})^2}{32(4.82 \text{ ft}/\text{s})(1.0 \text{ ft})} = 0.000207 \text{ lb s}/\text{ft}^2 = 2.07 \times 10^{-4} \text{ lb}\cdot\text{s}/\text{ft}^2$$

$$2.65 \quad \text{From Fig. 2.12, kinematic viscosity} = 78.0 \text{ SUS}$$

- 2.66 From Fig 2.12, kinematic viscosity = 257 SUS
- 2.67  $\nu = 4.632(188) = 871$  SUS
- 2.68  $\nu = 4.632(244) = 1130$  SUS
- 2.69 From Fig. 2.13,  $A = 0.996$ . At 100°F,  $\nu = 4.632(153) = 708.7$  SUS.  
At 40°F,  $\nu = 0.996(708.7) = 706$  SUS
- 2.70 From Fig. 2.13,  $A = 1.006$ . At 100°F,  $\nu = 4.632(205) = 949.6$  SUS.  
At 190°F,  $\nu = 1.006(949.6) = 955$  SUS
- 2.71  $\nu = 6250/4.632 = 1349$  mm<sup>2</sup>/s
- 2.72  $\nu = 438/4.632 = 94.6$  mm<sup>2</sup>/s
- 2.73 From Fig. 2.12,  $\nu = 12.5$  mm<sup>2</sup>/s
- 2.74 From Fig 2.12,  $\nu = 37.5$  mm<sup>2</sup>/s
- 2.75  $t = 80^\circ\text{C} = 176^\circ\text{F}$ . From Fig. 2.13,  $A = 1.005$ . At 100°F,  $\nu = 4690/4.632 = 1012.5$  mm<sup>2</sup>/s.  
At 176°F (80°C):  $\nu = 1.005(1012.5) = 1018$  mm<sup>2</sup>/s.
- 2.76  $t = 40^\circ\text{C} = 104^\circ\text{F}$ . From Fig. 2.13,  $A = 1.00$ . At 100°F,  $\nu = 526/4.632 = 113.6$  mm<sup>2</sup>/s.  
At 176°F (80°C):  $\nu = 1.000(113.6) = 113.6$  mm<sup>2</sup>/s.

## Kinematic Viscosity Conversions

### Problem 2.77

SAE Viscosity Grades - Engine Oils				
Kinematic Viscosity at 100 deg C				
SAE No.	(mm <sup>2</sup> /s)		SUS	
	Min	Max	Min	Max
0W	3.8	---	38.9	---
5W	3.8	---	38.9	---
10W	4.1	---	39.8	---
15W	5.6	---	44.6	---
20W	5.6	---	44.6	---
25W	9.3	---	56.8	---
20	5.6	9.3	44.6	56.8
30	9.3	12.5	56.8	68.3
40	12.5	16.3	68.3	83.2
50	16.3	21.9	83.2	106.6
60	21.9	26.1	106.6	125.1

### Conversion method for both Problem 2.77 and 2.78:

Used method from Section 2.7.5 in the text.

1: 100 deg C = 212 deg F.

S: From Fig. 2.13, A = 1.007

3: Read SUS for 100 deg F from Fig. 2.12.

4: Multiply A times SUS at 100 deg F to get SUS at 100 deg C (212 deg F)

**Example:** Given minimum kinematic viscosity = 21.9 mm<sup>2</sup>/s for SAE 60  
 Read SUS at 100 deg F = 105.9 from Fig. 2.12  
 SUS at 100 deg C (212 deg F) = 1.007(105.9) = 106.6 SUS

**NOTE: Results reported here used tabular values from ASTM 2161. Values read from Fig. 2.12 may vary because of precision of graph or reading of values from scale.**

### Problem 2.78 (See Problem 2.77 for method.)

SAE Viscosity Grades - Automotive Gear Lubricants				
Kinematic Viscosity at 100 deg C				
SAE No.	(mm <sup>2</sup> /s)		SUS	
	Min	Max	Min	Max
70W	4.1	---	39.8	---
75W	4.1	---	39.8	---
80W	7.0	---	49.1	---
85W	11.0	---	62.8	---
80	7.0	11.0	49.1	62.8
85	11.0	13.5	62.8	72.1
90	13.5	24.0	72.1	115.8
140	24.0	41.0	115.8	192.6
250	41.0	---	192.6	---

## Kinematic Viscosity Conversions

### Problem 2.79

ISO Viscosity Grades						
ISO VG	Kinematic Viscosity at 40 deg C					
	(mm <sup>2</sup> /s)			SUS		
	Min	Nom	Max	Min	Nom	Max
2	1.98	2.2	2.40	32.5	33.3	34.0
3	2.88	3.2	3.52	35.6	36.6	37.6
5	4.14	4.6	5.06	39.6	41.1	42.6
7	6.12	6.8	7.48	46.0	48.1	50.3
10	9.00	10	11.0	55.4	58.8	62.4
15	13.5	15	16.5	71.6	77.4	83.4
22	19.8	22	24.2	97.0	106.3	115.9
32	28.8	32	35.2	136.2	150.5	164.9
46	41.4	46	50.6	193.1	214	235
68	61.2	68	74.8	284	315	347
100	90.0	100	110	417	463	510
150	135	150	165	625	695	764
220	198	220	242	917	1019	1121
320	288	320	352	1334	1482	1630
460	414	460	506	1918	2131	2344
680	612	680	748	2835	3150	3465
1000	900	1000	1100	4169	4632	5095
1500	1350	1500	1650	6253	6948	7643
2200	1980	2200	2420	9171	10190	11209
3200	2880	3200	3520	13340	14822	16305

**Note: Method used is same as for Problem 2.77.**

**Temperature:  $t = 40 \text{ deg C} = 104 \text{ deg F}$**

**From Fig. 2.13,  $A = 1.000$**

**Therefore, SUS values are read directly from Fig. 2.12.**

# CHAPTER THREE

## PRESSURE MEASUREMENT

### *Absolute and gage pressure*

3.1 Pressure = force/area;  $p = F/A$

3.2 Absolute pressure is measured relative to a perfect vacuum.

3.3 Gage pressure is measured relative to atmospheric pressure.

3.4 Atmospheric pressure is the absolute pressure in the local area.

3.5  $p_{\text{abs}} = p_{\text{gage}} + p_{\text{atm}}$

3.6 True.

3.7 False. Atmospheric pressure varies with altitude and with weather conditions.

3.8 False. Absolute pressure cannot be negative because a perfect vacuum is the reference for absolute pressure and a perfect vacuum is the lowest possible pressure.

3.9 True.

3.10 False. A gage pressure can be no lower than one atmosphere below the prevailing atmospheric pressure. On earth, the atmospheric pressure would never be as high as 150 kPa.

3.11 At 4000 ft,  $p_{\text{atm}} = 12.7$  psia; from App. E by interpolation.

3.12 At 13,500 ft,  $p_{\text{atm}} = 8.84$  psia; from App. E by interpolation.

3.13 Zero gage pressure.

3.14  $p_{\text{gage}} = 583 - 103 = 480$  kPa(gage)

3.15  $p_{\text{gage}} = 157 - 101 = 56$  kPa(gage)

3.16  $p_{\text{gage}} = 30 - 100 = -70$  kPa(gage)

3.17  $p_{\text{gage}} = 74 - 97 = -23$  kPa(gage)

3.18  $p_{\text{gage}} = 101 - 104 = -3$  kPa(gage)

3.19  $p_{\text{abs}} = 284 + 100 = 384$  kPa(abs)

3.20  $p_{\text{abs}} = 128 + 98 = 226$  kPa(abs)

- 3.21  $p_{\text{abs}} = 4.1 + 101.3 = \mathbf{105.4 \text{ kPa(abs)}}$
- 3.22  $p_{\text{abs}} = -29.6 + 101.3 = \mathbf{71.7 \text{ kPa(abs)}}$
- 3.23  $p_{\text{abs}} = -86 + 99 = \mathbf{13 \text{ kPa(abs)}}$
- 3.24  $p_{\text{gage}} = 84.5 - 14.9 = \mathbf{69.6 \text{ psig}}$
- 3.25  $p_{\text{gage}} = 22.8 - 14.7 = \mathbf{8.1 \text{ psig}}$
- 3.26  $p_{\text{gage}} = 4.3 - 14.6 = \mathbf{-10.3 \text{ psig}}$
- 3.27  $p_{\text{gage}} = 10.8 - 14.0 = \mathbf{-3.2 \text{ psig}}$
- 3.28  $p_{\text{gage}} = 14.7 - 15.1 = \mathbf{-0.4 \text{ psig}}$
- 3.29  $p_{\text{abs}} = 41.2 + 14.5 = \mathbf{55.7 \text{ psia}}$
- 3.30  $p_{\text{abs}} = 18.5 + 14.2 = \mathbf{32.7 \text{ psia}}$
- 3.31  $p_{\text{abs}} = 0.6 + 14.7 = \mathbf{15.3 \text{ psia}}$
- 3.32  $p_{\text{abs}} = -4.3 + 14.7 = \mathbf{10.4 \text{ psia}}$
- 3.33  $p_{\text{abs}} = -12.5 + 14.4 = \mathbf{1.9 \text{ psia}}$

### ***Pressure-Elevation Relationship***

- 3.34  $p = \gamma h = 1.08(9.81 \text{ kN/m}^3)(0.550 \text{ m}) = 5.83 \text{ kN/m}^2 = \mathbf{5.83 \text{ kPa(gage)}}$
- 3.35  $p = \gamma h = (\text{sg})\gamma_w h : \text{sg} = p/\gamma_w h$   

$$\text{sg} = \frac{1.820 \text{ lb ft}^3}{\text{in}^2 (62.4 \text{ lb})(4.0 \text{ ft})} \times \frac{144 \text{ in}^2}{\text{ft}^2} = \mathbf{1.05}$$
- 3.36  $h = \frac{p}{\gamma} = \frac{52.75 \text{ kN m}^3}{\text{m}^2 7.87 \text{ kN}} = \mathbf{6.70 \text{ m}}$
- 3.37  $p = \gamma h = \frac{64.00 \text{ lb}}{\text{ft}^3} \times 12.50 \text{ ft} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} = \mathbf{5.56 \text{ psig}}$
- 3.38  $p = \gamma h = \frac{62.4 \text{ lb}}{\text{ft}^3} \times 50.0 \text{ ft} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} = \mathbf{21.67 \text{ psig}}$
- 3.39  $p = \gamma h = (10.79 \text{ kN/m}^3)(3.0 \text{ m}) = 32.37 \text{ kN/m}^2 = \mathbf{32.37 \text{ kPa(gage)}}$
- 3.40  $p = \gamma h = (10.79 \text{ kN/m}^3)(12.0 \text{ m}) = \mathbf{129.5 \text{ kPa(gage)}}$

- 3.41  $p_{\text{air}} = p_{\text{A}} - \gamma_o(64 \text{ in}) = 180 \text{ psig} - (0.9)(62.4 \text{ lb/ft}^3)(64 \text{ in})(1 \text{ ft}^3/1728 \text{ in}^3)$   
 $p_{\text{air}} = 180 \text{ psig} - 2.08 \text{ psi} = \mathbf{177.9 \text{ psig}}$
- 3.42  $p_i = \gamma h = (1.15)(9.81 \text{ kN/m}^3)(0.375 \text{ m}) = \mathbf{4.23 \text{ kPa(gage)}}$
- 3.43  $p_{\text{atm}} = \mathbf{24.77 \text{ kPa(abs)}}$  By interpolation - App. E:  $\gamma_m = (13.54)9.81 \text{ kN/m}^3$   
 $\gamma_m = 132.8 \text{ kN/m}^3$   
 $p_{\text{B}} = p_{\text{atm}} + \gamma h = 24.77 \text{ kPa} + (132.8 \text{ kN/m}^3)(0.325 \text{ m}) = \mathbf{67.93 \text{ kPa(abs)}}$
- 3.44  $p = \gamma h = (0.95)(62.4 \text{ lb/ft}^3)(28.5 \text{ ft})(1 \text{ ft}^2/144 \text{ in}^2) = \mathbf{11.73 \text{ psig}}$
- 3.45  $p = 50.0 \text{ psig} + \gamma h = 50.0 \text{ psig} + 11.73 \text{ psi} = \mathbf{61.73 \text{ psig}}$   
(See 3.44 for  $\gamma h = 11.73 \text{ psig}$ )
- 3.46  $p = -10.8 \text{ psig} + \gamma h = -10.8 \text{ psig} + (0.95) \frac{(62.4 \text{ lb})}{\text{ft}^3} \times 6.25 \text{ ft} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2}$   
 $p = -10.8 \text{ psig} + 2.57 \text{ psi} = \mathbf{-8.23 \text{ psig}}$
- 3.47  $p_{\text{top}} + \gamma_o h = p_{\text{bot}} : h = \frac{p_{\text{bot}} - p_{\text{top}}}{\gamma_o}$   
 $h = \frac{(35.5 - 30.0) \text{ lb ft}^3}{\text{in}^2 (0.95)(62.4 \text{ lb})} \times \frac{144 \text{ in}^2}{\text{ft}^2} = \mathbf{13.36 \text{ ft}}$
- 3.48  $0 + \gamma_o h_o + \gamma_w h_w = p_{\text{bot}}$   
 $h_o = \frac{p_{\text{bot}} - \gamma_w h_w}{\gamma_o} = \frac{52.3 \text{ kN/m}^2 - (9.81 \text{ kN/m}^3)(2.80 \text{ m})}{(0.86)(9.81 \text{ kN/m}^3)} = \mathbf{2.94 \text{ m}}$
- 3.49  $0 + \gamma_o h_o + \gamma_w h_w = p_{\text{bot}}$   
 $h_w = \frac{p_{\text{bot}} - \gamma_o h_o}{\gamma_w} = \frac{125.3 \text{ kN/m}^2 - (0.86)(9.81 \text{ kN/m}^3)(6.90 \text{ m})}{9.81 \text{ kN/m}^3} = \mathbf{6.84 \text{ m}}$
- 3.50  $0 + \gamma_o h_1 + \gamma_w h_2 = p_{\text{bot}}$ ; but  $h_1 = 18.0 - h_2$   
 $\gamma_o(18 - h_2) + \gamma_w h_2 = p_{\text{bot}}$   
 $18\gamma_o - \gamma_o h_2 + \gamma_w h_2 = p_{\text{bot}} = h_2(\gamma_w - \gamma_o) + 18\gamma_o$   
 $h_2 = \frac{p_{\text{bot}} - 18\gamma_o}{\gamma_w - \gamma_o} = \frac{158 \text{ kN/m}^2 - (18 \text{ m})(.86)(9.81 \text{ kN/m}^3)}{[9.81 - (0.86)(9.81)] \text{ kN/m}^3} = \mathbf{4.47 \text{ m}}$
- 3.51  $p = \gamma h = (1.80)(9.81 \text{ kN/m}^3)(4.0 \text{ m}) = 70.6 \text{ kN/m}^2 = \mathbf{70.6 \text{ kPa(gage)}}$
- 3.52  $p = \gamma h = (0.89)(62.4 \text{ lb/ft}^3)(32.0 \text{ ft})(1 \text{ ft}^2/144 \text{ in}^2) = \mathbf{12.34 \text{ psig}}$
- 3.53  $p = \gamma h = (10.0 \text{ kN/m}^3)(11.0 \times 10^3 \text{ m}) = 110 \times 10^3 \text{ kN/m}^2 = \mathbf{110 \text{ MPa}}$
- 3.54  $p_{\text{atm}}^0 + \gamma_m(.457 \text{ m}) - \gamma_w(1.381 \text{ m}) - \gamma_G(0.50 \text{ m}) = p_{\text{air}}$   
 $p_{\text{air}} = (13.54)(9.81 \text{ kN/m}^3)(.457 \text{ m}) - (9.81 \text{ kN/m}^3)(1.381 \text{ m}) - (.68)(9.81)(.50)$   
 $p_{\text{air}} = (60.70 - 13.55 - 3.34) \text{ kN/m}^2 = \mathbf{43.81 \text{ kPa(gage)}}$

$$\begin{aligned}
3.55 \quad p_{\text{bot}} &= -34.0 \text{ kPa} + \gamma_o h_o + \gamma_w h_w \\
&= -34.0 \text{ kPa} + (0.85)(9.81 \text{ kN/m}^3)(0.50 \text{ m}) + (9.81 \text{ kN/m}^3)(0.75 \text{ m}) \\
p_{\text{bot}} &= -34.0 \text{ kPa} + 4.17 + 7.36 = \mathbf{-22.47 \text{ kPa(gage)}}
\end{aligned}$$

$$\begin{aligned}
3.56 \quad p_{\text{bot}} &= p_{\text{air}} + \gamma_o h_o + \gamma_w h_w \\
&= 200 \text{ kPa} + [(0.80)(9.81)(1.5) + (9.81)(2.6)] \text{ kN/m}^2 \\
p_{\text{bot}} &= 200 + 11.77 + 25.51 = \mathbf{237.3 \text{ kPa(gage)}}
\end{aligned}$$

**Manometers** (See text for answers to 3.57 to 3.61.)

$$\begin{aligned}
3.62 \quad p_A^0 - \gamma_m(0.075 \text{ m}) - \gamma_w(0.10 \text{ m}) &= p_A \\
p_A &= -(13.54)(9.81 \text{ kN/m}^3)(0.075 \text{ m}) - (9.81)(0.10) = \mathbf{-10.94 \text{ kPa(gage)}}
\end{aligned}$$

$$\begin{aligned}
3.63 \quad p_A + \gamma_o(13 \text{ in}) + \gamma_w(9 \text{ in}) - \gamma_o(32 \text{ in}) &= p_B \\
p_B - p_A = \gamma_w(9 \text{ in}) - \gamma_o(19 \text{ in}) &= \frac{62.4 \text{ lb}}{\text{ft}^3} \times 9 \text{ in} \times \frac{1 \text{ ft}^3}{1728 \text{ in}^3} - \frac{(0.85)(62.4)(19)}{1728} \\
p_B - p_A &= 0.325 \text{ psi} - 0.583 \text{ psi} = \mathbf{-0.258 \text{ psi}}
\end{aligned}$$

$$\begin{aligned}
3.64 \quad p_B - \gamma_w(33 \text{ in}) + \gamma_o(8 \text{ in}) + \gamma_w(13 \text{ in}) &= p_A \\
p_A - p_B = \gamma_o(8 \text{ in}) - \gamma_w(20 \text{ in}) &= \frac{(0.85)(62.4) \text{ lb}}{\text{ft}^3} \times 8 \text{ in} \times \frac{1 \text{ ft}^3}{1728 \text{ in}^3} - \frac{(62.4)(20)}{1728} \\
p_A - p_B &= 0.246 \text{ psi} - 0.722 \text{ psi} = \mathbf{-0.477 \text{ psi}}
\end{aligned}$$

$$\begin{aligned}
3.65 \quad p_B + \gamma_o(.15 \text{ m}) + \gamma_m(.75 \text{ m}) - \gamma_w(.50 \text{ m}) &= p_A \\
p_A - p_B &= (.90)(9.81 \text{ kN/m}^3)(.15 \text{ m}) + (13.54)(9.81)(.75) - (9.81)(0.50) \\
p_A - p_B &= (1.32 + 99.62 - 4.91) \text{ kPa} = \mathbf{96.03 \text{ kPa}}
\end{aligned}$$

$$\begin{aligned}
3.66 \quad p_B + \gamma_w(.15 \text{ m}) + \gamma_m(0.75 \text{ m}) - \gamma_o(0.60 \text{ m}) &= p_A \\
p_A - p_B &= (9.81 \text{ kN/m}^3)(0.15 \text{ m}) + (13.54)(9.81)(0.75) - (0.86)(9.81)(0.60) \\
p_A - p_B &= (1.47 + 99.62 - 5.06) \text{ kPa} = \mathbf{96.03 \text{ kPa}}
\end{aligned}$$

$$\begin{aligned}
3.67 \quad p_A^0 + \gamma_m(.475 \text{ m}) - \gamma_w(.30 \text{ m}) + \gamma_m(.25 \text{ m}) - \gamma_o(.375 \text{ m}) &= p_A \\
p_A &= \gamma_m(.725 \text{ m}) - \gamma_w(.30 \text{ m}) - \gamma_o(.375 \text{ m}) \\
p_A &= (13.54)(9.81 \text{ kN/m}^3)(.725 \text{ m}) - (9.81)(.30) - (.90)(9.81)(.375) \\
p_A &= (96.30 - 2.94 - 3.31) \text{ kPa} = \mathbf{90.05 \text{ kPa(gage)}}
\end{aligned}$$

$$\begin{aligned}
3.68 \quad p_B + \gamma_w(6 \text{ in}) + \gamma_m(6 \text{ in}) - \gamma_w(10 \text{ in}) + \gamma_m(8 \text{ in}) - \gamma_o(6 \text{ in}) &= p_A \\
p_A - p_B = \gamma_m(14 \text{ in}) - \gamma_w(4 \text{ in}) - \gamma_o(6 \text{ in}) \\
p_A - p_B &= (13.54) \times \frac{62.4 \text{ lb}}{\text{ft}^3} \times (14 \text{ in}) \times \frac{1 \text{ ft}^3}{1728 \text{ in}^3} - \frac{(62.4)(4)}{1728} - \frac{(.9)(62.4)(6)}{1728} \\
p_A - p_B &= (6.85 - 0.14 - 0.195) \text{ psi} = \mathbf{6.51 \text{ psi}}
\end{aligned}$$

$$3.69 \quad p_B - \gamma_w(2 \text{ ft}) - \gamma_o(3 \text{ ft}) + \gamma_w(11 \text{ ft}) = p_A$$

$$p_A - p_B = \gamma_w(9 \text{ ft}) - \gamma_o(3 \text{ ft}) = \frac{62.4 \text{ lb}}{\text{ft}^3} \times 9 \text{ ft} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} - \frac{(.90)(62.4)(3)}{144}$$

$$p_A - p_B = 3.90 \text{ psi} - 1.17 \text{ psi} = \mathbf{2.73 \text{ psi}}$$

$$3.70 \quad p_{\text{atm}} + \gamma_w(6.8 \text{ in}) = p_A = 0 + \frac{62.4 \text{ lb}}{\text{ft}^3} \times 6.8 \text{ in} \times \frac{1 \text{ ft}^3}{1728 \text{ in}^3} = \mathbf{0.246 \text{ psi}}$$

$$3.71 \quad p_{\text{atm}} + \gamma_{GF}h = p_A : h = L \sin 15^\circ = 0.115 \text{ m} \sin 15^\circ = 0.0298 \text{ m}$$

$$p_A = (0.87)(9.81 \text{ kN/m}^3)(0.0298 \text{ m}) = \mathbf{0.254 \text{ kPa(gage)}}$$

$$3.72 \quad \text{a. } p_{\text{atm}} + \gamma_m(.815 \text{ m}) - \gamma_w(.60 \text{ m}) = p_A$$

$$p_A = (13.54)(9.81 \text{ kN/m}^3)(0.815 \text{ m}) - (9.81)(.60) = \mathbf{102.4 \text{ kPa(gage)}}$$

$$\text{b. } p_{\text{atm}} = \gamma_m h = (13.54)(9.81)(.737) = 97.89 \text{ kPa}$$

$$p_A = 102.4 + 97.89 = \mathbf{200.3 \text{ kPa(abs)}}$$

### **Barometers**

3.73 A barometer measures atmospheric pressure.

3.74 See Fig. 3.14 and Section 3.7.

3.75 The height of the mercury column is convenient.

$$3.76 \quad h = \frac{p_{\text{atm}}}{\gamma_w} = \frac{14.7 \text{ lb ft}^3}{\text{in}^2 62.4 \text{ lb}} \times \frac{144 \text{ in}^2}{\text{ft}^2} = \mathbf{33.92 \text{ ft}} \quad \text{very large (10.34 m)}$$

3.77  $h = 29.29 \text{ in}$  See Example Problem 3.13

3.78  $h = 760 \text{ mm}$  See Example Problem 3.11

3.79 The vapor pressure above the mercury column and the specific weight of the mercury change.

$$3.80 \quad \Delta h = \frac{-1.0 \text{ in of Mercury}}{1000 \text{ ft}} \times 1250 \text{ ft} = \mathbf{-1.25 \text{ in}}$$

3.81 101.3 kPa  $\rightarrow$  760 mm of Mercury (See Ex. Prob. 3.11)

$$\Delta h = \frac{-85 \text{ mm}}{1000 \text{ m}} \times 5200 \text{ ft} \times \frac{.3048 \text{ m}}{1 \text{ ft}} = \mathbf{-134.7 \text{ mm}}$$

$$h = 760 - 134.7 = 625.3 \text{ mm}$$

$$p_{\text{atm}} = \gamma_m h = 133.3 \frac{\text{kN}}{\text{m}^3} \times 0.6253 \text{ m} = \mathbf{83.35 \text{ kPa}}$$

$$3.82 \quad p_{\text{atm}} = \gamma_m h = \frac{848.7 \text{ lb}}{\text{ft}^3} \times 28.6 \text{ in} \times \frac{1 \text{ ft}^3}{1728 \text{ in}^3} = \mathbf{14.05 \text{ psia}}$$

$$3.83 \quad p_{\text{atm}} = \gamma_m h = \frac{848.7 \text{ lb}}{\text{ft}^3} \times 30.65 \text{ in} \times \frac{1 \text{ ft}^3}{1728 \text{ in}^3} = \mathbf{15.05 \text{ psia}}$$

$$3.84 \quad h = \frac{p_{\text{atm}}}{\gamma_m} = \frac{14.2 \text{ lb}}{\text{in}^2} \times \frac{\text{ft}^3}{848.7 \text{ lb}} \times \frac{1728 \text{ in}^3}{\text{ft}^3} = \mathbf{28.91 \text{ in}}$$

$$3.85 \quad p_{\text{atm}} = \gamma_m h = 133.3 \frac{\text{kN}}{\text{m}^3} \times 0.745 \text{ m} = \mathbf{99.3 \text{ kPa(abs)}}$$

***Expressing Pressures as the Height of a Column of Liquid***

$$3.86 \quad p = 5.37 \text{ inH}_2\text{O} (1.0 \text{ psi}/27.68 \text{ inH}_2\text{O}) = \mathbf{0.194 \text{ psi}}$$

$$p = 5.37 \text{ inH}_2\text{O} (249.1 \text{ Pa}/1.0 \text{ inH}_2\text{O}) = \mathbf{1338 \text{ Pa} = 134 \text{ kPa}}$$

$$3.87 \quad p = -3.68 \text{ inH}_2\text{O} (1.0 \text{ psi}/27.68 \text{ inH}_2\text{O}) = \mathbf{-0.133 \text{ psi}}$$

$$p = -3.68 \text{ inH}_2\text{O} (249.1 \text{ Pa}/1.0 \text{ inH}_2\text{O}) = \mathbf{-917 \text{ Pa}}$$

$$3.88 \quad p = 3.24 \text{ mmHg} (133.3 \text{ Pa}/1.0 \text{ mmHg}) = \mathbf{431.9 \text{ Pa}}$$

$$p = 3.24 \text{ mmHg} (1.0 \text{ psi}/57.71 \text{ mmHg}) = \mathbf{0.0627 \text{ psi}}$$

$$3.89 \quad p = 21.6 \text{ mmHg} (133.3 \text{ Pa}/1.0 \text{ mmHg}) = \mathbf{2879 \text{ Pa} = 2.88 \text{ kPa}}$$

$$p = 21.6 \text{ mmHg} (1.0 \text{ psi}/57.71 \text{ mmHg}) = \mathbf{0.418 \text{ psi}}$$

$$3.90 \quad p = -68.2 \text{ kPa} (1000 \text{ Pa}/\text{kPa})(1.0 \text{ mmHg}/133.3 \text{ Pa}) = \mathbf{-512 \text{ mmHg}}$$

$$3.91 \quad p = -12.6 \text{ psig} (2.036 \text{ inHg}/\text{psi}) = \mathbf{-25.7 \text{ inHg}}$$

$$3.92 \quad p = 12.4 \text{ inWC} = 12.4 \text{ inH}_2\text{O} (1.0 \text{ psi}/27.68 \text{ inH}_2\text{O}) = \mathbf{0.448 \text{ psi}}$$

$$p = 12.4 \text{ inH}_2\text{O} (249.1 \text{ Pa}/1.0 \text{ inH}_2\text{O}) = \mathbf{3089 \text{ Pa} = 3.09 \text{ kPa}}$$

$$3.93 \quad p = 115 \text{ inWC} = 115 \text{ inH}_2\text{O} (1.0 \text{ psi}/27.68 \text{ inH}_2\text{O}) = \mathbf{4.15 \text{ psi}}$$

$$p = 115 \text{ inH}_2\text{O} (249.1 \text{ Pa}/1.0 \text{ inH}_2\text{O}) = \mathbf{28\,646 \text{ Pa} = 28.6 \text{ kPa}}$$

***Pressure Gages and Transducers*** (See text for answers to 3.94 to 3.97.)

## CHAPTER FOUR

# FORCES DUE TO STATIC FLUIDS

### *Forces due to gas pressure*

$$4.1 \quad F = \Delta p \cdot A; \text{ where } \Delta p = p_{\text{atm}} - p_{\text{inside}}; A = \frac{\pi(12 \text{ in})^2}{4} = 113.1 \text{ in}^2$$

$$p_{\text{atm}} = \gamma_m h = \frac{844.9 \text{ lb}}{\text{ft}^3} \times 30.5 \text{ in} \times \frac{1 \text{ ft}^3}{1728 \text{ in}^3} = 14.91 \text{ psi}$$

$$F = (14.91 - 0.12) \text{ lb/in}^2 \times 113.1 \text{ in}^2 = \mathbf{1673 \text{ lb}}$$

$$4.2 \quad F = p \cdot A = (14.4 \text{ lb/in}^2)(\pi(30 \text{ in})^2/4) = 10180 \text{ lb}$$

$$4.3 \quad F = \Delta p \cdot A; A = 36 \times 80 \text{ in}^2 = 2880 \text{ in}^2$$

$$\Delta p = \gamma_w h = \frac{62.4 \text{ lb}}{\text{ft}^3} \times 1.20 \text{ in} \times \frac{1 \text{ ft}^3}{1728 \text{ in}^3} = 0.0433 \text{ lb/in}^2$$

$$F = (0.0433 \text{ lb/in}^2)(2880 \text{ in}^2) = \mathbf{125 \text{ lb}}$$

$$4.4 \quad F = p \cdot A; A = 0.9396 \text{ ft}^2 \text{ (App. F)}$$

$$F = (325 \text{ lb/in}^2)(0.9396 \text{ ft}^2)(144 \text{ in}^2/\text{ft}^2) = \mathbf{43973 \text{ lb}}$$

$$4.5 \quad F = p \cdot A; A = \frac{\pi(0.030 \text{ m})^2}{4} = 7.07 \times 10^{-4} \text{ m}^2$$

$$F = (3.50 \times 10^6 \text{ N/m}^2)(7.07 \times 10^{-4} \text{ m}^2) = 2.47 \times 10^3 \text{ N} = \mathbf{2.47 \text{ kN}}$$

$$4.6 \quad F = p \cdot A; A = \pi(0.050 \text{ m})^2/4 = 1.963 \times 10^{-3} \text{ m}^2$$

$$F = (20.5 \times 10^6 \text{ N/m}^2)(1.963 \times 10^{-3} \text{ m}^2) = 40.25 \times 10^3 \text{ N} = \mathbf{40.25 \text{ kN}}$$

$$4.7 \quad F = p \cdot A; A = (0.800 \text{ m})^2 = 0.640 \text{ m}^2$$

$$F = (34.4 \times 10^3 \text{ N/m}^2)(0.64 \text{ m}^2) = 22.0 \times 10^3 \text{ N} = \mathbf{22.0 \text{ kN}}$$

### *Forces on horizontal flat surfaces under liquids*

$$4.8 \quad F = p \cdot A; A = 24 \times 18 \text{ in}^2 = 432 \text{ in}^2$$

$$p = \gamma_A h = \frac{56.78 \text{ lb}}{\text{ft}^3} \times 12.3 \text{ ft} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} = 4.85 \text{ lb/in}^2$$

$$F = (4.85 \text{ lb/in}^2)(432 \text{ in}^2) = \mathbf{2095 \text{ lb}}$$

$$4.9 \quad F = p \cdot A; A = \pi(0.75 \text{ in})^2/4 = 0.442 \text{ in}^2$$

$$p = \gamma_m h = \frac{844.9 \text{ lb}}{\text{ft}^3} \times 28.0 \text{ in} \times \frac{1 \text{ ft}^3}{1728 \text{ in}^3} = 13.69 \text{ lb/in}^2$$

$$F = (13.76 \text{ lb/in}^2)(0.442 \text{ in}^2) = \mathbf{6.05 \text{ lb}}$$

4.10 Force on valve =  $p \cdot A$ ;  $A = \pi(0.095 \text{ m})^2/4 = 7.088 \times 10^{-3} \text{ m}^2$   
 $p = \gamma_w h = \frac{9.81 \text{ kN}}{\text{m}^3} \times 1.80 \text{ m} = 17.66 \text{ kN/m}^2$   
 $F = (17.66 \times 10^3 \text{ N/m}^2)(7.088 \times 10^{-3} \text{ m}^2) = 125 \text{ N}$  Acts at center  
 $\Sigma M_{\text{hinge}} = 0 = (125 \text{ N})(47.5 \text{ mm}) - F_O(65 \text{ mm})$   
 $F_O = 5946 \text{ N} \cdot \text{mm}/65 \text{ mm} = \mathbf{91.5 \text{ N}}$  = Opening force

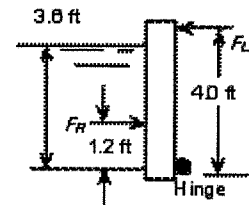
4.11  $F_B = p_B \cdot A$ ;  $A = 1.2 \times 1.8 \text{ m}^2 = 2.16 \text{ m}^2$   
 $p_B = p_{\text{air}} + \gamma_o(0.50 \text{ m}) + \gamma_w(0.75 \text{ m})$   
 $p_B = 52 \text{ kPa} + (0.85)(9.81 \text{ kN/m}^3)(0.5 \text{ m}) + (9.81)(0.75) = 63.5 \text{ kPa}$   
 $F_B = (63.5 \times 10^3 \text{ N/m}^2)(2.16 \text{ m}^2) = 137 \times 10^3 \text{ N} = \mathbf{137 \text{ kN}}$

4.12  $F_B = p_B \cdot A$ ;  $A = 2.0 \times 1.2 \text{ m}^2 = 2.4 \text{ m}^2$   
 $p_B = 200 \text{ kPa} + \gamma_o(1.5 \text{ m}) + \gamma_w(2.6 \text{ m})$   
 $p_B = 200 \text{ kPa} + (0.80)(9.81 \text{ kN/m}^3)(1.5 \text{ m}) + (9.81)(2.6) = 237.3 \text{ kPa}$   
 $F_B = (237.3 \times 10^3 \text{ N/m}^2)(2.4 \text{ m}^2) = 569 \times 10^3 \text{ N} = \mathbf{569 \text{ kN}}$

4.13  $F_P = \Delta p \cdot A$ ;  $A = \pi(0.60 \text{ m})^2/8 + (0.80 \text{ m})(0.60 \text{ m}) + \frac{1}{2} (.60 \text{ m})(0.30 \text{ m})$   
 $A = 0.711 \text{ m}^2$  : Assume std. atmosphere above water.  
 $p_w = p_{\text{atm}} + \gamma_{sw}h = 101.3 \text{ kPa} + (10.10 \text{ kN/m}^3)(175 \text{ m}) = 1869 \text{ kPa}$   
 $\Delta p = 1869 \text{ kPa} - 100 \text{ kPa} = 1769 \text{ kPa}$   
 $F_P = (1769 \times 10^3 \text{ N/m}^2)(0.711 \text{ m}^2) = 1.257 \times 10^6 \text{ N} = \mathbf{1.26 \text{ MN}}$

**Forces on rectangular walls**

4.14  $F_R = \gamma_w(h/2)A$   
 $= (62.4 \text{ lb/ft}^3)(1.8 \text{ ft})(8.0 \text{ ft})(3.6 \text{ ft}) = \mathbf{3235 \text{ lb}}$   
 $F_R$  acts  $\perp$  wall, 1.20 ft from bottom of gate



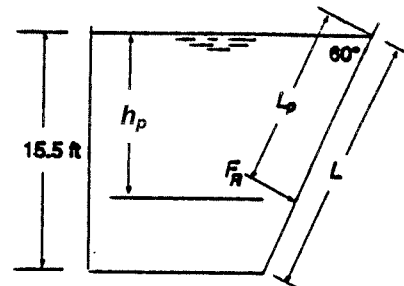
Part (b)

$\Sigma M_{\text{hinge}} = F_R(1.2 \text{ ft}) - F_{LT}(4.0 \text{ ft})$   
 $F_{LT} = F_R(1.2/4.0) = 3235 \text{ lb}(0.30) = 970.5 \text{ lb}$  on two latches  
 On each latch:  $F_L = (970.5 \text{ lb})/2 = \mathbf{485 \text{ lb}}$

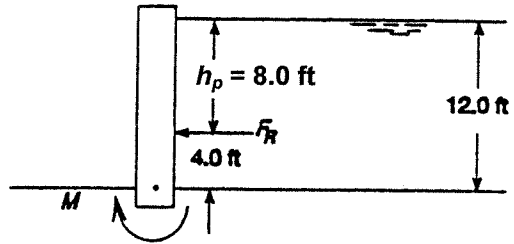
4.15 Length of sloped side =  $L = 15.5 \text{ ft}/\sin 60^\circ$   
 $= 17.90 \text{ ft}$

$A = (17.90 \text{ ft})(11.6 \text{ ft}) = 207.6 \text{ ft}^2$   
 $F_R = \gamma(h/2)(A)$   
 $= \frac{78.50 \text{ lb}}{\text{ft}^3} \times \frac{15.5 \text{ ft}}{2} \times 207.6 \text{ ft}$

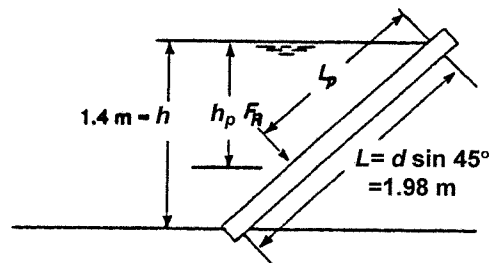
$F_R = \mathbf{126300 \text{ lb}}$   
 $h_p = 2/3 h = (2/3)(15.5 \text{ ft}) = \mathbf{10.33 \text{ ft}}$   
 $L_p = 2/3 L = (2/3)(17.90 \text{ ft}) = \mathbf{11.93 \text{ ft}}$



4.16  $F_R = \gamma(h/2)A = \frac{62.4 \text{ lb}}{\text{ft}^3} \times 6 \text{ ft} \times (12 \text{ ft})(20 \text{ ft})$   
 $F_R = 89850 \text{ lb}$   
 $h_p = 2/3 h = 2/3(12 \text{ ft}) = 8.0 \text{ ft}$   
 Moment =  $F_R \cdot 4 \text{ ft} = 359400 \text{ lb}\cdot\text{ft}$

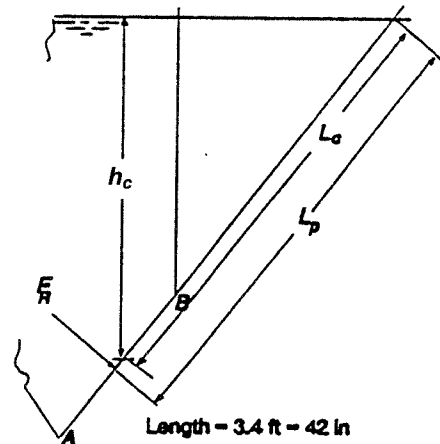


4.17  $F_R = \gamma_o(h/2)A$   
 $= (0.86) \frac{9.81 \text{ kN}}{\text{m}^3} \times 0.7 \text{ m} \times (1.98)(4.0) \text{ m}^2$   
 $F_R = 46.8 \text{ kN}$   
 $h_p = 2/3 h = (2/3)(1.4 \text{ m}) = 0.933 \text{ m}$   
 $L_p = 2/3 L = (2/3)(1.98 \text{ m}) = 1.32 \text{ m}$

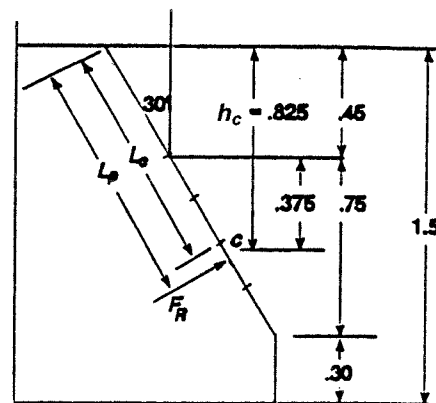


**Forces on submerged plane areas**

4.18 Centroid is at midpoint of AB  
 $h_c = 14 \text{ in} + 4 \text{ in} = 18 \text{ in} = 1.50 \text{ ft}$   
 $\overline{AB} = 10.0 \text{ in}$  [3-4-5 triangle]  
 $\frac{L_c}{d_c} = \frac{5}{4}; L_c = h_c \cdot \frac{5}{4} = 22.5 \text{ in}$   
 Area =  $\frac{\overline{AB}}{12} \cdot 3.5 \text{ ft} = \frac{10}{12} \cdot 3.5 = 2.92 \text{ ft}^2$  (420 in<sup>2</sup>)  
 $F_R = \gamma h_c A = 0.93(62.4 \text{ lb/ft}^3)(1.50 \text{ ft})(2.92 \text{ ft}^2)$   
 $F_R = 254 \text{ lb}$   
 $I_c = \frac{BH^3}{12} = \frac{(42)(10)^3 \text{ in}^4}{12} = 3500 \text{ in}^4$   
 $L_p - L_c = \frac{I_c}{L_c A} = \frac{3500 \text{ in}^4}{(22.5 \text{ in})(420 \text{ in}^2)} = 0.37 \text{ in}$   
 $L_c = L_c + 0.37 \text{ in} = 22.5 \text{ in} + 0.37 \text{ in} = 22.87 \text{ in}$



4.19  $h_c = 0.825 \text{ m} = 825 \text{ mm}$   
 $L_c = \frac{h_c}{\cos 30^\circ} = \frac{825 \text{ mm}}{\cos 30^\circ} = 953 \text{ mm}$   
 $A = \frac{\pi(450 \text{ mm})^2}{4} = 1.59 \times 10^5 \text{ mm}^2$  [.159 m<sup>2</sup>]  
 $F_R = \gamma h_c A = (0.85)(9.81 \text{ kN/m}^3)(.825 \text{ m})(.159 \text{ m}^2)$   
 $F_R = 1.09 \text{ kN}$   
 $I_c = \frac{\pi D^4}{64} = \frac{\pi(450)^4}{64} = 2.013 \times 10^9 \text{ mm}^4$   
 $L_p - L_c = \frac{I_c}{L_c A} = \frac{2.013 \times 10^9}{(953)(1.59 \times 10^5)} = 13.3 \text{ mm}$   
 $L_p = L_c + 13.3 \text{ mm} = 953 + 13.3 = 966 \text{ mm}$



4.20  $h_c = 3.0 \text{ m}; L_c = h_c / \cos 30^\circ = 3.464 \text{ m}$

$$A = \frac{\pi D^2}{4} = \frac{\pi(2.4 \text{ m})^2}{4} = 4.524 \text{ m}^2$$

$$I = \frac{\pi D^4}{64} = \frac{\pi(2.4 \text{ m})^4}{64} = 1.629 \text{ m}^4$$

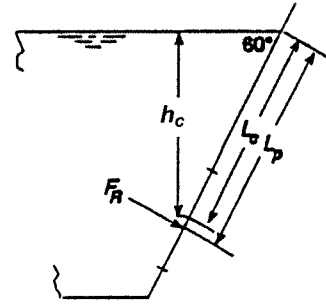
$$F_R = \gamma h_c A = (1.10)(9.81 \text{ kN/m}^3)(3.0 \text{ m})(4.524 \text{ m}^2)$$

$$F_R = 146.5 \text{ kN}$$

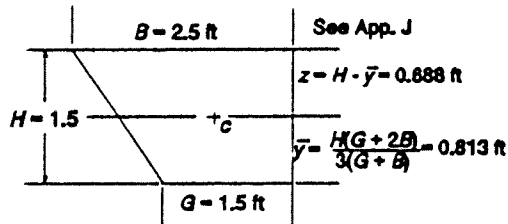
$$L_p - L_c = \frac{I_c}{L_c A} = \frac{1.629 \text{ m}^4}{(3.464 \text{ m})(4.524 \text{ m}^2)} = 0.104 \text{ m}$$

$$= 104 \text{ mm}$$

$$L_p = L_c + 0.104 \text{ m} = 3.464 + 0.104 = 3.568 \text{ m}$$



4.21



$$L_c = a + 1.5 + z = 8.0 / \cos 45^\circ + 1.5 + z$$

$$= 13.50 \text{ ft}$$

$$h_c = L_c \cos 45^\circ = 9.55 \text{ ft}$$

$$F_R = \gamma h_c A = (62.4 \text{ lb/ft}^3)(9.55 \text{ ft})(3.0 \text{ ft}^2)$$

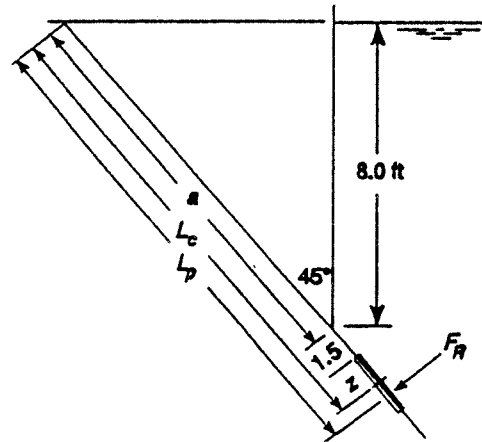
$$= 1787 \text{ lb}$$

$$A = H(G + B)/2 = 1.5(4.0)/2 = 3.0 \text{ ft}^2$$

$$I_c = \frac{H^3(G^2 + 4GB + B^2)}{36(G + B)} = 0.551 \text{ ft}^4$$

$$L_p - L_c = I_c / L_c A = 0.551 / (13.50)(3.0) = 0.0136 \text{ ft} = 0.163 \text{ in}$$

$$L_p = L_c + 0.0136 \text{ ft} = 13.50 + 0.0136 = 13.51 \text{ ft}$$



4.22  $L_c = a + 1.0 \text{ ft} = 3.0 / \cos 30^\circ + 1.0 = 4.464 \text{ ft}$

$$h_c = L_c \cos 30^\circ = 3.866 \text{ ft}$$

$$A = \pi(0.5 \text{ ft})^2 / 4 = 0.196 \text{ ft}^2$$

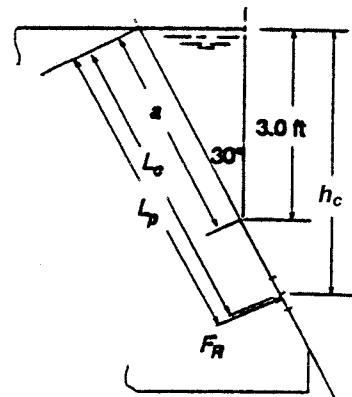
$$F_R = \gamma h_c A = (0.90)(62.4 \text{ lb/ft}^3)(3.866 \text{ ft})(0.196 \text{ ft}^2)$$

$$F_R = 42.6 \text{ lb}$$

$$I_c = \frac{\pi D^4}{64} = \frac{\pi(0.5)^2}{64} = 0.00307 \text{ ft}^4$$

$$L_p - L_c = \frac{I_c}{L_c A} = \frac{0.00307}{(4.46)(0.196)} = 0.00351 \text{ ft}$$

$$L_p = L_c + 0.00351 = 4.468 \text{ ft}$$



4.23  $L_c = h_c / \cos 40^\circ = 0.855 / \cos 40^\circ = 1.116 \text{ m}$

$$A = (.300)^2 + \frac{\pi(.30)^2}{4} = 0.1607 \text{ m}^2$$

$$F_R = \gamma h_c A = (0.90)(9.81 \text{ kN/m}^3)(0.855 \text{ m})(A)$$

$$F_R = 1.213 \text{ kN}$$

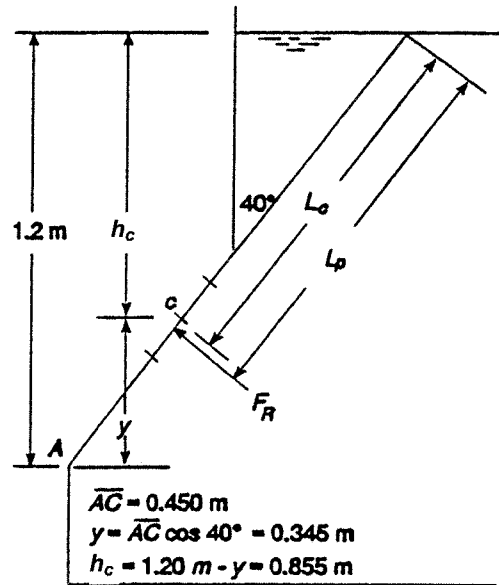
$$I_c = \frac{(0.300)^4}{12} + \frac{\pi(.300)^4}{64}$$

$$I_c = 0.001073 \text{ m}^4$$

$$L_p - L_c = \frac{I_c}{L_c A} = \frac{0.001073}{(1.116)(0.1607)}$$

$$L_p - L_c = .00598 \text{ m} = 5.98 \text{ mm}$$

$$L_p = 1.122 \text{ m}$$



4.24  $A = \pi D^2 / 4 = \pi(2.0)^2 / 4 = 3.142 \text{ ft}^2$

$$F_R = \gamma h_c A = 62.4 \text{ lb/ft}^3 \times 6.536 \text{ ft} \times 3.142 \text{ ft}^2$$

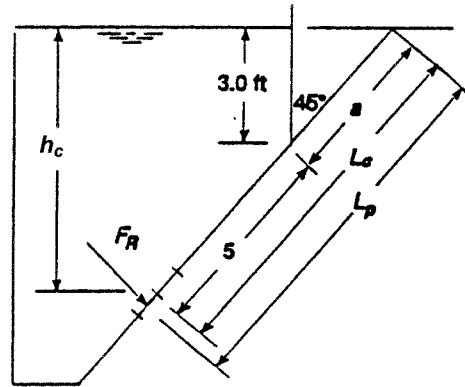
$$F_R = 1281 \text{ lb}$$

$$I_c = \frac{\pi D^4}{64} = 0.785 \text{ ft}^4$$

$$L_p - L_c = \frac{I_c}{L_c A} = \frac{0.785}{(9.243)(3.142)}$$

$$L_p - L_c = 0.027 \text{ ft} = [0.325 \text{ in}]$$

$$L_p = 9.270 \text{ ft}$$



$$a = 3.0 / \cos 45^\circ = 4.243 \text{ ft}$$

$$L_c = 5 + a = 9.243 \text{ ft}$$

$$h_c = L_c \cos 45^\circ = 6.536 \text{ ft}$$

4.25  $L_c = a + 0.50 \text{ m} = 0.76 \text{ m} / \cos 20^\circ + 0.50$

$$L_c = 1.309 \text{ m}$$

$$h_c = L_c \cos 20^\circ = 1.230 \text{ m}$$

$$A = (1.00)(0.60) = 0.60 \text{ m}^2$$

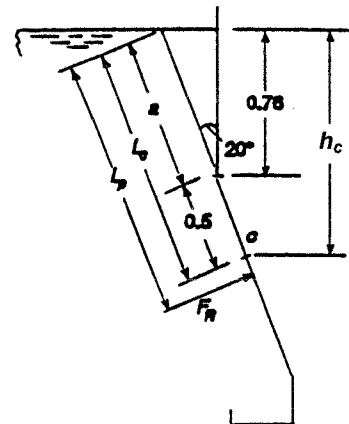
$$F_R = \gamma h_c A = (0.80)(9.81 \text{ kN/m}^3)(1.23 \text{ m})(0.60 \text{ m}^2)$$

$$F_R = 5.79 \text{ kN}$$

$$I_c = \frac{BH^3}{12} = \frac{(0.60)(1.00)^3 \text{ m}^4}{12} = 0.05 \text{ m}^4$$

$$L_p - L_c = \frac{I_c}{L_c A} = \frac{0.05}{(1.309)(0.60)} = 0.0637 \text{ m} = 63.7 \text{ mm}$$

$$L_p = L_c + 0.0637 = 1.372 \text{ m}$$



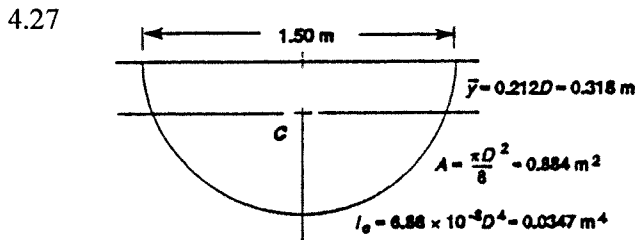
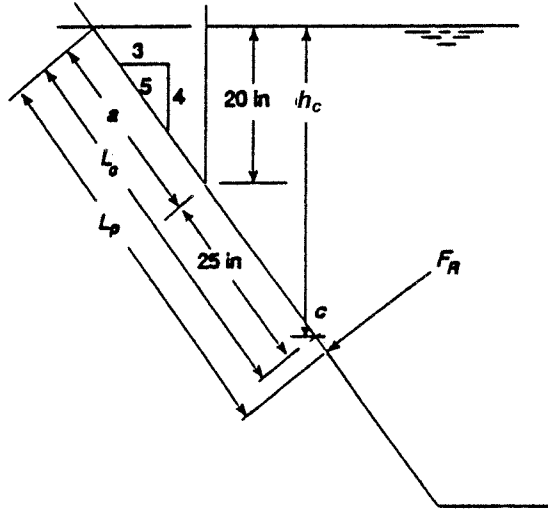
4.26  $a = \frac{5}{4} \cdot 20 = 25 \text{ in}$   
 $L_c = a + 25 = 50.0 \text{ in} = 4.167 \text{ ft}$   
 $h_c = \frac{4}{5} \cdot L_c = 40.0 \text{ in} = 3.333 \text{ ft}$   
 $A = (8)(50) = 400 \text{ in}^2 (1 \text{ ft}^2 / 144 \text{ in}^2)$   
 $= 2.778 \text{ ft}^2$

$F_R = \gamma h_c A$   
 $= (1.43)(62.4 \text{ lb/ft}^3)(3.333 \text{ ft})(2.778 \text{ ft}^2)$   
 $F_R = 826 \text{ lb}$

$I_c = \frac{BH^3}{12} = \frac{(8)(50)^3}{12} = 83,333 \text{ in}^4$

$L_p - L_c = \frac{I_c}{L_c A} = \frac{83333 \text{ in}^4}{(50.0 \text{ in})(400 \text{ in}^2)}$   
 $= 4.167 \text{ in}$

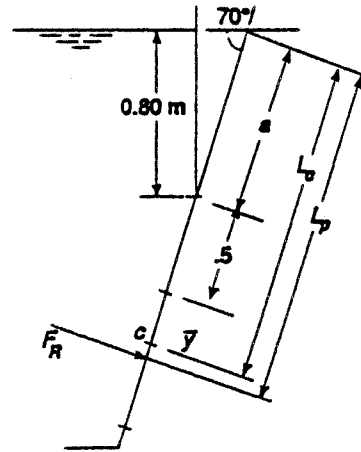
$L_p = L_c + 4.167 \text{ in} = 54.167 \text{ in} (4.514 \text{ ft})$



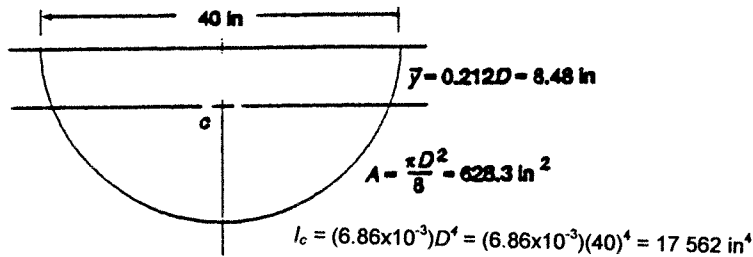
$a = 0.80 \text{ m} / \sin 70^\circ = 0.851 \text{ m}$   
 $L_c = a + 0.5 + y = 0.851 + 0.50 + 0.318 = 1.669 \text{ m}$   
 $h_c = L_c \sin 70^\circ = 1.569 \text{ m}$   
 $F_R = \gamma h_c A$   
 $= (0.88)(9.81 \text{ kN/m}^3)(1.569 \text{ m})(0.884 \text{ m}^2)$   
 $F_R = 11.97 \text{ kN}$

$L_p - L_c = \frac{I_c}{L_c A} = \frac{0.0347 \text{ m}^4}{(1.669 \text{ m})(0.884 \text{ m}^2)} = 0.0235 \text{ m}$   
 $= 23.5 \text{ mm}$

$L_p = L_c + 0.0235 \text{ m} = 1.669 \text{ m} + 0.0235 \text{ m} = 1.693 \text{ m}$



4.28



$$a = 10 \text{ in} / \cos 30^\circ = 11.55 \text{ in}$$

$$L_c = a + 8 + \bar{y} = 11.55 + 8.0 + 8.48 = 28.03 \text{ in}$$

$$h_c = L_c \cos 30^\circ = 24.27 \text{ in} [2.023 \text{ ft}]$$

$$F_R = \gamma h_c A$$

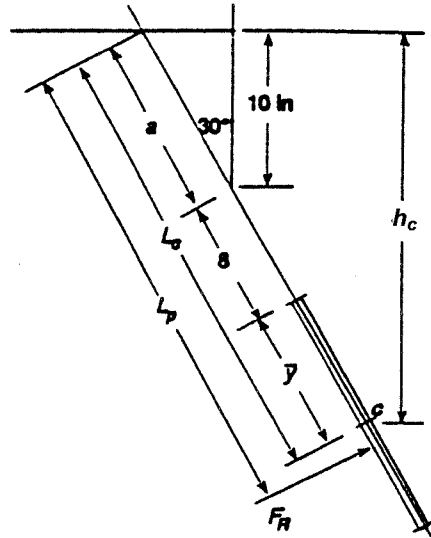
$$= (1.10)(62.4 \text{ lb/ft}^3)(2.023 \text{ ft}) \frac{(628.3 \text{ in}^2)(1 \text{ ft}^2)}{144 \text{ in}^2}$$

$$F_R = 605.8 \text{ lb}$$

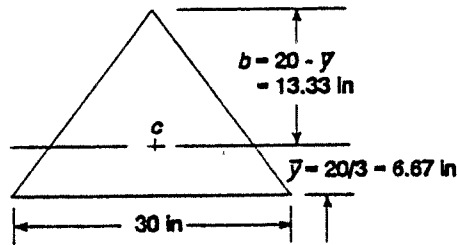
$$L_p - L_c = \frac{I_c}{L_c A} = \frac{17\,562 \text{ in}^4}{(28.03 \text{ in})(628.3 \text{ in}^2)} = 0.997$$

$$= 7.135 \text{ in}$$

$$L_p = L_c + 7.135 \text{ in} = 29.03 \text{ in}$$



4.29



$$A = \frac{1}{2} BH = \left(\frac{1}{2}\right)(30)(20) = 300 \text{ in}^2$$

$$I_c = \frac{BH^3}{36} = \frac{30(20)^3}{36} = 6667 \text{ in}^4$$

$$a = 18 \text{ in} / \cos 50^\circ = 28.0 \text{ in}$$

$$L_c = a + 6 + b = 28.0 + 6.0 + 13.33$$

$$L_c = 47.34 \text{ in}$$

$$h_c = L_c \cos 50^\circ = 30.43 \text{ in}$$

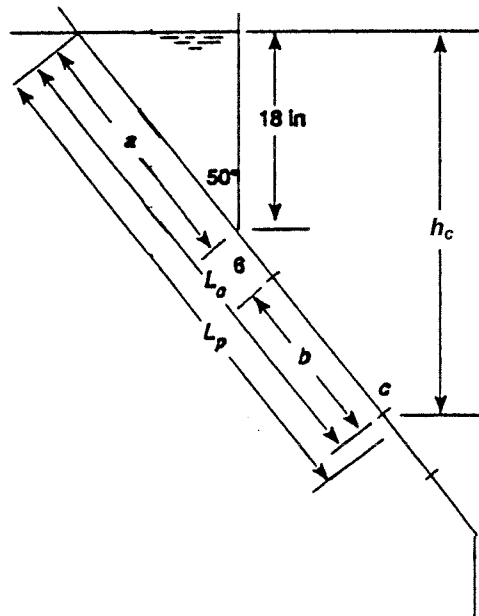
$$F_R = \gamma h_c A$$

$$F_R = 62.4 \text{ lb/ft}^3 \times 30.43 \text{ in} \times 300 \text{ in}^2$$

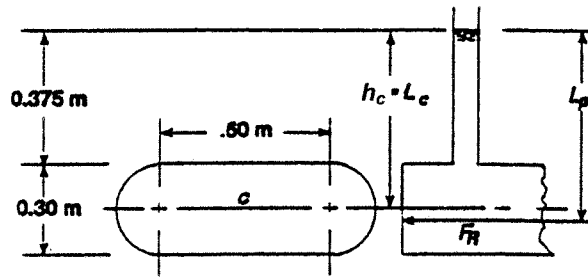
$$\times \frac{\text{ft}^3}{1728 \text{ in}^3} = 329.6 \text{ lb}$$

$$L_p - L_c = \frac{I_c}{L_c A} = \frac{6667 \text{ in}^4}{(47.34 \text{ in})(300 \text{ in}^2)} = 0.469 \text{ in}$$

$$L_p = L_c + 0.469 \text{ in} = 47.34 + 0.469 = 47.81 \text{ in}$$



4.30  $h_c = L_c$   
 $= 0.375 + 0.150 = 0.525 \text{ m}$   
 $A = (0.60)(0.30) + \pi(0.30)^2/4$   
 $A = 0.2507 \text{ m}^2$



$F_R = \gamma h_c A$   
 $F_R = (0.67)(9.81 \text{ kN/m}^3)(0.525 \text{ m})(0.2507 \text{ m}^2)$   
 $F_R = 0.865 \text{ kN} = \mathbf{865 \text{ N}}$

$I_c = \frac{(0.60)(0.30)^3}{12} + \frac{\pi(0.30)^4}{64} = 0.001748 \text{ m}^4$

$L_p - L_c = \frac{I_c}{L_c A} = \frac{0.001748 \text{ m}^4}{(0.525 \text{ m})(0.2507 \text{ m}^2)} = 0.0133 \text{ m} = \mathbf{13.3 \text{ mm}}$

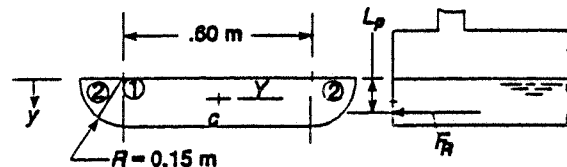
$L_p = L_c + 13.3 \text{ mm} = 525 + 13.3 = \mathbf{538 \text{ mm}}$

4.31 (See Prob. 4.30)  $h_c = L_c = 0.150 \text{ m}$   
 $F_R = \gamma h_c A = (0.67)(9.81)(0.150)(0.2507) = 0.247 \text{ kN} = \mathbf{247 \text{ N}}$

$L_p - L_c = \frac{I_c}{L_c A} = \frac{0.001748 \text{ m}^4}{(0.150 \text{ m})(0.2507 \text{ m}^2)} = 0.0465 \text{ m} = \mathbf{46.5 \text{ mm}}$

$L_p = L_c + 46.5 \text{ mm} = 150 \text{ mm} + 46.5 \text{ mm} = \mathbf{196.5 \text{ mm}}$

4.32  $\bar{Y} = \frac{\sum Ay}{A_T} = \frac{9.0 \times 10^{-3} \text{ m}^3}{0.1253 \text{ m}^2}$   
 $= 0.0718 \text{ m}$



$L_c = h_c = \bar{Y} = 0.0718 \text{ m} = \mathbf{71.8 \text{ mm}}$

	$A(\text{m}^2)$	$\bar{y}(\text{m})$	$A\bar{y}(\text{m}^3)$	$I_c(\text{m}^4)$	$h(\text{m})$	$Ah^2$
1 Rect.	0.0900	0.075	$6.750 \times 10^{-3}$	$1.688 \times 10^{-4}$	0.00324	$9.4 \times 10^{-7}$
2 Semicirc.	0.0353	0.0636	$2.245 \times 10^{-3}$	$5.557 \times 10^{-5}$	0.00816	$2.35 \times 10^{-6}$
	0.1253		$9.000 \times 10^{-3}$	$2.243 \times 10^{-4}$		$3.30 \times 10^{-6}$

$I_c = 2.276 \times 10^{-4} \text{ m}^4$

$L_p - L_c = \frac{I_c}{L_c A} = \frac{2.276 \times 10^{-4} \text{ m}^4}{(0.0718 \text{ m})(0.1253 \text{ m}^2)} = 0.0253 \text{ m} = \mathbf{25.3 \text{ mm}}$

$L_p = L_c + 25.3 \text{ mm} = \mathbf{97.1 \text{ mm}}$

$F_R = \gamma h_c A = (0.67)(9.81 \text{ kN/m}^3)(0.0718 \text{ m})(0.1253 \text{ m}^2) = 0.059 \text{ kN} = \mathbf{59 \text{ N}}$

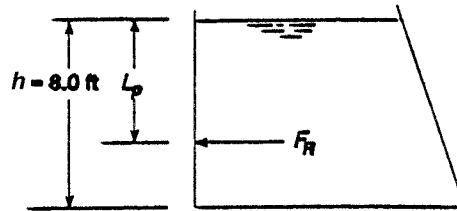
4.33 **Rectangular Wall**

$$F_R = \gamma(h/2)A$$

$$= 62.4 \text{ lb/ft}^3 \times 4.0 \text{ ft} \times (8.0 \text{ ft})(15.0 \text{ ft})$$

$$= \mathbf{29950 \text{ lb}}$$

$$L_p = \frac{2}{3}h = \frac{2}{3}(8.0 \text{ ft}) = \mathbf{5.333 \text{ ft}}$$



4.34  $G = 10.0 \text{ ft} - 8.0 \text{ ft}/\tan 60^\circ = 5.381 \text{ ft}$

$$A = \frac{H(G+B)}{2} = 61.52 \text{ ft}^2$$

$$\bar{y} = \frac{H(G+2B)}{3(G+B)} = 4.40 \text{ ft} = h_c = L_c$$

$$F_R = \gamma h_c A$$

$$F_R = 62.4 \text{ lb/ft}^3 \times 4.40 \text{ ft} \times 61.52 \text{ ft}^2$$

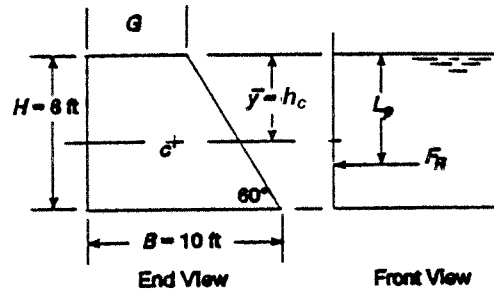
$$= \mathbf{16894 \text{ lb}}$$

$$I_c = \frac{H^3(G^2 + 4GB + B^2)}{36(G+B)}$$

$$= \frac{8^3[5.38^2 + 4(5.38)(10) + 10^2]}{36(5.38 + 10)} = 318.3 \text{ ft}^4$$

$$L_p - L_c = \frac{I_c}{L_c A} = \frac{318.3}{(4.40)(61.52)} = \mathbf{1.176 \text{ ft}}$$

$$L_p = L_c + 1.176 = \mathbf{5.576 \text{ ft}}$$



4.35 **Rectangular Wall**

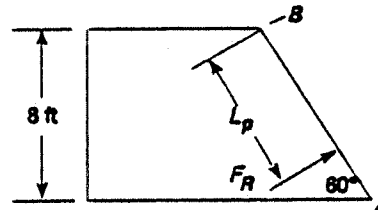
$$\overline{AB} = 8.0 \text{ ft}/\sin 60^\circ = 9.237 \text{ ft}$$

$$A = \overline{AB} \times 15 \text{ ft} = 138.6 \text{ ft}^2$$

$$F_R = \gamma(h/2)A$$

$$F_R = 62.4 \text{ lb/ft}^3 \times 4.0 \text{ ft} \times 138.6 \text{ ft}^2 = \mathbf{34586 \text{ lb}}$$

$$L_p = \frac{2}{3}(\overline{AB}) = \frac{2}{3}(9.237 \text{ ft}) = \mathbf{6.158 \text{ ft}}$$



4.36  $\bar{y} = \frac{H(G+2B)}{3(G+B)} = \frac{4.6[1.2 + 2(3.856)]}{3(1.2 + 3.856)} = 2.703 \text{ m}$

$$h_c = H - \bar{y} = 4.6 - 2.703 = 1.897 \text{ m} = L_c$$

$$F_R = \gamma h_c A \text{ Acts } \perp \text{ page}$$

$$A = \frac{H(G+B)}{2} = \frac{4.6(1.2 + 3.856)}{2} = 11.63 \text{ m}^2$$

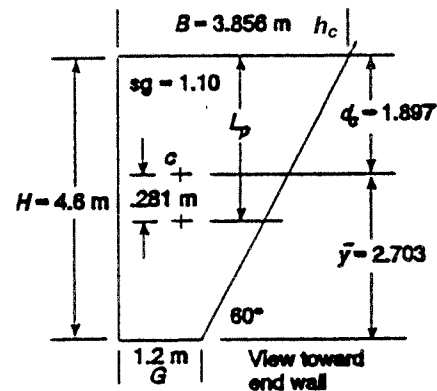
$$F_R = (1.10)(9.81 \text{ kN/m}^2)(1.897 \text{ m})(11.63 \text{ m}^2)$$

$$= \mathbf{238 \text{ kN}}$$

$$I_c = \frac{H^3(G^2 + 4GB + B^2)}{36(G+B)} = 18.62 \text{ m}^4$$

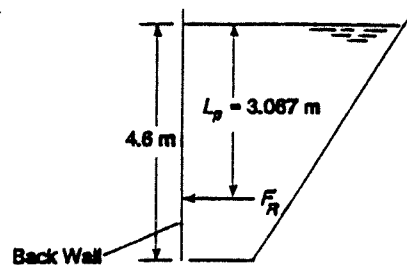
$$L_p - L_c = \frac{I_c}{L_c A} = \frac{18.62 \text{ m}^4}{(1.897 \text{ m})(11.63 \text{ m}^2)} = \mathbf{0.844 \text{ m}}$$

$$L_p = L_c + 0.844 \text{ m} = 1.897 + 0.844 = \mathbf{2.741 \text{ m}}$$



$$B = 1.2 \text{ m} + 4.6 \text{ m}/\tan 60^\circ = 3.856 \text{ m}$$

4.37 **Rectangular Wall:**  $F_R = \gamma h_c A$   
 $F_R = (1.10)(9.81 \text{ kN/m}^3)(4.60/2)\text{m}(4.6)(3.0)\text{m}^2$   
 $= 343 \text{ kN}$   
 $F_R$  acts 1/3 from bottom or 2/3 from surface  
 $L_p = \frac{2}{3} (4.60 \text{ m}) = 3.067 \text{ m}$



4.38

END WALL				
	A	$\bar{y}$	$A\bar{y}$	$y_i = \bar{y} - \bar{Y}$
①	1.046	0.75	0.784	0.096
②	0.151	0.15	0.023	-0.504
③	0.151	0.50	0.075	-0.154
$\sum A = 1.348 \text{ m}^2$		$\sum A\bar{y} = 0.882 \text{ m}^3$		

$$\bar{Y} = \frac{\sum A\bar{y}}{\sum A} = \frac{0.882 \text{ m}^3}{1.348 \text{ m}^2} = 0.654 \text{ m}$$

$$h_c = 1.5 \text{ m} - \bar{Y} = 0.846 \text{ m} = L_c$$

$$F_R = \gamma h_c A = (0.90)(9.81 \text{ kN/m}^3)(0.846 \text{ m})(1.348 \text{ m}^2) = 10.07 \text{ kN}$$

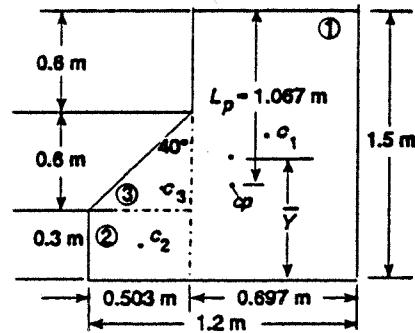
$$I_c = I_1 + A_1 y_1^2 + I_2 + A_2 y_2^2 + I_3 + A_3 y_3^2$$

$$I_c = \frac{(0.697)(1.5)^3}{12} + (1.046)(0.096)^2 + \frac{(0.503)(0.30)^3}{12} + (0.151)(0.504)^2$$

$$+ \frac{(0.503)(0.60)^3}{36} + (0.151)(0.154)^2$$

$$I_c = 0.1960 + 0.0096 + 0.0011 + 0.0384 + 0.0030 + 0.0036 = 0.2518 \text{ m}^4$$

$$L_p = L_c + \frac{I_c}{L_c A} = 0.846 \text{ m} + \frac{0.2518}{(0.846)(1.348)} \text{ m} = 0.846 + \frac{0.221}{L_p - L_c} = 1.067 \text{ m}$$



4.39 Vertical back wall is **rectangular**

$$F_R = \gamma h_c A = \gamma (h/2)(A)$$

$$\gamma = 0.90(9.81 \text{ kN/m}^3) = 8.829 \text{ kN/m}^3$$

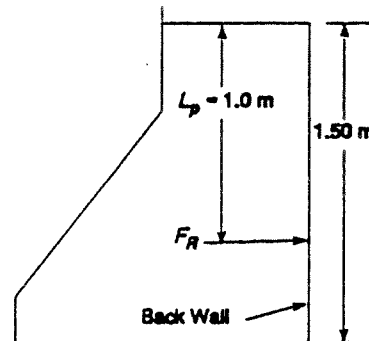
$$h/2 = 1.50 \text{ m}/2 = 0.75 \text{ m}$$

$$A = (1.50 \text{ m})(1.20 \text{ m}) = 1.80 \text{ m}^2$$

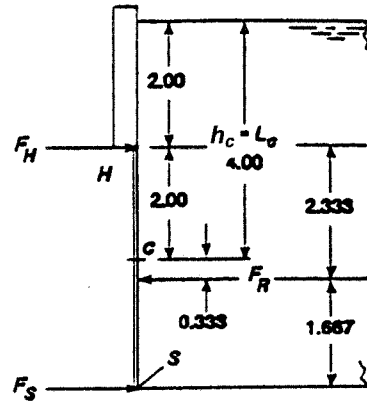
$$F_R = (8.829 \text{ kN/m}^3)(0.75 \text{ m})(1.80 \text{ m}^2)$$

$$= 11.92 \text{ kN}$$

$$L_p = \frac{2}{3} \times h = \frac{2}{3} \times 1.50 \text{ m} = 1.00 \text{ m}$$



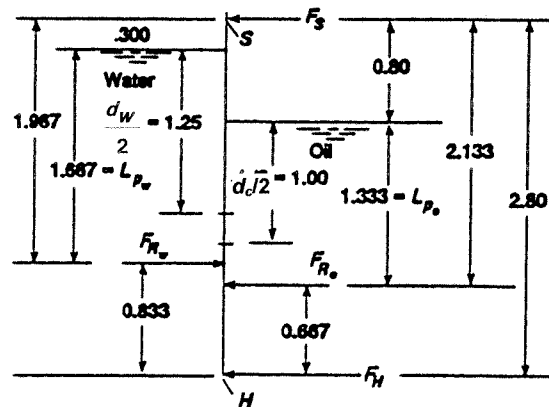
4.40  $h_c = L_c = 4.00$  ft;  $A = (4.00)(1.25) = 5.00$  ft<sup>2</sup>  
 $F_R = \gamma h_c A = (62.4 \text{ lb/ft}^3)(4.00 \text{ ft})(5.00 \text{ ft}^2)$   
 $= 1248$  lb  
 $I_c = BH^3/12 = (1.25)(4.00)^3/12 = 6.667$  ft<sup>4</sup>  
 $L_p - L_c = \frac{I_c}{L_c A} = \frac{6.667 \text{ ft}^4}{(4.00 \text{ ft})(5.00 \text{ ft}^2)}$   
 $= 0.333$  ft  
 $\Sigma M_S = 0 = F_R(1.667) - F_H(4.00)$   
 $F_H = \frac{(1248)(1.667)}{4.00} = 520$  lb  
 $\Sigma M_H = 0 = F_R(2.333) - F_S(4.00)$   
 $F_S = \frac{(1248)(2.333)}{4} = 728$  lb



4.41 **Water side:**  
 $F_{R_w} = \gamma_w(h_w/2)A_w$   
 $A_w = (2.50)(0.60) = 1.50$  m<sup>2</sup>  
 $F_{R_w} = (9.81)(1.25)(1.50) = 18.39$  kN  
 $L_{p_w} = \frac{2}{3} \cdot 2.50 = 1.667$  m

**Oil side:**  
 $F_{R_o} = \gamma_o(h_o/2)A_o$   
 $A_o = (2.00)(0.60) = 1.20$  m<sup>2</sup>  
 $F_{R_o} = (9.81)(0.9)(1.00)(1.20) = 10.59$  kN

$L_{p_o} = \frac{2}{3} \cdot 2.00 = 1.333$  m  
 $\Sigma M_S = 0$   
 $= F_{R_w}(1.967) - F_{R_o}(2.133) - F_H(2.80)$   
 $F_H = [(18.39)(1.967) - (10.59)(2.133)]/2.80 = 4.85$  kN ←  
 $\Sigma M_H = 0 = F_{R_w}(0.833) - F_{R_o}(0.667) - F_S(2.80)$   
 $F_S = [(18.39)(0.833) - (10.59)(0.667)]/2.80 = 2.95$  kN ←



$$4.42 \quad h_c = 38 + y = 38 + 5 \cos 30^\circ = 42.33 \text{ in}$$

$$L_c = h_c / \cos 30^\circ = 48.88 \text{ in}$$

$$F_R = \gamma h_c A$$

$$A = \pi(10)^2/4 = 78.54 \text{ in}^2$$

$$F_R = \frac{62.4 \text{ lb}}{\text{ft}^3} \cdot \frac{42.33 \text{ in} \cdot 78.54 \text{ in}^2}{1728 \text{ in}^3/\text{ft}^3}$$

$$F_R = 120.1 \text{ lb}$$

$$I_c = \frac{\pi(10)^4}{64} = 490.9 \text{ in}^4$$

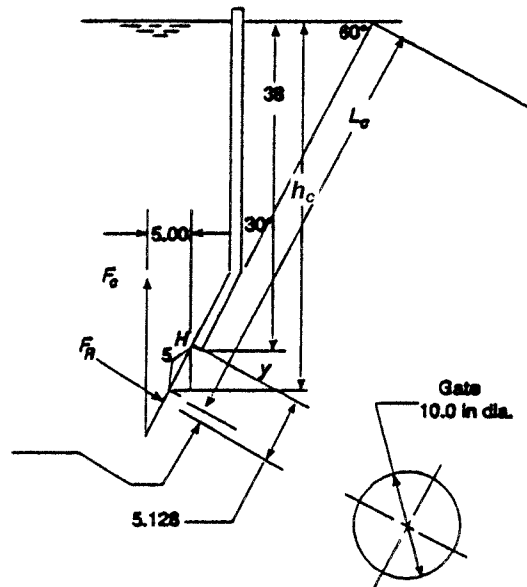
$$L_p - L_c = \frac{I_c}{L_c A}$$

$$L_p - L_c = \frac{490.9 \text{ in}^4}{(48.88 \text{ in})(78.54 \text{ in}^2)} = 0.128 \text{ in}$$

Sum moments about hinge at top of gate.

$$\Sigma M_H = 0 = F_R(5.128) - F_c(5.00)$$

$$F_c = \frac{(120.1 \text{ lb})(5.128 \text{ in})}{5.00 \text{ in}} = 123.2 \text{ lb} = \text{cable force}$$



### Piezometric head

$$4.43 \quad h_a = \frac{p_a}{\gamma_o} = \frac{13.8 \text{ kN}}{\text{m}^2} \times \frac{\text{m}^3}{(0.85)(9.81 \text{ kN})} = 1.655 \text{ m}$$

$$h_{ce} = h_c + h_a = 0.825 \text{ m} + 1.655 \text{ m} = 2.480 \text{ m}$$

$$L_{ce} = h_{ce} / \cos 30^\circ = 2.480 \text{ m} / \cos 30^\circ = 2.864 \text{ m}$$

$$F_R = \gamma_o h_{ce} A = (0.85)(9.81 \text{ kN/m}^3)(2.480 \text{ m})(0.159 \text{ m}^2) = 3.29 \text{ kN}$$

$$L_{pe} - L_{ce} = \frac{I_c}{L_{ce} A} = \frac{2.013 \times 10^9 \text{ mm}^4}{(2.864 \text{ mm})(1.59 \times 10^5 \text{ mm}^2)} = 4.42 \text{ mm}$$

See Prob. 4.19  
for data.

$$4.44 \quad h_a = \frac{p_a}{\gamma_{oD}} = \frac{25.0 \text{ kN}}{\text{m}^2} \times \frac{\text{m}^3}{(1.10)(9.81 \text{ kN})} = 2.317 \text{ m}$$

$$h_{ce} = h_c + h_a = 3.000 \text{ m} + 2.317 \text{ m} = 5.317 \text{ m}$$

$$L_{ce} = h_{ce} / \cos 30^\circ = 5.317 / \cos 30^\circ = 6.140 \text{ m}$$

$$F_R = \gamma_{oD} h_{ce} A = (1.10)(9.81 \text{ kN/m}^3)(5.317 \text{ m})(4.524 \text{ m}^2) = 259.6 \text{ kN}$$

$$L_{pe} - L_{ce} = \frac{I_c}{L_{ce} A} = \frac{1.629 \text{ m}^4}{(6.140 \text{ m})(4.524 \text{ m}^2)} = 0.0586 \text{ m} = 58.6 \text{ mm}$$

See Prob. 4.20  
for data.

$$4.45 \quad h_a = \frac{p_a}{\gamma_{cs}} = \frac{2.50 \text{ lb ft}^3}{\text{in}^2 (1.43)(62.4 \text{ lb})} \times \frac{1728 \text{ in}^3}{1 \text{ ft}^3} = 48.41 \text{ in} = 4.034 \text{ ft}$$

$$h_{ce} = h_c + h_a = 40.0 \text{ in} + 48.41 \text{ in} = 88.41 \text{ in} = 7.368 \text{ ft}$$

$$L_{ce} = h_{ce} \left( \frac{5}{4} \right) = 88.41 \text{ in} \left( \frac{5}{4} \right) = 110.5 \text{ in} = 9.209 \text{ ft}$$

See Prob. 4.26.

$$F_R = \gamma_{cs} h_{ce} A = (1.43)(62.4 \text{ lb/ft}^3)(7.368 \text{ ft})(2.778 \text{ ft}^2) = \mathbf{1826 \text{ lb}}$$

$$L_{pe} - L_{ce} = \frac{I_c}{L_c A} = \frac{83333 \text{ in}^4}{(110.5 \text{ in})(400 \text{ in}^2)} = \mathbf{1.885 \text{ in}}$$

$$4.46 \quad h_a = \frac{p_a}{\gamma_{EG}} = \frac{4.0 \text{ lb}}{\text{in}^2} \times \frac{\text{ft}^3}{(1.10)(62.4 \text{ lb})} \times \frac{1728 \text{ in}^3}{\text{ft}^3} = 100.7 \text{ in} = 8.392 \text{ ft}$$

$$h_{ce} = h_c + h_a = 24.27 \text{ in} + 100.7 \text{ in} = 124.97 \text{ in} \text{ [See Prob. 4.28]}$$

$$L_{ce} = h_{ce} / \cos 30^\circ = 144.3 \text{ in} = 12.03 \text{ ft}$$

$$F_R = \gamma_{EG} h_{ce} A = (1.10)(62.4 \text{ lb/ft}^3)(124.97 \text{ in})(1 \text{ ft}/12 \text{ in})(628.3 \text{ in}^2)(1 \text{ ft}^2/144 \text{ in}^2)$$

$$F_R = \mathbf{3119 \text{ lb}}$$

See Prob. 4.28.

$$L_{pe} - L_{ce} = \frac{I_c}{L_{ce} A} = \frac{17\,562 \text{ in}^4}{(144.3 \text{ in})(628.3 \text{ in}^2)} = \mathbf{0.194 \text{ in}}$$

### Forces on curved surfaces

$$4.47 \quad R = 0.75 \text{ m}, w = 2.00 \text{ m}; F_V = \gamma V = \gamma A w$$

$$F_V = 9.81 \text{ kN/m}^3 \times \left[ (1.85)(0.75) + \frac{\pi(0.75)^2}{4} \right] \times 2.00 \text{ m}^3$$

$$= \mathbf{35.89 \text{ kN}}$$

$$\bar{x} = \frac{A_1 x_1 + A_2 x_2}{A_1 + A_2}$$

$$A_1 = (0.75)(1.85) = 1.388 \text{ m}^2$$

$$A_2 = \pi(0.75)^2/4 = 0.442 \text{ m}^2$$

$$\bar{x} = \frac{(1.388)(.375) + (0.442)(0.318)}{1.388 + 0.442} = \mathbf{0.361 \text{ m}}$$

$$h_c = h_1 + s/2 = 1.85 + 0.75/2 = 2.225 \text{ m}$$

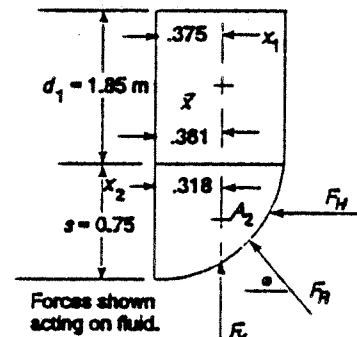
$$F_H = \gamma s w h_c = 9.81 \text{ kN/m}^3 \times (0.75)(2.00)(2.225) \text{ m}^3$$

$$F_H = \mathbf{32.74 \text{ kN}}$$

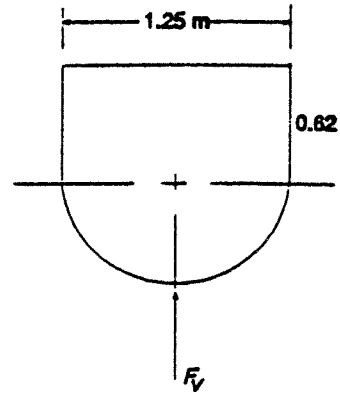
$$h_p = h_c + \frac{s^2}{12h_c} = 2.225 + \frac{0.75^2}{12(2.225)} = 2.225 + 0.021 = \mathbf{2.246 \text{ m}}$$

$$F_R = \sqrt{F_V^2 + F_H^2} = \sqrt{35.89^2 + 32.74^2} = \mathbf{48.58 \text{ kN}}$$

$$\phi = \tan^{-1} \frac{F_V}{F_H} = \tan^{-1} \frac{35.89}{32.74} = \mathbf{47.6^\circ}$$



4.48  $F_V = \gamma V = \gamma A w$   
 $F_V = (0.826)(9.81 \text{ kN/m}^3)(1.389 \text{ m}^2)(2.50 \text{ m}) = 28.1 \text{ kN}$   
 $A = A_1 + A_2 = (0.62)(1.25) + \pi(1.25)^2/8$   
 $A = 1.389 \text{ m}^2$   
 $F_H = 0$  because horiz. forces are balanced  
 $F_R = F_V = 28.1 \text{ kN}$



4.49  $y_1 = R \sin 15^\circ = 3.882 \text{ ft}$   
 $s = R - y_1 = 15.00 - 3.882 = 11.118 \text{ ft}$   
 $h_c = h + y_1 + s/2$   
 $= 10.0 + 3.882 + 5.559$   
 $h_c = 19.441 \text{ ft}$   
 $F_H = \gamma h_c s w = (62.4)(19.441)(11.118)(5.00)$   
 $F_H = 67,437 \text{ lb}$

$h_p = h_c + \frac{s^2}{12h_c} = 19.441 + 0.530 \text{ ft}$

$h_p = 19.971 \text{ ft}$

$F_V = \gamma V = \gamma A_T w$

$A_1 = (14.489)(10.0) = 144.89 \text{ ft}^2$

$A_2 = \frac{1}{2} (y_1)(R \cos 15^\circ) = \frac{1}{2} (3.882)(14.489)$   
 $= 28.12 \text{ ft}^2$

$A_3 = \pi R^2 \cdot \frac{75}{360} = \pi(15.0)^2 \frac{75}{360}$   
 $= 147.26 \text{ ft}^2$

$A_T = A_1 + A_2 + A_3 = 320.27 \text{ ft}^2$

$F_V = \gamma A_T w = (62.4)(320.27)(5.00)$   
 $= 99,925 \text{ lb}$

$x_1 = 14.489/2 = 7.245 \text{ ft}$

$x_2 = \frac{2}{3} (14.489) = 9.659 \text{ ft}$

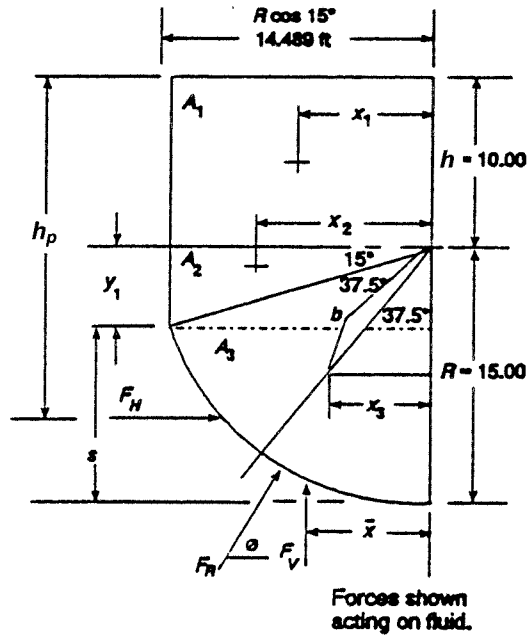
$x_3 = b \sin 37.5^\circ$  where  $b = 38.197 \frac{R \sin(37.5^\circ)}{37.5^\circ} = 9.301 \text{ ft}$  (from *Machinery's Handbook*)

$x_3 = 9.301 \sin 37.5^\circ = 5.662 \text{ ft}$

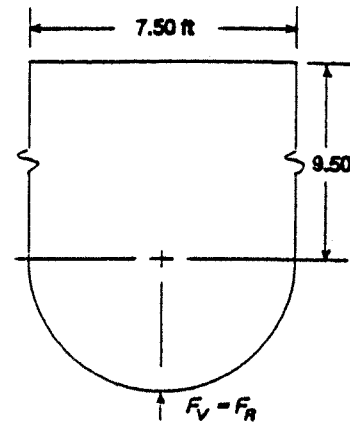
$\bar{x} = \frac{A_1 x_1 + A_2 x_2 + A_3 x_3}{A_T} = 6.738 \text{ ft}$

$F_R = \sqrt{F_H^2 + F_V^2} = \sqrt{67437^2 + 99925^2} = 120550 \text{ lb}$

$\phi = \tan^{-1} \frac{F_V}{F_H} = \tan^{-1} \frac{99925}{67437} = 56.0^\circ$



- 4.50  $F_V = \gamma_o V = \gamma_o A w$   
 $A = A_1 + A_2 = (7.50)(9.50) + \pi(7.50)^2/8$   
 $A = 93.34 \text{ ft}^2$   
 $F_V = \gamma_o A w = (0.85)(62.4)(93.34)(3.50)$   
 $F_V = 17328 \text{ lb} = F_R$   
 $F_H = 0$  because horiz. forces are balanced



- 4.51  $s = R - y = 6.00 - 5.196 = 0.804 \text{ m}$   
 $h_c = h + y + s/2 = 5.20 + 5.196 + 0.402$   
 $h_c = 10.798 \text{ m}$   
 $F_H = \gamma s w h_c = (0.72)(9.81)(0.804)(4.00)(10.798)$   
 $F_H = 245.3 \text{ kN}$

$$h_p = h_c + \frac{s^2}{12h_c} = 10.798 + \frac{0.804^2}{12(10.798)}$$

$$h_p = 10.798 + 0.0050 \text{ m}$$

$$h_p = 10.803 \text{ m}$$

$$F_V = \gamma V = \gamma A w$$

$$A_1 = (5.20)(3.00) = 15.60 \text{ m}^2$$

$$A_2 = \frac{1}{2} (3.00)(5.196) = 7.794 \text{ m}^2$$

$$A_3 = \pi R^2 \cdot \frac{30}{360} = \frac{\pi(6.0)^2}{12} = 9.425 \text{ m}^2$$

$$A_T = A_1 + A_2 + A_3 = 32.819 \text{ m}^2$$

$$F_V = \gamma A w = (0.72)(9.81)(32.819)(4.00) = 927.2 \text{ kN}$$

$$x_1 = 3.00/2 = 1.500 \text{ m}$$

$$x_2 = 2(3.00)/3 = 2.00 \text{ m}$$

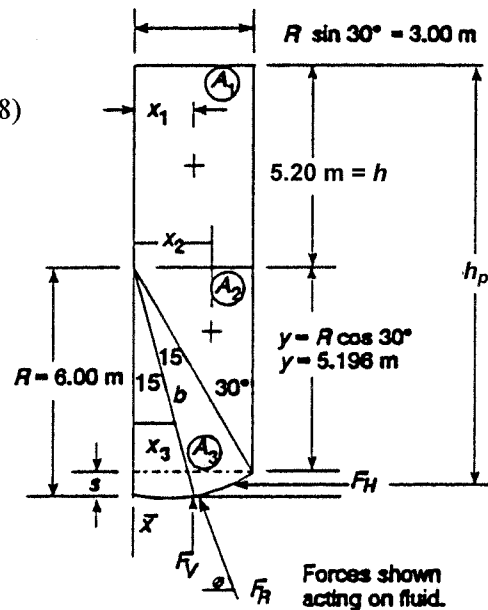
$$x_3 = b \sin 15^\circ \text{ where } b = 38.197 \frac{R \sin 15^\circ}{15} = 3.954 \text{ m (from Machinery's Handbook)}$$

$$x_3 = (3.954) \sin 15^\circ = 1.023 \text{ m}$$

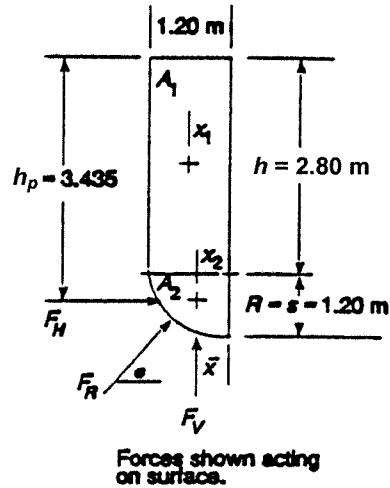
$$\bar{x} = \frac{A_1 x_1 + A_2 x_2 + A_3 x_3}{A_T} = 1.482 \text{ m}$$

$$F_R = \sqrt{F_H^2 + F_V^2} = \sqrt{245.3^2 + 927.2^2} = 959.1 \text{ kN}$$

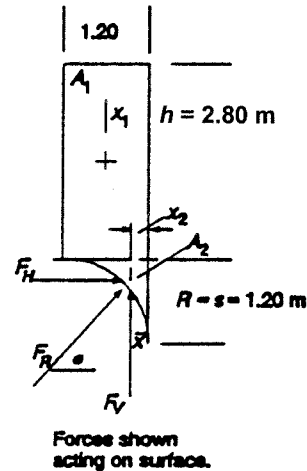
$$\phi = \tan^{-1} \frac{F_V}{F_H} = \tan^{-1} \frac{927.2}{245.3} = 75.2^\circ$$



4.52  $F_V = \gamma Aw$   
 $A = A_1 + A_2 = (1.20)(2.80) + \pi(1.20)^2/4 = 4.491 \text{ m}^2$   
 $F_V = (9.81 \text{ kN/m}^3)(4.491 \text{ m}^2)(1.50 \text{ m}) = 66.1 \text{ kN}$   
 $x_1 = 0.5(1.20) = 0.60 \text{ m}; x_2 = 0.424(1.20) = 0.509 \text{ m}$   
 $\bar{x} = \frac{A_1 x_1 + A_2 x_2}{A_T} = \frac{(3.36)(.60) + (1.13)(0.509)}{4.491}$   
 $= 0.577 \text{ m}$   
 $h_c = h + s/2 = 2.80 + 1.20/2 = 3.40 \text{ m}$   
 $F_H = \gamma s w h_c = (9.81)(1.20)(1.50)(3.40) = 60.0 \text{ kN}$   
 $h_p = h_c + \frac{s^2}{12h_c} = 3.40 + \frac{(1.20)^2}{12(3.40)} = 3.435 \text{ m}$   
 $F_R = \sqrt{F_V^2 + F_H^2} = \sqrt{66.1^2 + 60.0^2} = 89.3 \text{ kN}$   
 $\phi = \tan^{-1} \frac{F_V}{F_H} = \tan^{-1} \frac{66.1}{60.0} = 47.8^\circ$



4.53  $A_1 = (1.20)(2.80) = 3.36 \text{ m}^2$   
 $A_2 = R^2 - \pi R^2/4 = 0.309 \text{ m}^2$  }  $A = 3.669 \text{ m}^2$   
 $F_V = \gamma Aw = (9.81)(3.669)(1.50) = 54.0 \text{ kN}$   
 $x_1 = 1.20/2 = 0.60 \text{ m}$   
 $x_2 = 0.2234R = 0.268 \text{ m}$  [*Machinery's Handbook*]  
 $\bar{x} = \frac{A_1 x_1 + A_2 x_2}{A} = \frac{(3.36)(0.60) + (0.309)(0.268)}{3.669}$   
 $\bar{x} = 0.572 \text{ m}$   
 $h_c = h + s/2 = 2.80 + 0.60 = 3.40 \text{ m}$   
 $F_H = \gamma s w h_c = (9.81)(1.20)(1.50)(3.40) = 60.0 \text{ kN}$   
 $h_p = h_c + \frac{s^2}{12h_c} = 3.40 + \frac{1.20^2}{12(3.40)} = 3.435 \text{ m}$   
 $F_R = \sqrt{F_V^2 + F_H^2} = \sqrt{54.0^2 + 60.0^2} = 80.7 \text{ kN}$   
 $\phi = \tan^{-1} \frac{F_V}{F_H} = \tan^{-1} \frac{54.0}{60.0} = 42.0^\circ$

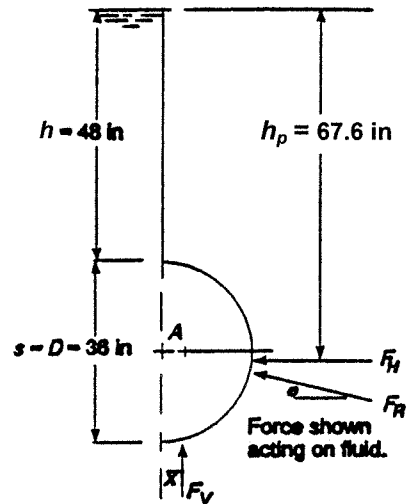


4.54  $A = \pi D^2/8 = \pi(36)^2/8 = 508.9 \text{ in}^2 = 3.534 \text{ ft}^2$   
 $F_V = \gamma A w = (0.79)(62.4)(3.534)(5.0) = 871 \text{ lb}$   
 $\bar{x} = 0.212D = 0.212(36 \text{ in}) = 7.63 \text{ in}$   
 $h_c = h + s/2 = 48 + 36/2 = 66.0 \text{ in} = 5.50 \text{ ft}$   
 $F_H = \gamma s w h_c = (0.79)(62.4)(3.0)(5.0)(5.50)$   
 $F_H = 4067 \text{ lb}$

$$h_p = h_c = \frac{s^2}{12h_c} = 66 + \frac{36^2}{12(66)} = 67.64 \text{ in}$$

$$F_R = \sqrt{F_V^2 + F_H^2} = \sqrt{871^2 + 4067^2} = 4159 \text{ lb}$$

$$\phi = \tan^{-1} \frac{F_V}{F_H} = \tan^{-1} \frac{871}{4067} = 12.1^\circ$$



4.55 (See Prob. 4.47)

$$\text{Eq. Depth} = h_a = \frac{P}{\gamma} = \frac{7.5 \text{ kN/m}^2}{9.81 \text{ kN/m}^3} = 0.765 \text{ m}$$

$$h_{1e} = h_1 + h_a = 1.85 + 0.765 = 2.615 \text{ m}; h_{ce} = h_{1e} + s/2 = 2.615 + 0.75/2 = 2.990 \text{ m}$$

$$A_1 = (0.75)(2.615) = 1.961 \text{ m}^2; A_2 = 0.442 \text{ m}^2; A_T = 2.403 \text{ m}^2$$

$$F_V = \gamma A w = (9.81)(2.403)(2.000) = 47.15 \text{ kN}$$

$$\bar{x} = \frac{A_1 x_1 + A_2 x_2}{A_T} = \frac{(1.961)(0.375) + (0.442)(0.318)}{2.403} = 0.365 \text{ m}$$

$$F_H = \gamma s w h_{ce} = (9.81)(0.75)(2.00)(2.99) = 44.00 \text{ kN}$$

$$h_{pe} - h_{ce} = \frac{s^2}{12h_{ce}} = \frac{0.75^2}{12(2.99)} = 0.016 \text{ m} = 16 \text{ mm}$$

$$F_R = \sqrt{F_V^2 + F_H^2} = \sqrt{47.15^2 + 44.00^2} = 64.49 \text{ kN}$$

$$\phi = \tan^{-1} \frac{F_V}{F_H} = \tan^{-1} \frac{47.15}{44.00} = 47.0^\circ$$

4.56 (See Prob. 4.48)

$$\text{Eq. Depth} = h_a = \frac{P}{\gamma} = \frac{4.65 \text{ kN/m}^2}{(0.826)(9.81 \text{ kN/m}^3)} = 0.574 \text{ m}$$

$$h_{1e} = h_1 + h_a = 0.62 \text{ m} + 0.574 \text{ m} = 1.194 \text{ m}$$

$$A = (1.194)(1.25) + \pi(1.25)^2/8 = 2.106 \text{ m}^2$$

$$F_V = \gamma A w = (0.826)(9.81 \text{ kN/m}^3)(2.106 \text{ m}^2)(2.50 \text{ m}) = 42.66 \text{ kN} = F_R$$

4.57 Net horizontal force = 0

From Section 4.11, net vertical force equals the weight of the displaced fluid acting upward and the weight of the cylinder acting downward.

$$w_f = \gamma_f V_d = (62.4 \text{ lb/ft}^3)(0.164 \text{ ft}^3) = 10.2 \text{ lb}$$

$$V_d = A \cdot L = \frac{\pi D^2}{4} \cdot L = \frac{\pi(6.00 \text{ in})^2}{4} \cdot 10.0 \text{ in} = 282.7 \text{ in}^3 \times \frac{\text{ft}^3}{1728 \text{ in}^3} = 0.164 \text{ ft}^3$$

$$w_c = \gamma_c V = (0.284 \text{ lb/in}^3)(282.7 \text{ in}^3) = 80.3 \text{ lb}$$

$$\text{Net force on bottom} = w_c - w_f = 80.3 - 10.2 = 70.1 \text{ lb down}$$

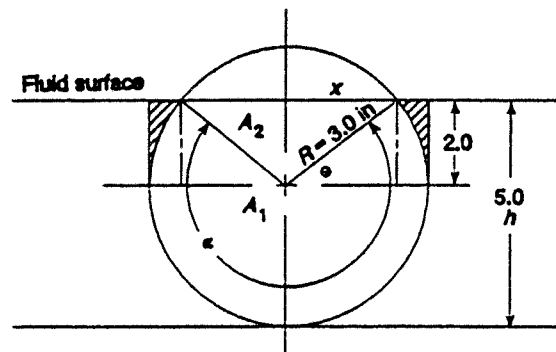
4.58 See Prob. 4.57.  $w_f = 10.2 \text{ lb}$

$$w_c = \gamma_c V = (0.100 \text{ lb/in}^3)(282.7 \text{ in}^3) = 28.27 \text{ lb}$$

$$F_{\text{net}} = w_c - w_f = 28.27 - 10.2 = 18.07 \text{ lb down}$$

- 4.59 See Prob. 4.57.  $w_f = 10.2$  lb  
 $w_c = \gamma_c V = (30.0 \text{ lb/ft}^3)(0.164 \text{ ft}^3) = 4.92$  lb  
 $F_{\text{net}} = w_c - w_f = 4.92 - 10.2 = 5.28$  lb up  
 But this indicates that the cylinder would float, as expected. Then, the force exerted by the cylinder on the bottom of the tank is **zero**.
- 4.60 The specific weight of the cylinder must be less than or equal to that of the fluid if no force is to be exerted on the tank bottom.
- 4.61 (See Prob. 4.57.) Because the depth of the fluid does not affect the result,  $F_{\text{net}} = 70.1$  lb down. This is true as long as the fluid depth is greater than or equal to the diameter of the cylinder.

- 4.62 (See Prob. 4.57.)  $w_c = 80.3$  lb  
 Force (downward) on upper part of cylinder = wt. of volume of cross-hatched volume. Force (upward) on lower part of cylinder = wt. of entire displaced volume **plus** that of cross-hatched volume. Then net force is wt. of displaced volume (upward).



$$\begin{aligned} \theta &= \sin^{-1}(2.0/3.0) = 41.8^\circ \\ x &= R \cos \theta = 3.0 \cos \theta \\ x &= 2.236 \text{ in} \\ \alpha &= 180^\circ + 2\theta = 263.6^\circ \end{aligned}$$

$$w_f = \gamma_f V_d = \gamma_f A_d L$$

$$A_d = \frac{\pi D^2}{4} \cdot \frac{\alpha}{360} + \frac{1}{2}(2x)(2.0) = A_1 + A_2$$

$$A_d = \frac{\pi(6.0 \text{ in})^2}{4} \cdot \frac{263.6}{360} + (2.236)(2.0) = 25.18 \text{ in}^2$$

$$w_f = \gamma_f A_d L = 62.4 \text{ lb/ft}^3 \cdot 25.18 \text{ in}^2 \cdot 10.0 \text{ in} \cdot \frac{1 \text{ ft}^3}{1728 \text{ in}^3} = 9.09 \text{ lb}$$

$$F_{\text{net}} = w_c - w_f = 80.3 - 9.09 = 71.21 \text{ lb down}$$

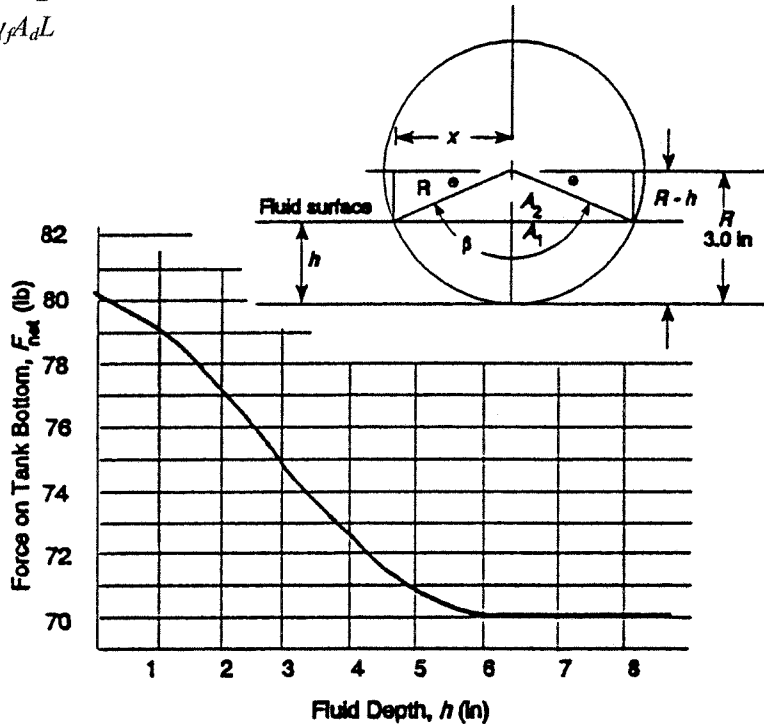
- 4.63 (See Prob. 4.57) For any depth  $\geq 6.00$  in,  $F_{\text{net}} = 70.1$  lb down  
 Method of Prob. 4.62 used for  $h < 6.00$  in and  $\geq 3.00$  in. For any depth  $< 3.00$  in, use figure below.

$$A_d = A_1 - A_2 = \frac{\pi D^2}{4} \times \frac{\beta}{360} - \frac{1}{2}(2x)(R-h)$$

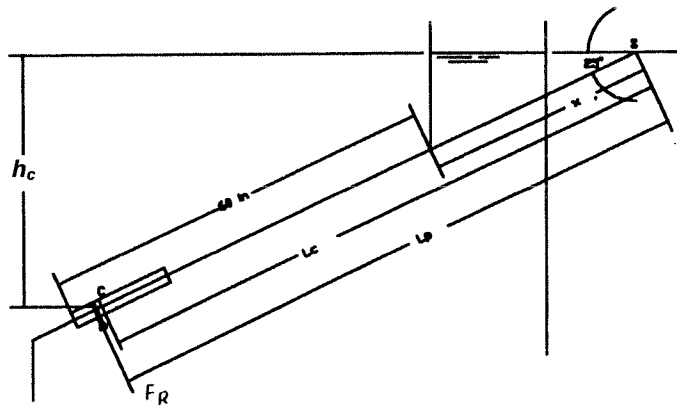
$$F_{\text{net}} = w_c - w_f = 80.3 \text{ lb} - \gamma_f A_d L$$

**Summary of Results:**

$h$ (in)	$F_{\text{net}}$ (lb)
6.00	70.1
5.50	70.5
5.00	71.2
4.50	72.08
4.00	73.07
3.50	74.12
3.00	75.19
2.50	76.27
2.00	77.32
1.50	78.30
1.00	79.18
0.50	79.89
0.00	80.30



- 4.64 **Centroid:**  $y = 0.212 D = 0.212(36 \text{ in}) = (7.63 \text{ in})(1 \text{ ft}/12 \text{ in}) = 0.636 \text{ ft}$   
 $x = (20 \text{ in})/\sin 25^\circ = 47.32 \text{ in}$   
 $L_c = 60 \text{ in} + x - y = 60 + 47.32 - 7.632 = (99.69 \text{ in})(1 \text{ ft}/12 \text{ in}) = 8.308 \text{ ft}$   
 $h_c = L_c \sin 25^\circ = (8.308 \text{ ft})(\sin 25^\circ) = 3.511 \text{ ft}$   
 $A = \pi D^2/8 = \pi(3.0 \text{ ft})^2/8 = 3.534 \text{ ft}^2$   
 $F_R = \gamma h_c A = (1.06)(62.4 \text{ lb}/\text{ft}^3)(3.511 \text{ ft})(3.534 \text{ ft}^2) = 820 \text{ lb} = F_R$   
 $I = 6.86 \times 10^{-3} D^4 = 6.86 \times 10^{-3} (3.00 \text{ ft})^4 = 0.556 \text{ ft}^4$   
 $L_p - L_c = I/[L_c A] = (0.556 \text{ ft}^4)/[(8.308 \text{ ft})(3.534 \text{ ft}^2)] = 0.0189 \text{ ft}$   
 $L_p = L_c + 0.0189 \text{ ft} = 8.308 \text{ ft} + 0.0189 \text{ ft} = 8.327 \text{ ft} = L_p$



# CHAPTER FIVE

## BUOYANCY AND STABILITY

### Buoyancy

5.1  $\Sigma F_V = 0 = w + T - F_b$   
 $F_b = \gamma_f V = (10.05 \text{ kN/m}^3)(0.45)(0.60)(0.30) \text{ m}^3 = 0.814 \text{ kN} = 814 \text{ N}$   
 $T = F_b - w = 814 - 258 = 556 \text{ N}$

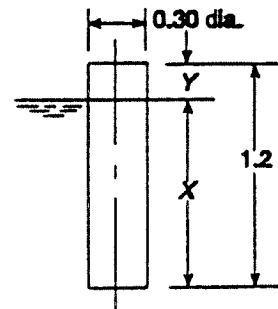
5.2 If both concrete block and sphere are submerged:  
 Upward forces =  $F_U = F_{b_s} + F_{b_c} = \gamma_w V_s + \gamma_w V_C = \gamma_w (V_s + V_C)$   
 $V_s = \pi D^3 / 6 = \pi (1.0 \text{ m})^3 / 6 = 0.5236 \text{ m}^3$   
 $V_C = \frac{w_C}{\gamma_C} = \frac{4.10 \text{ kN}}{23.6 \text{ kN/m}^3} = 0.1737 \text{ m}^3$  } =  $V_{\text{tot}} = 0.6973 \text{ m}^3$

$F_U = \gamma_w V_{\text{tot}} = (9.81 \text{ kN/m}^3)(0.6973 \text{ m}^3) = 6.84 \text{ kN}$   
 Downward forces =  $F_D = w_C + w_S = 4.1 + 0.20 = 4.30 \text{ kN}$  }  $F_U > F_D$  It will float.

5.3 If pipe is submerged,  $F_b = \gamma_f V = (1.26)(9.81 \text{ kN/m}^3)(\pi(0.168 \text{ m})^2/4)(1.00 \text{ m})$   
 $F_b = 0.2740 \text{ kN} = 274 \text{ N}$ ; because  $w = 277 \text{ N} > F_b$ —It will sink.

5.4  $w_c - F_b = 0$ ;  $w_c = F_b$ ;  $\gamma_c V_c = \gamma_f V_d = \gamma_f 0.9 V_c$   
 Then,  $\gamma_c = 0.9 \gamma_f = (0.90)(1.10)(62.4 \text{ lb/ft}^3) = 61.78 \text{ lb/ft}^3$

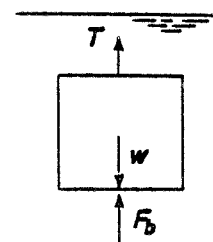
5.5  $w_c - F_b = 0$ ;  $\gamma_c V_c - \gamma_f V_d$   
 $V_d = V_c \frac{\gamma_c}{\gamma_f}$   
 $= \frac{\pi (.30 \text{ m})^2}{4} \cdot 1.2 \text{ m} \cdot \frac{7.90}{9.81} = 0.0683 \text{ m}^3 = \frac{\pi D^2}{4} \cdot X$   
 $X = \frac{4(0.0683) \text{ m}^3}{\pi (0.30 \text{ m})^2} = 0.9664 \text{ m} = 966 \text{ mm}$



$Y = 1200 - 966 = 234 \text{ mm}$

5.6  $w - F_b = 0 = \gamma_c V_c - \gamma_f V_d$   
 $\gamma_c = \gamma_f \frac{V_d}{V_c} = (0.90)(9.81 \text{ kN/m}^3)(75/100) = 6.62 \text{ kN/m}^3$

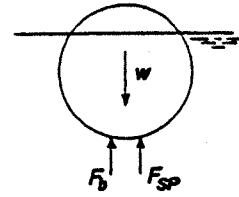
5.7  $w - F_b - T = 0 = \gamma_c V_C - \gamma_f V_C - T = V_C(\gamma_c - \gamma_f) - T$   
 $V_C = \frac{T}{(\gamma_c - \gamma_f)} = \frac{2.67 \text{ kN}}{[23.6 - (1.15)(9.81)] \text{ kN/m}^3} = 0.217 \text{ m}^3$



$$5.8 \quad w - F_b - F_{SP} = 0 = W - \gamma_o V_d - F_{SP}$$

$$F_{SP} = w - \gamma_o V_d = 14.6 \text{ lb} - (0.90)(62.4 \text{ lb/ft}^3)(40 \text{ in}^3) \frac{1 \text{ ft}^3}{1728 \text{ in}^3}$$

$$F_{SP} = \mathbf{13.3 \text{ lb}}$$



$$5.9 \quad \Sigma F_V = 0 = w_F + w_S - F_{b_F} - F_{b_S}$$

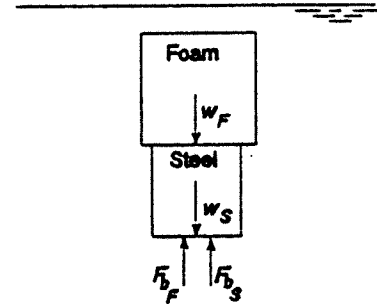
$$F_{b_S} = \gamma_w V_S = 9.81 \text{ kN/m}^3 \times (0.100 \text{ m})^3 = 9.81 \text{ N}$$

$$0 = \gamma_F V_F + 80 \text{ N} - \gamma_w V_F - 9.81 \text{ N}$$

$$0 = V_F(\gamma_F - \gamma_w) + 70.19 \text{ N}$$

$$V_F = \frac{-70.19 \text{ N}}{\gamma_F - \gamma_w} = \frac{-70.19 \text{ N}}{(470 - 9810) \text{ N/m}^3}$$

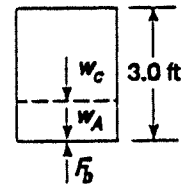
$$= \mathbf{7.515 \times 10^{-3} \text{ m}^3}$$



$$5.10 \quad w_c + w_A = F_b = \gamma_w V_c = 62.4 \text{ lb/ft}^3 \cdot \frac{\pi(2)^2}{4} \cdot 3 \text{ ft} = 588.1 \text{ lb}$$

$$w_A = F_b - w_c = 588.1 - 30 = 558.1 \text{ lb} = \gamma_A V_A$$

$$V_A = \frac{w_A}{\gamma_A} = \frac{558.1 \text{ lb}}{0.100 \text{ lb}} \cdot \frac{1 \text{ ft}^3}{1728 \text{ in}^3} = \mathbf{3.23 \text{ ft}^3}$$



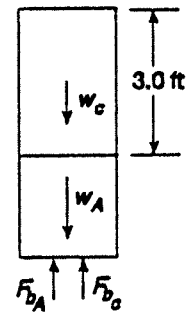
$$5.11 \quad w_c + w_A - F_{b_c} - F_{b_A} = 0$$

$$w_A - F_{b_A} = F_{b_c} - w_c = 588.1 - 30 = 558.1 \text{ lb (See Prob 5.10)}$$

$$\gamma_A V_A - \gamma_w V_A = 558.1 \text{ lb}$$

$$\gamma_A = (0.100 \text{ lb/in}^3)(1728 \text{ in}^3/\text{ft}^3) = 172.8 \text{ lb/ft}^3$$

$$V_A = \frac{558.1 \text{ lb}}{\gamma_A - \gamma_w} = \frac{558.1 \text{ lb}}{(172.8 - 62.4) \text{ lb/ft}^3} = \mathbf{5.055 \text{ ft}^3}$$



$$5.12 \quad w_c - F_b = 0 = \gamma_c V_c - \gamma_f V_d = \gamma_c S^3 - \gamma_f S^2 X$$

$$X = \frac{\gamma_c S^3}{\gamma_f S^2} = \frac{\gamma_c S}{\gamma_f}$$

$$5.13 \quad w_H + w_S - F_b = 0$$

$$F_b = \gamma_w (V_1 + V_2) = 62.4 \text{ lb/ft}^3 \left[ \frac{\pi(1.0)^2}{4} \cdot 1.50 + \frac{\pi(.25)^2}{4} \times 1.30 \right] \frac{\text{in}^3 \text{ ft}^3}{1728 \text{ in}^3}$$

$$= 0.04485 \text{ lb}$$

$$w_S = F_b - w_H = 0.04485 - 0.020 = \mathbf{0.02485 \text{ lb}}$$

5.14 From Prob. 5.13:  $w_H + w_S = 0.02 + 0.02485 = 0.04485 \text{ lb} = w = F_b$

$$w = F_b = \gamma_F V_d = \gamma_f (V_1 + V_2) = \gamma_f \left[ \frac{\pi(1.0)^2}{4} \cdot 1.50 + \frac{\pi(0.25)^2}{4} \cdot 2.30 \right] \frac{\text{in}^3 \text{ft}^3}{1728 \text{in}^3}$$

$$= \gamma_f (7.47 \times 10^{-4} \text{ft}^3)$$

$$\gamma_f = \frac{w}{V_d} = \frac{0.04485 \text{ lb}}{7.47 \times 10^{-4} \text{ft}^3} = 60.03 \text{ lb/ft}^3; \text{sg} = \frac{\gamma_f}{\gamma_w} = 60.03/62.40 = \mathbf{0.962}$$

5.15  $V_d = V_1 + V_2 = \left[ \frac{\pi(1.0)^2}{4} \cdot 1.50 + \frac{\pi(0.25)^2}{4} \cdot 0.30 \right] \frac{\text{in}^3 \text{ft}^3}{1728 \text{in}^3} = 6.903 \times 10^{-4} \text{ft}^3$

$$\gamma_f = \frac{w}{V_d} = \frac{0.04485 \text{ lb}}{6.903 \times 10^{-4} \text{ft}^3} = 64.97 \text{ lb/ft}^3; \text{sg} = \frac{\gamma_f}{\gamma_w} = 64.97/62.4 = \mathbf{1.041}$$

5.16  $w_B + w_C - F_{b_b} - F_{b_c} = 0$

$$w_C = F_{b_b} + F_{b_c} - w_B$$

$$w_B = \gamma_B \cdot V_B = 8.00 \text{ lb/ft}^3 \left[ \frac{\pi(1.00)^2}{4} \cdot 3.0 + \frac{\pi(1.00)^3}{6} \right] \text{ft}^3$$

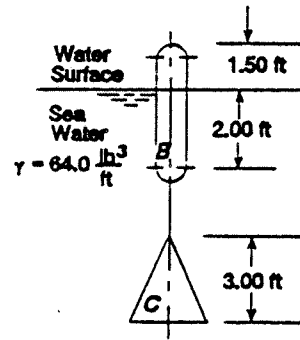
$$= 23.04 \text{ lb}$$

$$F_{b_c} = \gamma_f V_C = 64.0 \text{ lb/ft}^3 \left[ \frac{\pi(2.0)^2(3.0)}{12} \text{ft}^3 \right] = 201.06 \text{ lb}$$

$$F_{b_b} = \gamma_f V_d = 64.0 \text{ lb/ft}^3 \left[ \frac{\pi(1.0)^2}{4} \cdot 2.00 + \frac{\pi(1.0)^3}{12} \right] \text{ft}^3$$

$$= 117.29 \text{ lb}$$

$$w_C = 117.29 + 201.06 - 23.04 = \mathbf{295.31 \text{ lb}}$$

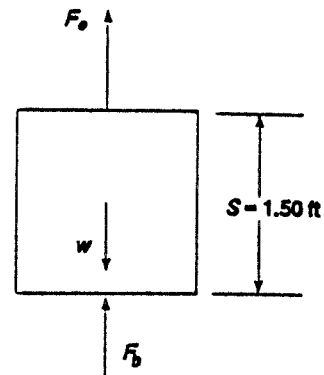


5.17  $S = 18.00 \text{ in}(1 \text{ ft}/12 \text{ in}) = 1.50 \text{ ft}$

$$w - F_b - F_e = 0$$

$$F_e = w - F_b = \gamma_S V_C - \gamma_w V_C = V_C(\gamma_S - \gamma_w)$$

$$F_e = (1.50)^3 \text{ft}^3 (491 - 62.4) \text{lb/ft}^3 = \mathbf{1447 \text{ lb} \uparrow}$$



5.18  $\gamma_m = 844.9 \text{ lb/ft}^3 > \gamma_w$  - cube would tend to float.

$$w - F_b + F_e = 0$$

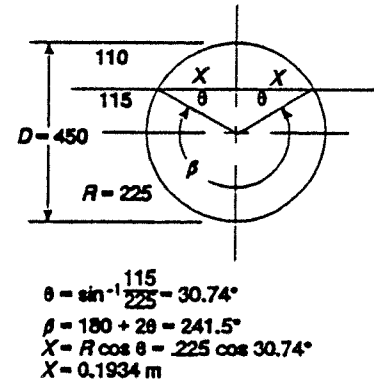
$$F_e = F_b - w = \gamma_m V_C - \gamma_S V_C = V_C(\gamma_m - \gamma_S) = (1.50)^3 \text{ft}^3 (844.9 - 491) \text{lb/ft}^3 = \mathbf{1194 \text{ lb} \downarrow}$$

5.19  $w - F_b = 0 = w - \gamma_{sw} V_d$

$$V_d = \frac{w}{\gamma_{sw}} = \frac{292 \times 10^6 \text{ gm}}{10.10 \text{ kN/m}^3} \times \frac{9.81 \text{ m}}{\text{s}^2} \times \frac{\text{kg}}{10^3 \text{ gm}} \times \frac{1 \text{ N}}{\text{kg m/s}^2} \times \frac{1 \text{ kN}}{10^3 \text{ N}} = \mathbf{283.6 \text{ m}^3}$$

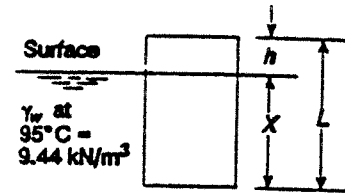
5.20  $w = F_b; \gamma_I V_I = \gamma_{sw} V_d$   
 $V_d = V_I \frac{\gamma_I}{\gamma_{sw}} = V_I \cdot \frac{8.72 \text{ kN/m}^3}{10.10 \text{ kN/m}^3} = V_I \cdot 0.863; 86.3\% \text{ submerged}; 13.7\% \text{ above}$

5.21  $w = F_b; \gamma_{wood} V_T = \gamma_w V_d$   
 $\gamma_{wood} = \gamma_w \frac{V_d}{V_T}$   
 $V_T = \frac{\pi D^2}{4} \cdot L = \frac{\pi (450)^2}{4} \cdot 6.750 = 1.074 \text{ m}^3$   
 $V_d = \left[ \frac{\pi D^2}{4} \cdot \frac{\beta}{360} + \frac{1}{2} (2X)(.115) \right] L$   
 $V_d = \left[ \frac{\pi (.45)^2}{4} \cdot \frac{241.5}{360} + (.1934)(.115) \right] 6.75 \text{ m}^3$   
 $= 0.8703 \text{ m}^3$   
 $\gamma_{wood} = (9.81 \text{ kN/m}^3)(.8703/1.074) = 7.95 \text{ kN/m}^3$



5.22  $w - F_b = 0 = \gamma_c V_c - \gamma_k V_d$   
 $\gamma_c = \gamma_k \frac{V_d}{V_c} = 8.07 \text{ kN/m}^3 \cdot \frac{A \cdot 600 \text{ mm}}{A \cdot 750 \text{ mm}} = 6.46 \text{ kN/m}^3$

5.23  $w - F_b = 0 = \gamma_c V_c - \gamma_w V_d = \gamma_c A \cdot L - \gamma_w A \cdot X$   
 $X = \frac{\gamma_c A \cdot L}{\gamma_w A} = \frac{6.46 \text{ kN/m}^3}{9.44 \text{ kN/m}^3} \cdot 750 \text{ mm} = 513 \text{ mm}$   
 $h = L - X = 750 - 513 = 237 \text{ mm}$

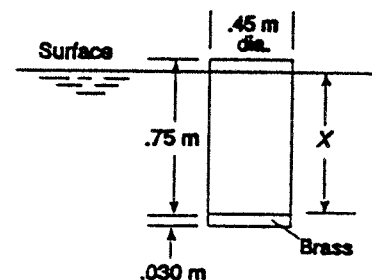


5.24  $w_c - F_{bc} + w_B - F_{bb} = 0$   
 $\gamma_c V_c - \gamma_w V_c + \gamma_B V_B - \gamma_w V_B = 0$   
 $\gamma_c A \cdot L - \gamma_w A \cdot L + \gamma_B A \cdot t - \gamma_w A \cdot t = 0$   
 $t(\gamma_B - \gamma_w) = L(\gamma_w - \gamma_c)$   
 $t = L \frac{\gamma_w - \gamma_c}{\gamma_B - \gamma_w} = 750 \text{ mm} \frac{(9.44 - 6.46) \text{ kN/m}^3}{(84.0 - 9.44) \text{ kN/m}^3} = 30.0 \text{ mm}$

5.25  $\gamma_w \text{ at } 15^\circ\text{C} = 9.81 \text{ kN/m}^3$ —it would float.  
 $w_c - F_{bc} + w_B - F_{bb} = 0$

$$w_c = \gamma_c V_c = 6.46 \text{ kN/m}^3 \times \frac{\pi (.45)^2}{4} \times .75 \text{ m}^3 = 0.771 \text{ kN}$$

$$w_B = \gamma_B V_B = 84.0 \text{ kN/m}^3 \times \frac{\pi (.45)^2}{4} \times .030 \text{ m}^3 = 0.4008 \text{ kN}$$



$$F_{b_b} = \gamma_w V_B = 9.81 \text{ kN/m}^3 \times \frac{\pi(.45)^2}{4} \times .03 \text{ m}^3$$

$$= 0.0468 \text{ kN}$$

$$F_{b_c} = \gamma_w V_d = w_C + w_B - F_{b_b} = 0.771 + 0.4008 - 0.0468 = 1.125 \text{ kN}$$

$$F_{b_c} = \gamma_w V_d = \gamma_w A X$$

$$X = \frac{F_{b_c}}{\gamma_w A} = \frac{1.125 \text{ kN}}{(9.81 \text{ kN/m}^3)(\pi(.45)^2 \text{ m}^2/4)} = \mathbf{0.721 \text{ m submerged} = 721 \text{ mm}}$$

**29 mm above surface**

5.26  $\gamma_{CT} = 15.60 \text{ kN/m}^3$

$$w_c - F_{b_c} + w_B - F_{b_b} = 0$$

$$w_c = \gamma_c V_c = 6.50 \text{ kN/m}^3 \times \frac{\pi(.45)^2}{4} \times .75 \text{ m}^3 = 0.7753 \text{ kN}$$

$$F_{b_c} = \gamma_{CT} V_d = 15.60 \text{ kN/m}^3 \times \frac{\pi(.45)^2}{4} \times .70 \text{ m}^3 = 1.737 \text{ kN}$$

$$w_B - F_{b_b} = \gamma_B V_B - \gamma_{CT} V_B = V_B(\gamma_B - \gamma_{CT}) = F_{b_c} - w_c = 1.737 - 0.7753$$

$$= 0.9614 \text{ kN}$$

$$V_B = \frac{0.9614 \text{ kN}}{\gamma_B - \gamma_{CT}} = \frac{0.9614 \text{ kN}}{(84.0 - 15.60) \text{ kN/m}^3} = 0.01406 \text{ m}^3 = At$$

$$t = \frac{V_B}{A} = \frac{0.01406 \text{ m}^3}{\pi(0.45)^2/4 \text{ m}^2} = 0.0884 \text{ m} = \mathbf{88.4 \text{ mm}}$$

5.27  $w = F_b = \gamma_f V_d = (1.16)(9.81 \text{ kN/m}^3)(0.8836 \text{ m}^3) = \mathbf{10.05 \text{ kN}}$

$$V_d = \pi D^3/12 = \pi(1.50 \text{ m})^3/12 = 0.8836 \text{ m}^3$$

Entire hemisphere is submerged.

5.28  $w = F_b = \gamma_f V_d = \gamma_w A \cdot X$

$$X = \frac{w}{\gamma_w A} = \frac{0.05 \text{ N}}{(9.81 \text{ kN/m}^3)(\pi(0.082 \text{ m})^2)} \times \frac{\text{kN}}{10^3 \text{ N}} = 0.965 \times 10^{-3} \text{ m} = \mathbf{0.965 \text{ mm}}$$

5.29 Wt. of steel bar  $= w_S = \gamma_S V_S = \gamma_S A L = \gamma_S \frac{\pi D^2}{4} L$

$$w_S = 76.8 \text{ kN/m}^2 \cdot \frac{\pi(.038 \text{ m})^2}{4} \cdot 0.08 \text{ m} \cdot \frac{10^3 \text{ N}}{\text{kN}} = 6.97 \text{ N}$$

$$w_S + w_C = 6.97 + 0.05 = 7.02 \text{ N} = F_b = \gamma_w A X$$

$$X = \frac{w_T}{\gamma_w A} = \frac{7.02 \text{ N}}{(9.81 \text{ kN/m}^3) \pi(0.082 \text{ m})^2} \cdot \frac{1 \text{ kN}}{10^3 \text{ N}} = 0.135 \text{ m} = \mathbf{135 \text{ mm}}$$

5.30 From Prob. 5.29,  $w_T = 7.02 \text{ N}$

$$V_S = \frac{\pi D^2}{4} \cdot L = \frac{\pi (0.038 \text{ m})^2}{4} \cdot 0.080 \text{ m} = 9.073 \times 10^{-5} \text{ m}^3$$

$$F_{b_s} = \gamma_w V_S = 9.81 \text{ kN/m}^3 \times 9.073 \times 10^{-5} \text{ m}^3 \times 10^3 \text{ N/kN} = 0.890 \text{ N}$$

$$w_T - F_{b_s} - F_{b_c} = 0$$

$$F_{b_c} = w_T - F_{b_s} = 7.02 \text{ N} - 0.890 \text{ N} = 6.13 \text{ N} = \gamma_w A X$$

$$X = \frac{6.13 \text{ N}}{9.81 \text{ kN/m}^3} \times \frac{4}{\pi (0.082 \text{ m})^2} \times \frac{1 \text{ kN}}{10^3 \text{ N}} = 0.118 \text{ m} = \mathbf{118 \text{ mm}}$$

5.31  $w_T = F_b = 4\gamma_w V_{\text{drum}} = 4(62.4 \text{ lb/ft}^3) \frac{(\pi(21 \text{ in})^2)}{4} \frac{(36 \text{ in})}{1728 \text{ in}^3} \text{ft}^3 = 1801 \text{ lb}$

Drums Weigh  $4(30 \text{ lb}) = 120 \text{ lb}$

Wt. of platform and load =  $1801 - 120 = \mathbf{1681 \text{ lb}}$

5.32 Vol. of Wood:  $2(6.0 \text{ ft})(1.50 \text{ in})(5.50 \text{ in})(1 \text{ ft}^2/144 \text{ in}^2) = 0.6875 \text{ ft}^3$  ends  
 $4(96 - 3) \text{ in}(1.50 \text{ in})(5.50 \text{ in})(1 \text{ ft}^3/1728 \text{ in}^3) = 1.776 \text{ ft}^3$  main boards  
 $(0.50 \text{ in})(6 \text{ ft})(8 \text{ ft})(1 \text{ ft}/12 \text{ in}) = 2.000 \text{ ft}^3$  plywood  
 $4.464 \text{ ft}^3$  total

$$w_w = \gamma_w V = (40.0 \text{ lb/ft}^3)(4.464 \text{ ft}^3) = \mathbf{178.5 \text{ lb}}$$

5.33  $w_D + w_P = F_b = \gamma_w V_d$

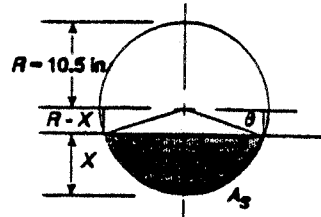
$$V_d = \frac{w_D + w_P}{\gamma_w} = \frac{120 \text{ lb} + 178.5 \text{ lb}}{62.4 \text{ lb/ft}^3} = 4.78 \text{ ft}^3 \text{ total}$$

$$V_D = 4.78/4 = 1.196 \text{ ft}^3 \text{ sub. each drum}$$

$$V_D = A_S \cdot L$$

$$A_S = \frac{V_D}{L} = \frac{1.196 \text{ ft}^3}{3.0 \text{ ft}} = 0.399 \text{ ft}^2 \times \frac{144 \text{ in}^2}{\text{ft}^2} = 57.4 \text{ in}^2$$

By trial:  $X = \mathbf{4.67 \text{ in}}$  when  $A_S = 57.4 \text{ in}^2$



See Prob. 4.63 for method of computing  $A_S$ .

5.34  $w_{\text{drums}} + w_{\text{wood}} + w_{\text{load}} - F_{b_d} - F_{b_w} = 0$

$$w_{\text{drums}} = 4(30 \text{ lb}) = 120 \text{ lb (Prob. 5.31)}$$

$$w_{\text{wood}} = 178.5 \text{ lb (Prob. 5.32)}$$

$$F_{b_d} = 1801 \text{ lb (Prob. 5.31)}$$

$$F_{b_w} = \gamma_w V_w = 62.4 \text{ lb/ft}^3 \times 4.464 \text{ ft}^3 = 278.6 \text{ lb (Prob. 5.32)}$$

$$w_{\text{load}} = F_{b_d} + F_{b_w} - w_D - w_w = 1801 + 278.6 - 120 - 178.5 = \mathbf{1781 \text{ lb}}$$

- 5.35 Given:  $\gamma_F = 12.00 \text{ lb/ft}^3$ ,  $\gamma_C = 150 \text{ lb/ft}^3$ ,  $w_C = 600 \text{ lb}$   
Find: Tension in cable

**Float only:**  $\Sigma F_V = 0 = w_F + T - F_{b_f}$

$$T = F_{b_f} - w_F$$

But  $w_F = \gamma_F V_F = 12.0 \text{ lb/ft}^3 \times 9.0 \text{ ft}^3 = 108 \text{ lb}$

$$V_F = \frac{(18.0 \text{ in})^2 (48 \text{ in})}{1728 \text{ in}^3/\text{ft}^3} = 9.00 \text{ ft}^3$$

$$F_{b_f} = \gamma_w V_d = (64.0 \text{ lb/ft}^3)(6.375 \text{ ft}^3) = 408 \text{ lb}$$

$$V_d = \frac{(18.0 \text{ in})^2 (34 \text{ in})}{1728 \text{ in}^3/\text{ft}^3} = 6.375 \text{ ft}^3$$

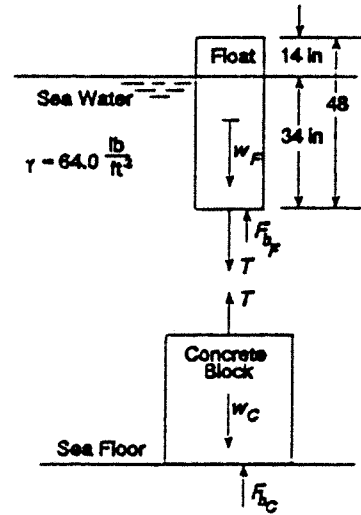
$$T = 408 - 108 = \mathbf{300 \text{ lb}}$$

Check concrete block:  $F_{\text{net}} = w_C - F_{b_c} - T$

$$w_C = 600 \text{ lb}; V_C = \frac{w_C}{\gamma_C} = \frac{600 \text{ lb}}{150 \text{ lb/ft}^3} = 4.00 \text{ ft}^3$$

$$F_{b_c} = \gamma_w V_C = (64.0 \text{ lb/ft}^3)(4.00 \text{ ft}^3) = 256 \text{ lb}$$

$$F_{\text{net}} = 600 - 256 - 300 = 44 \text{ lb down—OK—block sits on bottom.}$$



- 5.36 Rise of water level by 18.00 in would tend to submerge entire float. But additional buoyant force on float is sufficient to lift concrete block off sea floor.

With block suspended:  $T = w_C - F_{b_c}$

$$T = 600 - 256 = 344 \text{ lb (see Problem 5.35)}$$

**Float:**  $w_F + T - F_{b_f} = 0$

$$F_{b_f} = w_F + T = 108 \text{ lb} + 344 \text{ lb} = 452 \text{ lb} = \gamma_w V_d$$

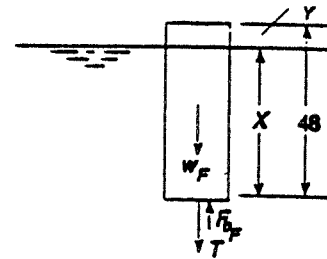
$$V_d = \frac{F_{b_f}}{\gamma_w} = \frac{452 \text{ lb}}{64.0 \text{ lb/ft}^3} = 7.063 \text{ ft}^3 \times \frac{1728 \text{ in}^3}{\text{ft}^3} = 12204 \text{ in}^3$$

$$V_d = (18.0 \text{ in})^2 (X)$$

$$X = \frac{V_d}{(18.0 \text{ in})^2} = \frac{12204 \text{ in}^3}{324 \text{ in}^2} = 37.67 \text{ in submerged}$$

$$Y = 48 - X = 10.33 \text{ in above surface}$$

With concrete block suspended, float is unrestrained and it would drift with the currents.



- 5.37  $\Sigma F_V = 0 = w_A - F_{b_w} - F_{b_o} - T$

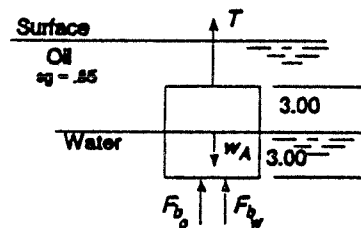
$$T = w_A - F_{b_w} - F_{b_o}$$

$$w_A = \gamma_A V_T = \frac{0.10 \text{ lb}}{\text{in}^3} \times (6.0 \text{ in})^3 = 21.6 \text{ lb}$$

$$F_{b_w} = \gamma_w V_{d_w} = 62.4 \text{ lb/ft}^3 \times \frac{(6 \text{ in})^2 (3.0 \text{ in})}{1728 \text{ in}^3/\text{ft}^3} = 3.90 \text{ lb}$$

$$F_{b_o} = \gamma_o V_{d_o} = 0.85 F_{b_w} = 3.315 \text{ lb}$$

$$\text{Then: } T = 21.6 - 3.90 - 3.315 = \mathbf{14.39 \text{ lb}}$$



5.38  $F_S = w_c - F_{b_c} = \gamma_c V_c - \gamma_f V_c = V_c(\gamma_c - \gamma_f)$

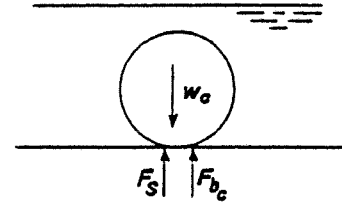
$$V_c = \frac{\pi D^2}{4} \cdot L = \frac{\pi(6.0 \text{ in})^2}{4} \times 10.0 \text{ in} \times \frac{\text{ft}^3}{1728 \text{ in}^3}$$

$$= 0.1636 \text{ ft}^3$$

$$F_S = 0.1636 \text{ ft}^3 \left( \frac{0.284 \text{ lb}}{\text{in}^3} \times \frac{1728 \text{ in}^3}{\text{ft}^3} - \frac{62.4 \text{ lb}}{\text{ft}^3} \right)$$

$$= 70.1 \text{ lb}$$

$F_S$  acts **up** on cylinder; **down** on tank bottom



**Stability**

5.39  $w - F_b = 0$

$$\gamma_c V_c = \gamma_f V_d = \gamma_f A X$$

$$X = \frac{\gamma_c V_c}{\gamma_f A} = \frac{\gamma_c A (1.0 \text{ m})}{\gamma_f A} = \frac{8.00 \text{ kN/m}^3 / (1.0 \text{ m})}{9.81 \text{ kN/m}^3}$$

$$= 0.8155 \text{ m}$$

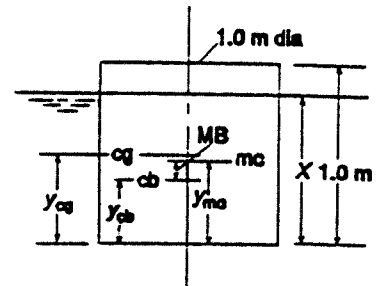
$$y_{cg} = 1.00 \text{ m} / 2 = 0.500 \text{ m}$$

$$y_{cb} = X / 2 = 0.8155 \text{ m} / 2 = 0.4077 \text{ m}$$

$$MB = \frac{I}{V_d} = \frac{\pi D^4 / 64}{(\pi D^2 / 4)(X)} = \frac{\pi(1.0 \text{ m})^4 / 64}{[\pi(1.0 \text{ m})^2 / 4](0.8155 \text{ m})}$$

$$= \frac{0.04909 \text{ m}^4}{0.6405 \text{ m}^3} = 0.0766 \text{ m}$$

$$y_{mc} = y_{cb} + MB = 0.4077 + 0.0766 = 0.4844 \text{ m} < y_{cg} \text{---unstable}$$



5.40  $w = F_b = \gamma_w V_d = \gamma_w A X$

$$X = \frac{w}{\gamma_w A} = \frac{250 \text{ lb}(144 \text{ in}^2/\text{ft}^2)}{(62.4 \text{ lb}/\text{ft}^3)(30 \text{ in})(40 \text{ in})} = 0.4808 \text{ ft}$$

$$X = 5.77 \text{ in}; y_{cb} = X / 2 = 2.88 \text{ in}$$

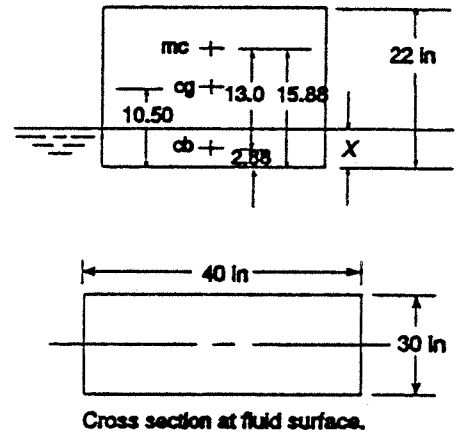
$$I = (40 \text{ in})(30 \text{ in})^3 / 12 = 90000 \text{ in}^4$$

$$V_d = A X = (30 \text{ in})(40 \text{ in})(5.77 \text{ in}) = 6923 \text{ in}^3$$

$$MB = I / V_d = 90000 \text{ in}^4 / 6923 \text{ in}^3 = 13.0 \text{ in}$$

$$y_{mc} = y_{cb} + MB = 2.88 \text{ in} + 13.0 \text{ in}$$

$$= 15.88 \text{ in} > y_{cg} \text{---stable}$$



5.41  $w = F_b = \gamma_{sw} V_d = \gamma_{sw} A X$   

$$X = \frac{w}{\gamma_{sw} A} = \frac{450000 \text{ lb}}{(64.0 \text{ lb/ft}^3)(20 \text{ ft})(50 \text{ ft})}$$

$$= 7.031 \text{ ft}$$

$$y_{cb} = X/2 = 3.516 \text{ ft}$$

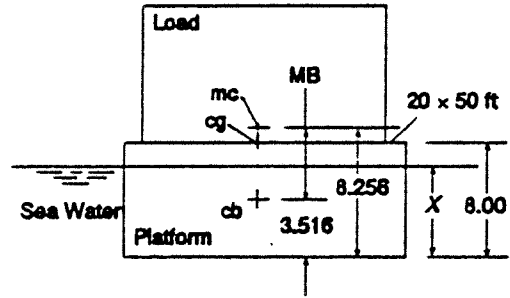
$$I = (50)(20)^3/12 = 3.333 \times 10^4 \text{ ft}^4$$

$$V_d = A X = (20)(50)(7.031) \text{ ft}^3 = 7031 \text{ ft}^3$$

$$\text{MB} = I/V_d = 4.741 \text{ ft}$$

$$y_{mc} = y_{cb} + \text{MB} = 3.516 + 4.741$$

$$= 8.256 \text{ ft} > y_{cg} \text{—stable}$$



5.42 From Prob. 5.4;  $X = 0.9$   $H = 0.9(12) = 10.8$  in  

$$y_{cb} = X/2 = 5.40 \text{ in}$$

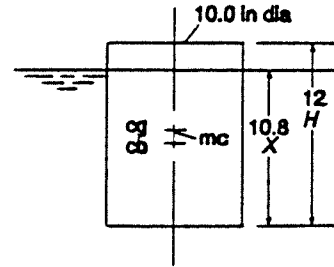
$$y_{cg} = H/2 = 6.00 \text{ in}$$

$$I = \pi D^4/64 = \pi(10.0 \text{ in})^4/64 = 490.9 \text{ in}^4$$

$$V_d = (\pi D^2/4)(X) = [\pi(10.0 \text{ in})^2/4](10.80 \text{ in}) = 848.2 \text{ in}^3$$

$$\text{MB} = I/V_d = 490.9/848.2 = 0.579 \text{ in}$$

$$y_{mc} = y_{cb} + \text{MB} = 5.40 + 0.579 = 5.98 \text{ in} < y_{cg} \text{—unstable}$$



5.43 From Prob. 5.5:  $X = 966$  mm  

$$y_{cb} = X/2 = 483 \text{ mm}$$

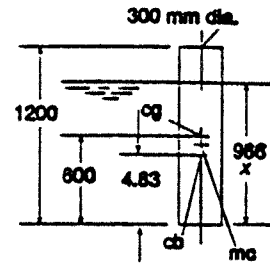
$$y_{cg} = H/2 = 1200/2 = 600 \text{ mm}$$

$$I = \pi D^4/64 = \pi(300 \text{ mm})^4/64 = 3.976 \times 10^8 \text{ mm}^4$$

$$V_d = (\pi D^2/4)(X) = [\pi(300 \text{ mm})^2/4](966 \text{ mm}) = 6.828 \times 10^7 \text{ mm}^3$$

$$\text{MB} = I/V_d = 5.82 \text{ mm}$$

$$y_{mc} = y_{cb} + \text{MB} = 483 + 5.8 = 488.8 \text{ mm} < y_{cg} \text{—unstable}$$



5.44 From Prob. 5.6:  $X = 75$  mm  

$$y_{cb} = X/2 = 37.5 \text{ mm}$$

$$y_{cg} = H/2 = 100/2 = 50.0 \text{ mm}$$

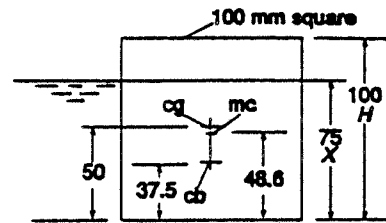
$$I = H^4/12 = (100 \text{ mm})^4/12 = 8.333 \times 10^6 \text{ mm}^4$$

$$V_d = (H^2)(X) = (100 \text{ mm})^2(75 \text{ mm}) = 7.50 \times 10^5 \text{ mm}^3$$

$$\text{MB} = I/V_d = 11.11 \text{ mm}$$

$$y_{mc} = y_{cb} + \text{MB} = 37.5 + 11.11$$

$$= 48.61 \text{ mm} < y_{cg} \text{—unstable}$$



5.45  $w = F_b = \gamma_w V_d = \gamma_w A X$   

$$X = \frac{w}{\gamma_w A} = \frac{70.0 \text{ lb}}{(62.4 \text{ lb/ft}^3)(\pi(2.0 \text{ ft})^2/4)}$$

$$= 0.357 \text{ ft}(12 \text{ in/ft}) = 4.28 \text{ in}$$

$$y_{cb} = X/2 = 2.14 \text{ in}$$

$$y_{cg} = H/2 = 48/2 = 24.0 \text{ in}$$

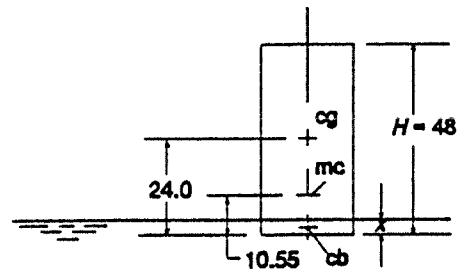
$$I = \pi D^4/64 = \pi(24 \text{ in})^4/64 = 16286 \text{ in}^4$$

$$V_d = A X = (\pi D^2/4)(X) = [\pi(24 \text{ in})^2/4](4.28 \text{ in})$$

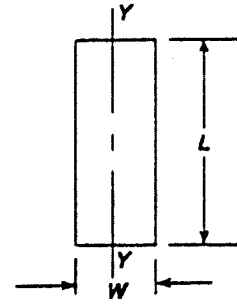
$$= 1936 \text{ in}^3$$

$$\text{MB} = I/V_d = 8.41 \text{ in}$$

$$y_{mc} = y_{cb} + \text{MB} = 2.14 + 8.41 = 10.55 \text{ in} < y_{cg} \text{—unstable}$$



5.46  $X = 8.00$  ft;  $y_{cb} = X/2 = 4.00$  ft;  $y_{cg} = 12.00$  ft  
 $y_{mc} = y_{cb} + MB$   
 Scow is stable if  $y_{mc} > y_{cg}$   
 $MB_{\min} = y_{mc} - y_{cb} = y_{cg} - y_{cb} = 12.0 - 4.0 = 8.0$  ft  
 $MB_{\min} = \frac{I_y}{V_d} = \frac{LW^3/12}{LWX} = \frac{W^2}{12X}$   
 $W_{\min} = \sqrt{12(X)(MB_{\min})} = \sqrt{12(8)(8)\text{ft}^2} = 27.71$  ft



5.47  $X = 16.0$  ft;  $y_{cb} = X/2 = 8.00$  ft;  $y_{cg} = 13.50$  ft  
 $MB_{\min} = y_{mc} - y_{cb} = y_{cg} - y_{cb} = 13.50$  ft  $- 8.00$  ft  $= 5.50$  ft  
 $W_{\min} = \sqrt{12(X)(MB_{\min})} = \sqrt{12(16.0)(5.50)\text{ft}^2} = 32.50$  ft

5.48  $y_{cg} = 0.70$  m from bottom

For hemisphere—submerged—  $\bar{y} = \frac{3D}{16}$  from dia.

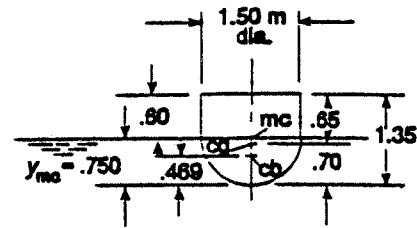
$$y_{cb} = R - \bar{y} = \frac{D}{2} - \frac{3D}{16} = \frac{5D}{16} = \frac{5(1.50 \text{ m})}{16} = 0.469 \text{ m}$$

$$I = \pi D^4/64 = \pi(1.50 \text{ m})^4/64 = 0.2485 \text{ m}^4$$

$$V_d = \pi D^3/12 = \pi(1.50 \text{ m})^3/12 = 0.8836 \text{ m}^3$$

$$MB = I/V_d = 0.281 \text{ m}$$

$$y_{mc} = y_{cb} + MB = 0.469 + 0.281 = 0.750 \text{ m} > y_{cg} \text{—stable}$$



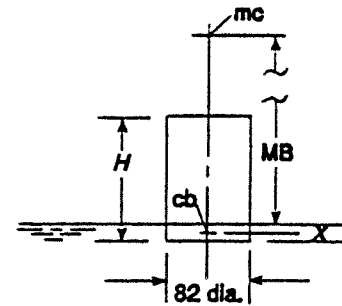
5.49 From Prob. 5.28:  $X = 0.965$  mm;  $D = 82$  mm;  
 $H = 150$  mm

$$MB = \frac{I}{V_d} = \frac{\pi D^4/64}{(\pi D^2/4)(X)} = \frac{D^2}{16X} = \frac{82^2}{16(0.965)} = 435 \text{ mm}$$

$$y_{mc} = y_{cb} + MB = X/2 + MB = .965/2 + 435 = 436 \text{ mm}$$

mc is well above cup; cg is within cup

$\therefore$  It is stable



5.50 From Prob. 5.29,  $X = 135$  mm

$$y_{cb} = X/2 = 67.5 \text{ mm}$$

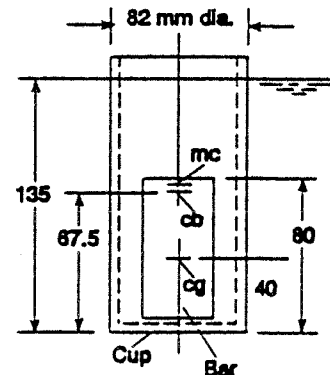
$$MB = \frac{I}{V_d} = \frac{\pi D^4/64}{(\pi D^2/4)(X)} = \frac{D^2}{16X} = \frac{82^2}{16(135)} = 3.11 \text{ mm}$$

$$y_{mc} = y_{cb} + MB = 67.5 + 3.11 = 70.61 \text{ mm}$$

Because wt. of bar is  $\gg$  wt. of cup,

$$y_{cg} \approx L \text{ Bar}/2 = 80/2 = 40 \text{ mm}$$

$$y_{mc} > y_{cg} \text{—stable}$$



5.51 From Prob. 5.30,  $X = 118$  mm  
 $V_s = \text{Vol. of steel bar} = 9.073 \times 10^4 \text{ mm}^3$

$$V_{CS} = \text{Sub. vol. of cup} = \frac{\pi D_c^2}{4} \times X$$

$$V_{CS} = \frac{\pi(82)^2}{4} (118) = 6.232 \times 10^5 \text{ mm}^3$$

$$V_d = V_s + V_{CS} = 7.139 \times 10^5 \text{ mm}^3$$

$$y_s = \text{cb of steel bar} = \frac{D_s}{2} = 19 \text{ mm}$$

$$y_{CS} = \text{cb of sub. vol. of cup}$$

$$y_{CS} = D_s + \frac{X}{2} = 38 + \frac{118}{2} = 97 \text{ mm}$$

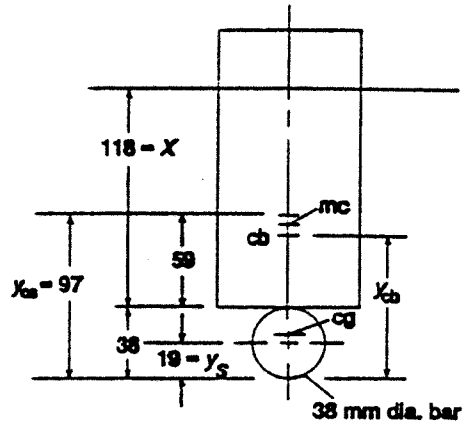
$$y_{cb} = \frac{y_s V_s + y_{CS} V_{CS}}{V_d}$$

$$= \frac{(19)(9.073 \times 10^4) + (97)(6.232 \times 10^5)}{7.139 \times 10^5} = 87.1 \text{ mm}$$

$$MB = \frac{I}{V_d} = \frac{\pi(82)^4/64}{7.139 \times 10^5} \text{ mm} = 3.11 \text{ mm}$$

$$y_{mc} = y_{cb} + MB = 90.2 \text{ mm}$$

$y_{cg}$  is very low because wt. of bar is  $\gg$  wt. of cup—**stable**



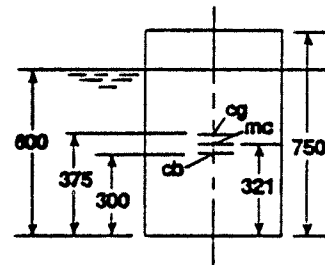
5.52 From Prob. 5.22, Fig. 5.23:  $X = 600$  mm

$$y_{cb} = X/2 = 300 \text{ mm}$$

$$y_{cg} = H/2 = 750/2 = 375 \text{ mm}$$

$$MB = \frac{I}{V_d} = \frac{\pi D^4/64}{(\pi D^2/4)(X)} = \frac{D^2}{16X} = \frac{(450)^2}{16(600)} = 21.1 \text{ mm}$$

$$y_{mc} = y_{cb} + MB = 300 + 21.1 = 321.1 \text{ mm} < y_{cg} \text{—unstable}$$



5.53 From Prob. 5.26, Fig. 5.25;  $t = 88.4$  mm

$$X = 700 + t = 788.4 \text{ mm}$$

$$y_{cb} = X/2 = 394.2 \text{ mm}$$

$$MB = \frac{I}{V_d} = \frac{\pi D^4/64}{[\pi D^2/4](X)} = \frac{D^2}{16X}$$

$$MB = \frac{450^2}{16(788.4)} = 16.1 \text{ mm}$$

$$y_{mc} = y_{cb} + MB = 394.2 + 16.1 = 410.3 \text{ mm}$$

$$y_{cg} w_{tot} = y_c w_c + y_B w_B \text{ composite cyl.}$$

$$w_c = \gamma_c V_c = 0.7753 \text{ kN}$$

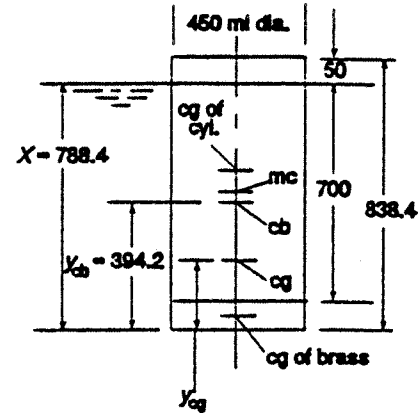
$$y_c = 750/2 + t = 375 + 88.4 = 463.4 \text{ mm}$$

$$w_B = \gamma_B V_B = \frac{840.0 \text{ kN}}{\text{m}^3} \times \frac{\pi(.45 \text{ m})^2}{4} (0.0884 \text{ m})$$

$$= 1.181 \text{ kN}$$

$$y_B = t/2 = 44.2 \text{ mm}$$

$$y_{cg} = \frac{y_c w_c + y_B w_B}{w_{tot}} = \frac{(463.4)(0.7753) + (44.2)(1.181)}{(0.7753 + 1.181)} = 210.3 \text{ mm} < y_{mc} \text{—stable}$$



5.54  $w = F_b = \gamma_{sw} A X$

$$X = \frac{w}{\gamma_{sw} A} = \frac{3840 \text{ lb}}{(64.0 \text{ lb/ft}^3)(2 \text{ ft})(4 \text{ ft})} = 7.50 \text{ ft}$$

$$y_{cb} = X/2 = 3.75 \text{ ft}$$

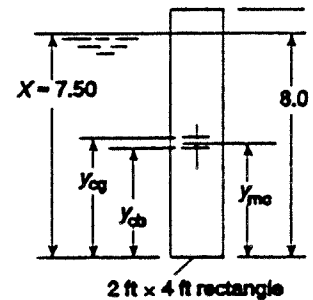
$$I = 4(2)^3/12 = 2.667 \text{ ft}^4$$

$$V_d = A X = (2)(4)(7.5) = 60 \text{ ft}^3$$

$$MB = I/V_d = 2.667/60 = 0.0444 \text{ ft}$$

$$y_{mc} = y_{cb} + MB = 3.75 + 0.0444 = 3.794 \text{ ft}$$

$$y_{cg} = H/2 = 8.00/2 = 4.00 \text{ ft} > y_{mc} \text{—unstable}$$



5.55  $w = F_b = \gamma_{sw} A X$

$$X = \frac{w}{\gamma_{sw} A} = \frac{130 \text{ lb}(12 \text{ in/ft})}{(64.0 \text{ lb/ft}^3)(3 \text{ ft})(4 \text{ ft})}$$

$$= 2.03 \text{ in}$$

$$y_{cb} = X/2 = 1.016 \text{ in}$$

$$y_{cg} = 12 \text{ in} + 34 \text{ in} = 46.0 \text{ in}$$

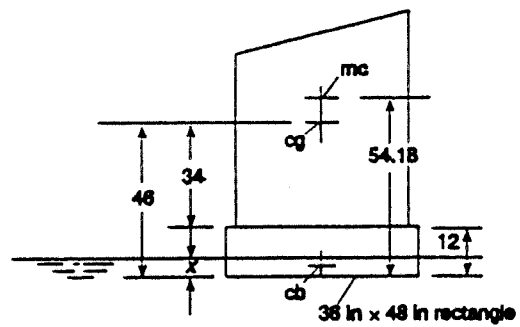
$$I = (48)(36)^3/12 = 1.866 \times 10^5 \text{ in}^4$$

$$V_d = (48)(36)(2.03) \text{ in}^3 = 3510 \text{ in}^3$$

$$MB = I/V_d = 53.17 \text{ in}$$

$$y_{mc} = y_{cb} + MB = 1.016 + 53.17$$

$$= 54.18 \text{ in} > y_{cg} \text{—stable}$$



5.56  $w - F_b = 0 = \gamma_w V_{\text{tot}} - \gamma_o V_d = \gamma_w AH - \gamma_o AX$

$$X = \frac{\gamma_w AH}{\gamma_o A} = \frac{\gamma_w H}{\gamma_o} = \frac{(32 \text{ lb/ft}^3)(6 \text{ in})}{0.90(62.4 \text{ lb/ft}^3)}$$

$$= 3.419 \text{ in}$$

$$y_{\text{cb}} = X/2 = 1.709 \text{ in}$$

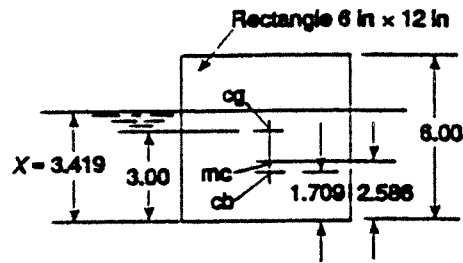
$$y_{\text{cg}} = H/2 = 6.00/2 = 3.00 \text{ in}$$

$$I = 12(6)^3/12 = 216 \text{ in}^4$$

$$V_d = (12)(6)(3.419) = 246.2 \text{ in}^3$$

$$MB = I/V_d = 0.877 \text{ in}$$

$$y_{\text{mc}} = y_{\text{cb}} + MB = 1.709 + 0.877 = 2.586 \text{ in} < y_{\text{cg}} \text{—unstable}$$



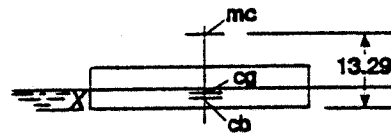
5.57  $w - F_b = \gamma_w V_d = \gamma_w AX$

$$X = \frac{w}{\gamma_w A} = \frac{210000 \text{ lb}}{(62.4 \text{ lb/ft}^3)(60 \text{ ft})(20 \text{ ft})} = 2.804 \text{ ft}$$

$$y_{\text{cb}} = X/2 = 1.402 \text{ ft}; y_{\text{cg}} = 1.50 \text{ ft given}$$

$$MB = \frac{I}{V_d} = \frac{(60)(20)^3/12}{(60)(20)(2.804)} = 11.888 \text{ ft}$$

$$y_{\text{mc}} = y_{\text{cb}} + MB = 1.402 + 11.888 \text{ ft} = 13.290 \text{ ft} > y_{\text{cg}} \text{—stable}$$



5.58  $w_{\text{total}} = 210000 + 240000 = 450000 \text{ lb}$

$$X = \frac{w}{\gamma_w A} = \frac{450000 \text{ lb}}{(62.4)(60)(20)} = 6.010 \text{ ft (See Prob. 5.57)}$$

$$y_{\text{cb}} = X/2 = 3.005 \text{ ft}$$

$$MB = \frac{I}{V_d} = \frac{(60)(20)^3/12}{(60)(20)(6.010)} = 5.547 \text{ ft}$$

$$y_{\text{mc}} = y_{\text{cb}} + MB = 3.005 + 5.547 = 8.552 \text{ ft—above barge}$$

**cg is within barge—stable**

More complete solution:

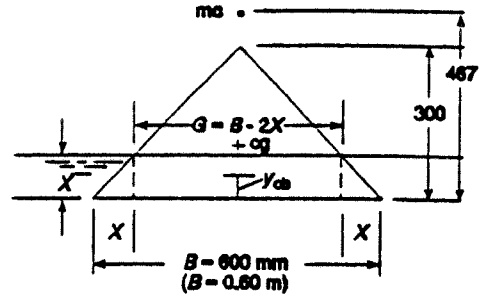
$$\text{Depth of coal} = d_c = \frac{w_c}{\gamma_c A} = \frac{240000 \text{ lb}}{(45 \text{ lb/ft}^3)(60 \text{ ft})(20 \text{ ft})} = 4.444 \text{ ft}$$

$$y_c = d_c/2 = 2.222 \text{ ft from bottom to cg of coal}$$

$$y_{\text{cg}_{\text{tot}}} = \frac{w_c y_c + w_B y_B}{w_{\text{tot}}} = \frac{(240000)(2.222) + (210000)(1.50)}{450000} = 1.885 \text{ ft} < y_{\text{mc}} \text{—stable}$$

5.59  $w = F_b = \gamma_T V_d = \gamma_T A_d L$   
 $w = \gamma_c A_{\text{tot}} L$   
 $= \frac{1}{2} (.600)(.300)(1.20)(2.36) \text{ kN}$   
 $= 0.255 \text{ kN}$

$A_d = GX + 2 \left( \frac{1}{2} \right) (X)(X)$   
 $= (B - 2X)(X) + X^2$



Equate  $\left\{ \begin{array}{l} A_d = BX - 2X^2 + X^2 = BX - X^2 = 600X - X^2 \\ A_d = \frac{w}{\gamma_T L} = \frac{0.255 \text{ kN}}{(0.87)(9.81 \text{ kN/m}^3)(1.20 \text{ m})} \\ A_d = 0.02489 \text{ m}^2 \times \frac{(10^3 \text{ mm})^2}{\text{m}^2} = 2.489 \times 10^4 \text{ mm}^2 \end{array} \right.$

$600X - X^2 = 2.489 \times 10^4$

$X^2 - 600X + 2.489 \times 10^4 = 0$ ;  $X = 44.8 \text{ mm}$  by Quadratic Eq.

$G = B - 2X = 600 - 2(44.8) = 510 \text{ mm}$

$I = G^3 L / 12 = (510)^3 (1200) / 12 = 1.329 \times 10^{10} \text{ mm}^4$

$V_d = A_d L = [600(44.8) - 44.8^2](1200) = 2.985 \times 10^7 \text{ mm}^3$

$MB = I / V_d = 445 \text{ mm}$

$y_{cb} = X - \frac{X(G + 2B)}{3(G + B)} = 44.8 - \frac{44.8(510 + 1200)}{3(510 + 600)} = 21.8 \text{ mm}$

$y_{mc} = y_{cb} + MB = 21.8 + 445 = 467 \text{ mm}$

$y_{cg} = \frac{1}{3} (300) = 100 \text{ mm} < y_{mc}$ —stable

5.60 a) Cube is stable if  $y_{mc} > y_{cg} = S/2$

$y_{mc} = y_{cb} + MB = \frac{X}{2} + \frac{I}{V_d} = \frac{X}{2} + \frac{S^4}{12(S^2)(X)}$

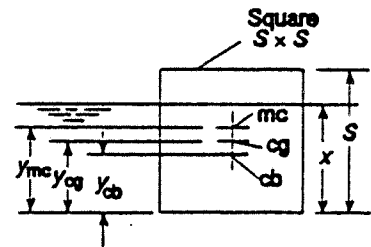
$\frac{X}{2} + \frac{S^2}{12X} = \frac{S}{2}$  or  $X^2 + \frac{S^2}{6} - SX = 0$

$X^2 - SX + S^2/6 = 0$

$X = \frac{S \pm \sqrt{S^2 - 4S^2/6}}{2} = \frac{S}{2} \pm \frac{S}{2} \sqrt{1 - 2/3}$

$= S \left[ \frac{1}{2} \pm \frac{1}{2}(0.5774) \right] = 0.788S \text{ or } 0.211S$

$X > 0.788S$  or  $X < 0.211S$  will result in stable cube.



b) For  $S = 75 \text{ mm}$

$X > 0.788S = 59.2 \text{ mm}$ ,  $X < 0.211S = 15.8 \text{ mm}$

5.61 Entire hull:

$$y_{cg} = \frac{A_1 y_1 + A_2 y_2}{A_T}$$

$$= \frac{(.72)(.40) + (2.88)(1.2)}{3.60}$$

$$y_{cg} = 1.040 \text{ m}$$

Submerged Volume:

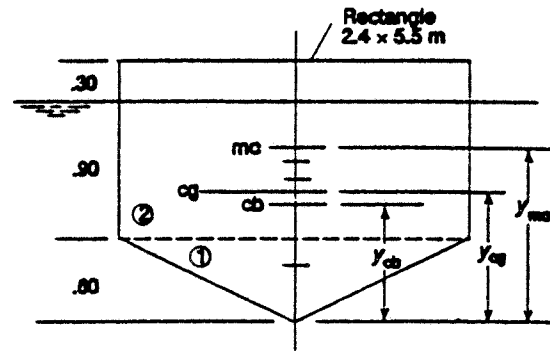
$$y_{cb} = \frac{(.72)(0.4) + (2.16)(1.05)}{2.88}$$

$$= 0.8875 \text{ m}$$

$$V_d = (2.88)(5.5) = 15.84 \text{ m}^3$$

$$I = 5.5(2.4)^3/12 = 6.336 \text{ m}^4$$

$$y_{mc} = y_{cb} + I/V_d = 0.8875 + 0.40 = \mathbf{1.2875 \text{ m}} > y_{cg} \text{—stable}$$



5.62 a)  $w_C = F_b$ ;  $\gamma_C V_C = \gamma_w V_d$

$$w_C = \frac{30 \text{ lb}}{\text{ft}^3} \times \frac{\pi(.5 \text{ ft})^2(1.0 \text{ ft})}{12} = 1.963 \text{ lb}$$

$$V_d = \frac{w_C}{\gamma_w} = \frac{1.963 \text{ lb}}{62.4 \text{ lb/ft}^3} = 0.03147 \text{ ft}^3$$

$$V_d = \frac{(0.03147 \text{ ft}^3)(1728 \text{ in}^3)}{\text{ft}^3} = 54.37 \text{ in}^3$$

$$V_d = \frac{\pi(D_x)^2(X)}{12} = \frac{\pi(X/2)^2 X}{12} = \frac{\pi X^3}{48}$$

$$X = \sqrt[3]{\frac{48 V_d}{\pi}} = \sqrt[3]{\frac{48(54.37)}{\pi}} = 9.40 \text{ in}$$

$$y_{cb} = \frac{3X}{4} = 0.75(9.40) = 7.05 \text{ in}$$

$$I = \frac{\pi D_x^4}{64} = \frac{\pi(9.40/2)^4}{64} = 23.95 \text{ in}^4$$

$$\text{MB} = I/V_d = 23.95/54.37 = 0.441 \text{ in}$$

$$y_{mc} = y_{cb} + \text{MB} = 7.05 + 0.441 = \mathbf{7.491 \text{ in}}$$

$$y_{cg} = \frac{3H}{4} = 0.75(12) = \mathbf{9.00 \text{ in}}$$

$$y_{mc} < y_{cg} \text{—unstable}$$

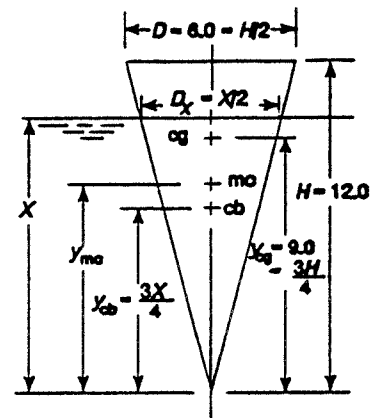


Figure for part (a) only.

b)  $\gamma_C = 55.0 \text{ lb/ft}^3$

$$w_C = 1.963(55/30) = 3.600 \text{ lb}$$

$$V_d = \frac{w_C}{\gamma_w} = \frac{3.600 \text{ lb}}{62.4 \text{ lb/ft}^3} = \frac{0.0577 \text{ ft}^3(1778 \text{ in}^3)}{\text{ft}^3} = 99.69 \text{ in}^3$$

$$X = \sqrt[3]{\frac{48 V_d}{\pi}} = \sqrt[3]{\frac{48(99.69)}{\pi}} = 11.51 \text{ in}$$

$$I = \frac{\pi D_x^4}{64} = \frac{\pi(11.51/2)^4}{64} = 53.77 \text{ in}^4$$

$$MB = \frac{I}{V_d} = \frac{53.77}{99.69} = 0.539 \text{ in}$$

$$y_{cb} = 0.75X = 0.75(11.51) = 8.633 \text{ in}$$

$$y_{mc} = y_{cb} + MB = 8.633 + 0.539 = \mathbf{9.172 \text{ in}}$$

$$y_{cg} = \mathbf{9.00 \text{ in}} < y_{mc} \text{—stable}$$

5.63 (a)  $\sum F_v = 0 = F_b - W_c - W_v$

$W_c$  = Weight of contents;  $W_v$  = Weight of vessel; Find  $W_c + W_v$

$W_c + W_v = F_b$ ; But  $F_b = \gamma_f V_d$

$V_d = V_{hs} + V_{cyl-d}$ ; Where  $V_{hs}$  = Vol. of hemisphere;  $V_{cyl-d}$  = Vol. of cyl. below surface

$$V_{hs} = \pi D^3/12 = \pi(1.50 \text{ m})^3/12 = 0.8836 \text{ m}^3$$

$$V_{cyl-d} = \pi D^2 h_d/4 = \pi(1.50 \text{ m})^2(0.35 \text{ m})/4 = 0.6185 \text{ m}^3$$

$$\text{Then } V_d = V_{hs} + V_{cyl-d} = 0.8836 + 0.6185 = 1.502 \text{ m}^3$$

$$F_b = \gamma_f V_d = (1.16)(9.81 \text{ kN/m}^3)(1.502 \text{ m}^3) = \mathbf{17.09 \text{ kN}} = W_c + W_v \text{ (Answer)}$$

(b) Find  $\gamma_v$  = Specific weight of vessel material =  $W_v/V_{vT}$ ; Given  $W_c = 5.0 \text{ kN}$

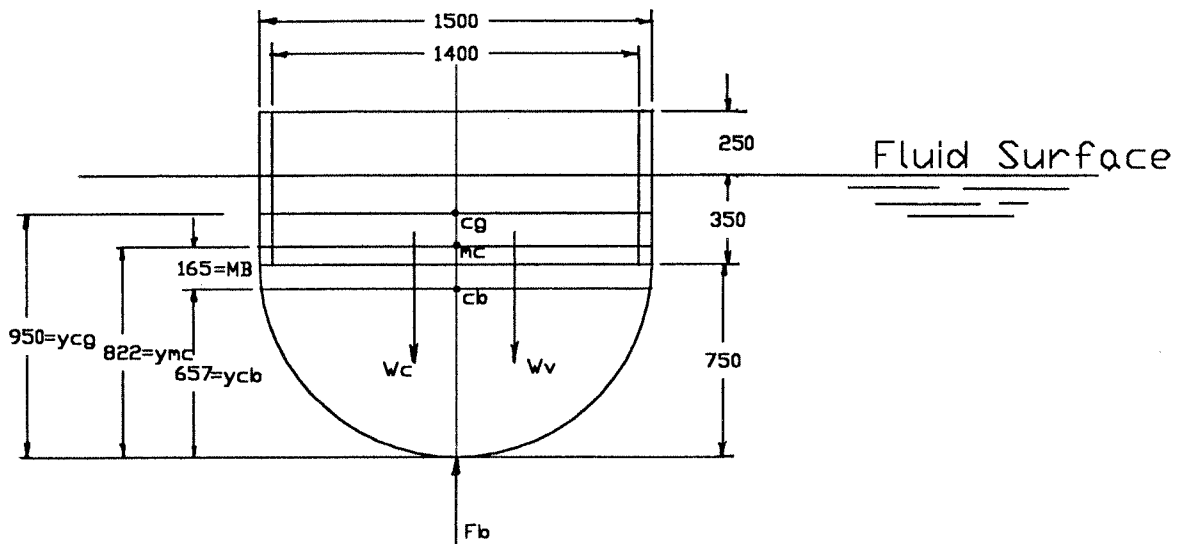
From part (a),  $17.09 \text{ kN} = W_c + W_v$ ; Then  $W_v = 17.09 - W_c = 17.09 - 5.0 = 12.09 \text{ kN}$

$V_{vT}$  = Total volume of vessel =  $V_{hs} + V_{cyl-T}$

$$V_{cyl-T} = (D_o^2 - D_i^2)(0.60 \text{ m})/4 = \pi[(1.50 \text{ m})^2 - (1.40 \text{ m})^2](0.60 \text{ m})/4 = 0.1367 \text{ m}^3$$

$$V_{vT} = V_{hs} + V_{cyl-T} = 0.8836 \text{ m}^3 + 0.1367 \text{ m}^3 = 1.020 \text{ m}^3$$

$$\gamma_v = \text{Specific weight of vessel material} = W_v/V_{vT}; = (12.09 \text{ kN})/(1.020 \text{ m}^3) \\ = \mathbf{11.85 \text{ kN/m}^3} = \gamma_v$$



- (c) Evaluate stability. Find metacenter,  $y_{mc}$ . See figure for key dimensions.

Given:  $y_{cg} = 0.75 + 0.60 - 0.40 = 0.950$  m from bottom of vessel.

We must find:  $y_{mc} = y_{cb} + MB = y_{cb} + I/V_d$

$$I = \pi D^4/64 = \pi(1.50 \text{ m})^4/64 = 0.2485 \text{ m}^4 \text{ For circular cross section at fluid surface.}$$

$$V_d = 1.502 \text{ m}^3 \text{ From part (a).}$$

$$MB = (0.2548 \text{ m}^4)/(1.502 \text{ m}^3) = 0.1654 \text{ m}$$

The center of buoyancy is at the centroid of the displaced volume. The displaced volume is a composite of a cylinder and a hemisphere. The position of its centroid must be computed from the principle of composite volumes. *Measure all y values from bottom of vessel.*

$$(y_{cb})(V_d) = (y_{hs})(V_{hs}) + (y_{cyl-d})(V_{cyl-d})$$

$$y_{cb} = [(y_{hs})(V_{hs}) + (y_{cyl-d})(V_{cyl-d})]/V_d$$

We know from part (a):  $V_d = 1.502 \text{ m}^3$ ;  $V_{hs} = 0.8836 \text{ m}^3$ ;  $V_{cyl-d} = 0.6185 \text{ m}^3$

$$y_{hs} = D/2 - y = D/2 - 3D/16 = (1.50 \text{ m})/2 - 3(1.50 \text{ m})/16 = 0.4688 \text{ m}$$

$$y_{cyl-d} = D/2 + (0.35 \text{ m})/2 = (1.50 \text{ m})/2 + 0.175 \text{ m} = 0.925 \text{ m}$$

Then  $y_{cb} = [(0.4688 \text{ m})(0.8836 \text{ m}^3) + (0.925 \text{ m})(0.6185 \text{ m}^3)]/(1.502 \text{ m}^3) = 0.657 \text{ m}$

Now,  $y_{mc} = y_{cb} + MB = 0.657 \text{ m} + 0.1654 \text{ m} = 0.822 \text{ m}$  From bottom of vessel.

**Because  $y_{mc} < y_{cg}$ , vessel is unstable.**

- 5.64 Let  $F_s$  be the supporting force acting vertically upward when the club head is suspended in the water.

$$\sum F_v = 0 = F_s + F_b - W; \text{ Then } F_s = W - F_b$$

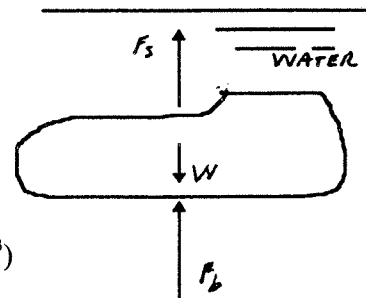
$$F_b = \gamma_w V_{al}; \quad W = \gamma_{al} V_{al}$$

Where  $V_{al}$  = Volume of aluminum club head

$$V_{al} = W/\gamma_{al} = (0.500 \text{ lb})/(0.100 \text{ lb/in}^3) = 5.00 \text{ in}^3$$

$$F_s = W - F_b = 5.00 \text{ lb} - (62.4 \text{ lb/ft}^3)(5.00 \text{ in}^3)(1 \text{ ft}^3)/(1728 \text{ in}^3)$$

$$F_s = \mathbf{0.319 \text{ lb}}$$



# CHAPTER SIX

## FLOW OF FLUIDS

### *Conversion factors*

- 6.1  $Q = 3.0 \text{ gal/min} \times 6.309 \times 10^{-5} \text{ m}^3/\text{s}/1.0 \text{ gal/min} = 1.89 \times 10^{-4} \text{ m}^3/\text{s}$
- 6.2  $Q = 459 \text{ gal/min} \times 6.309 \times 10^{-5} \text{ m}^3/\text{s}/1.0 \text{ gal/min} = 2.90 \times 10^{-2} \text{ m}^3/\text{s}$
- 6.3  $Q = 8720 \text{ gal/min} \times 6.309 \times 10^{-5} \text{ m}^3/\text{s}/1.0 \text{ gal/min} = 0.550 \text{ m}^3/\text{s}$
- 6.4  $Q = 84.3 \text{ gal/min} \times 6.309 \times 10^{-5} \text{ m}^3/\text{s}/1.0 \text{ gal/min} = 5.32 \times 10^{-3} \text{ m}^3/\text{s}$
- 6.5  $Q = 125 \text{ L/min} \times 1.0 \text{ m}^3/\text{s}/60000 \text{ L/min} = 2.08 \times 10^{-3} \text{ m}^3/\text{s}$
- 6.6  $Q = 4500 \text{ L/min} \times 1.0 \text{ m}^3/\text{s}/60000 \text{ L/min} = 7.50 \times 10^{-2} \text{ m}^3/\text{s}$
- 6.7  $Q = 15000 \text{ L/min} \times 1.0 \text{ m}^3/\text{s}/60000 \text{ L/min} = 0.250 \text{ m}^3/\text{s}$
- 6.8  $Q = 459 \text{ gal/min} \times 3.785 \text{ L/min}/1.0 \text{ gal/min} = 1737 \text{ L/min}$
- 6.9  $Q = 8720 \text{ gal/min} \times 3.785 \text{ L/min}/1.0 \text{ gal/min} = 3.30 \times 10^4 \text{ L/min}$
- 6.10  $Q = 23.5 \text{ cm}^3/\text{s} \times \text{m}^3/(\text{100 cm})^3 = 2.35 \times 10^{-5} \text{ m}^3/\text{s}$
- 6.11  $Q = 0.296 \text{ cm}^3/\text{s} \times 1 \text{ m}^3/(\text{100 cm})^3 = 2.96 \times 10^{-7} \text{ m}^3/\text{s}$
- 6.12  $Q = 0.105 \text{ m}^3/\text{s} \times 60000 \text{ L/min}/1.0 \text{ m}^3/\text{s} = 6300 \text{ L/min}$
- 6.13  $Q = 3.58 \times 10^{-3} \text{ m}^3/\text{s} \times 60000 \text{ L/min}/1.0 \text{ m}^3/\text{s} = 215 \text{ L/min}$
- 6.14  $Q = 5.26 \times 10^{-6} \text{ m}^3/\text{s} \times 60000 \text{ L/min}/1.0 \text{ m}^3/\text{s} = 0.316 \text{ L/min}$
- 6.15  $Q = 459 \text{ gal/min} \times 1.0 \text{ ft}^3/\text{s}/449 \text{ gal/min} = 1.02 \text{ ft}^3/\text{s}$
- 6.16  $Q = 20 \text{ gal/min} \times 1.0 \text{ ft}^3/\text{s}/449 \text{ gal/min} = 4.45 \times 10^{-2} \text{ ft}^3/\text{s}$
- 6.17  $Q = 2500 \text{ gal/min} \times 1.0 \text{ ft}^3/\text{s}/449 \text{ gal/min} = 5.57 \text{ ft}^3/\text{s}$
- 6.18  $Q = 2.50 \text{ gal/min} \times 1.0 \text{ ft}^2/\text{s}/449 \text{ gal/min} = 5.57 \times 10^{-3} \text{ ft}^3/\text{s}$
- 6.19  $Q = 1.25 \text{ ft}^3/\text{s} \times 449 \text{ gal/min}/1.0 \text{ ft}^3/\text{s} = 561 \text{ gal/min}$
- 6.20  $Q = 0.06 \text{ ft}^3/\text{s} \times 449 \text{ gal/min}/1.0 \text{ ft}^3/\text{s} = 26.9 \text{ gal/min}$
- 6.21  $Q = 7.50 \text{ ft}^3/\text{s} \times 449 \text{ gal/min}/1.0 \text{ ft}^3/\text{s} = 3368 \text{ gal/min}$

$$6.22 \quad Q = 0.008 \text{ ft}^3/\text{s} \times 449 \text{ gal/min}/1.0 \text{ ft}^3/\text{s} = \mathbf{3.59 \text{ gal/min}}$$

$$6.23 \quad Q = 500 \text{ gal/min} \times 1.0 \text{ ft}^3/\text{s}/449 \text{ gal/min} = \mathbf{1.11 \text{ ft}^3/\text{s}}$$

$$Q = 2500/449 = \mathbf{5.57 \text{ ft}^3/\text{s}}$$

$$Q = 500 \text{ gal/min} \times 6.309 \times 10^{-5} \text{ m}^3/\text{s}/1.0 \text{ gal/min} = \mathbf{3.15 \times 10^{-2} \text{ m}^3/\text{s}}$$

$$Q = 2500(6.309 \times 10^{-5}) = \mathbf{0.158 \text{ m}^3/\text{s}}$$

$$6.24 \quad Q = 3.0 \text{ gal/min} \times 1.0 \text{ ft}^3/\text{s}/449 \text{ gal/min} = \mathbf{6.68 \times 10^{-3} \text{ ft}^3/\text{s}}$$

$$Q = 30.0/449 = \mathbf{6.68 \times 10^{-2} \text{ ft}^3/\text{s}}$$

$$Q = 3.0 \text{ gal/min} \times 6.309 \times 10^{-5} \text{ m}^3/\text{s}/1.0 \text{ gal/min} = \mathbf{1.89 \times 10^{-4} \text{ m}^3/\text{s}}$$

$$Q = 30(6.309 \times 10^{-5}) = \mathbf{1.89 \times 10^{-3} \text{ m}^3/\text{s}}$$

$$6.25 \quad Q = \frac{745 \text{ gal}}{\text{h}} \times \frac{1 \text{ h}}{60 \text{ min}} \times \frac{1.0 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = \mathbf{2.77 \times 10^{-2} \text{ ft}^3/\text{s}}$$

$$6.26 \quad Q = \frac{0.85 \text{ gal}}{\text{h}} \times \frac{1 \text{ h}}{60 \text{ min}} \times \frac{1.0 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = \mathbf{3.16 \times 10^{-5} \text{ ft}^3/\text{s}}$$

$$6.27 \quad Q = \frac{11.4 \text{ gal}}{24 \text{ h}} \times \frac{1 \text{ h}}{60 \text{ min}} \times \frac{1.0 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = \mathbf{1.76 \times 10^{-5} \text{ ft}^3/\text{s}}$$

$$6.28 \quad Q = \frac{19.5 \text{ mL}}{\text{min}} \times \frac{1.0 \text{ L}}{10^3 \text{ mL}} \times \frac{1.0 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = \mathbf{3.25 \times 10^{-7} \text{ m}^3/\text{s}}$$

### ***Fluid flow rates***

$$6.29 \quad W = \gamma Q = (9.81 \text{ kN/m}^3)(0.075 \text{ m}^3/\text{s}) = 0.736 \text{ kN/s}(10^3 \text{ N/kN}) = \mathbf{736 \text{ N/s}}$$

$$M = \rho Q = (1000 \text{ kg/m}^3)(0.075 \text{ m}^3/\text{s}) = \mathbf{75.0 \text{ kg/s}}$$

$$6.30 \quad W = \gamma Q = (0.90)(9.81 \text{ kN/m}^3)(2.35 \times 10^{-3} \text{ m}^3/\text{s}) = 2.07 \times 10^{-2} \text{ kN/s} = \mathbf{20.7 \text{ N/s}}$$

$$M = \rho Q = (0.90)(1000 \text{ kg/m}^3)(2.35 \times 10^{-3} \text{ m}^3/\text{s}) = \mathbf{2.115 \text{ kg/s}}$$

$$6.31 \quad Q = \frac{W}{\gamma} = \frac{28.5 \text{ N}}{\text{h}} \times \frac{\text{m}^3}{1.08(9.81 \text{ kN})} \times \frac{1.0 \text{ kN}}{10^3 \text{ N}} \times \frac{1.0 \text{ h}}{3600 \text{ s}} = \mathbf{7.47 \times 10^{-7} \text{ m}^3/\text{s}}$$

$$M = \rho Q = (1.08)(1000 \text{ kg/m}^3)(7.47 \times 10^{-7} \text{ m}^3/\text{s}) = \mathbf{8.07 \times 10^{-4} \text{ kg/s}}$$

$$6.32 \quad Q = \frac{W}{\gamma} = \frac{28.5 \text{ N}}{\text{h}} \times \frac{\text{m}^3}{12.50 \text{ N}} \times \frac{1 \text{ h}}{3600 \text{ s}} = \mathbf{6.33 \times 10^{-4} \text{ m}^3/\text{s}}$$

$$6.33 \quad M = \rho Q = \frac{1.20 \text{ kg}}{\text{m}^3} \times \frac{640 \text{ ft}^3}{\text{min}} \times \frac{1.0 \text{ slug}}{14.59 \text{ kg}} \times \frac{1 \text{ min}}{60 \text{ s}} \times \frac{0.0283 \text{ m}^3}{\text{ft}^3}$$

$$= \mathbf{2.48 \times 10^{-2} \text{ slug/s}}$$

$$M = \rho Q = \gamma Q/g = W/g$$

$$W = gM = \frac{32.2 \text{ ft}}{\text{s}^2} \times \frac{2.48 \times 10^{-2} \text{ slug}}{\text{s}} \times \frac{1 \text{ lb} \cdot \text{s}^2/\text{ft}}{\text{slug}} \times \frac{3600 \text{ s}}{\text{hr}} = \mathbf{2878 \text{ lb/hr}}$$

$$6.34 \quad W = \gamma Q = (0.075 \text{ lb/ft}^3)(45700 \text{ ft}^3/\text{min}) = \mathbf{3428 \text{ lb/min}}$$

$$M = \rho Q = \frac{\gamma Q}{g} = \frac{W}{g} = \frac{3428 \text{ lb/min}}{32.2 \text{ ft/s}^2} = \frac{106 \text{ lb} \cdot \text{s}^2/\text{ft}}{\text{min}} = \mathbf{106 \text{ slugs/min}}$$

$$6.35 \quad Q = \frac{W}{\gamma} = \frac{1200 \text{ lb}}{\text{hr}} \times \frac{\text{ft}^3}{0.062 \text{ lb}} \times \frac{1 \text{ hr}}{3600 \text{ s}} = \mathbf{5.38 \text{ ft}^3/\text{s}}$$

$$6.36 \quad W = \gamma Q = \frac{62.4 \text{ lb}}{\text{ft}^3} \times \frac{1.65 \text{ gal}}{\text{min}} \times \frac{1.0 \text{ ft}^3}{7.48 \text{ gal}} = 13.76 \text{ lb/min} = \frac{w}{t}$$

$$t = \frac{w}{W} = \frac{7425 \text{ lb min}}{13.76 \text{ lb}} \times \frac{1 \text{ hr}}{60 \text{ min}} = \mathbf{8.99 \text{ hr}}$$

**Continuity equation**

$$6.37 \quad Q = Av: A = \frac{Q}{v} = \frac{75.0 \text{ ft}^3/\text{s}}{10.0 \text{ ft/s}} = 7.50 \text{ ft}^2 = \frac{\pi D^2}{4}$$

$$D = \sqrt{4A/\pi} = \sqrt{4(7.50)/\pi} = \mathbf{3.09 \text{ ft}}$$

$$6.38 \quad A_1 v_1 = A_2 v_2; v_2 = v_1 \frac{A_1}{A_2} = v_1 \left( \frac{D_1}{D_2} \right)^2 = \frac{1.65 \text{ ft}}{\text{s}} \left( \frac{12}{3} \right)^2 = \mathbf{26.4 \text{ ft/s}}$$

$$6.39 \quad Q = 2000 \text{ L/min} \times \frac{1.0 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 0.0333 \text{ m}^3/\text{s}$$

$$v_1 = \frac{Q}{A_1} = \frac{0.0333 \text{ m}^3/\text{s}}{\pi(0.30 \text{ m})^2/4} = \mathbf{0.472 \text{ m/s}}$$

$$v_2 = \frac{Q}{A_2} = \frac{0.0333 \text{ m}^3/\text{s}}{\pi(0.15 \text{ m})^2/4} = \mathbf{1.89 \text{ m/s}}$$

$$6.40 \quad A_1 v_1 = A_2 v_2; v_2 = v_1 \frac{A_1}{A_2} = v_1 \left( \frac{D_1}{D_2} \right)^2 = 1.20 \text{ m/s} \left( \frac{150}{300} \right)^2 = \mathbf{0.300 \text{ m/s}}$$

$$6.41 \quad Q_1 = A_1 v_1 = A_2 v_2 + A_3 v_3 = Q_2 + Q_3$$

$$Q_2 = A_2 v_2 = \frac{\pi(0.050 \text{ m})^2}{4} \times 12.0 \text{ m/s} = 0.0236 \text{ m}^3/\text{s}$$

$$Q_3 = Q_1 - Q_2 = 0.072 - 0.0236 = 0.0484 \text{ m}^3/\text{s}$$

$$v_3 = \frac{Q_3}{A_3} = \frac{0.0484 \text{ m}^3/\text{s}}{\pi(0.100 \text{ m})^2/4} = \mathbf{6.17 \text{ m/s}}$$

$$6.42 \quad A_{\min} = \frac{Q}{v} = 10 \text{ gal/min} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} \times \frac{1}{1.0 \text{ ft/s}} = 0.02227 \text{ ft}^2: \mathbf{2\text{-in Sch. 40 pipe}}$$

$$6.43 \quad W = \gamma Q = \gamma A v = \frac{60.6 \text{ lb}}{\text{ft}^3} \times 0.2006 \text{ ft}^2 \times \frac{4.50 \text{ ft}}{\text{s}} \times \frac{3600 \text{ s}}{\text{hr}} = 1.97 \times 10^5 \text{ lb/h}$$

$$6.44 \quad v = \frac{Q}{A} = 19.7 \text{ L/min} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} \times \frac{1}{3.835 \times 10^{-4} \text{ m}^2} = 0.856 \text{ m/s}$$

$$6.45 \quad Q = 30 \text{ gal/min} \times 1.0 \text{ ft}^3/\text{s}/449 \text{ gal/min} = 0.0668 \text{ ft}^3/\text{s}$$

$$A_1 = \frac{Q}{v_1} = \frac{0.0668 \text{ ft}^3/\text{s}}{8.0 \text{ ft/s}} = 8.35 \times 10^{-3} \text{ ft}^2 \text{ max.}$$

$$1 \text{ 1/4} \times 0.065 \text{ tube} \rightarrow A_1 = 6.842 \times 10^{-3} \text{ ft}^2$$

$$\text{Actual } v_1 = Q/A_1 = (0.0668 \text{ ft}^3/\text{s})/(6.842 \times 10^{-3} \text{ ft}^2) = 9.77 \text{ ft/s}$$

$$A_2 = \frac{Q}{v_2} = \frac{0.0668 \text{ ft}^3/\text{s}}{25.0 \text{ ft/s}} = 2.67 \times 10^{-3} \text{ ft}^2 \text{ min.}$$

$$7/8 \times 0.065 \text{ tube} \rightarrow A_2 = 3.027 \times 10^{-3} \text{ ft}^2$$

$$\text{Actual } v_2 = Q/A_2 = (0.0668 \text{ ft}^3/\text{s})/(3.027 \times 10^{-3} \text{ ft}^2) = 22.07 \text{ ft/s}$$

$$6.46 \quad A_1 = \frac{Q}{v_1} = \frac{0.0668 \text{ ft}^3/\text{s}}{2.0 \text{ ft/s}} = 3.34 \times 10^{-2} \text{ ft}^2 \text{ max.}$$

$$2\text{-in} \times 0.065 \text{ is largest tube listed} \rightarrow A_1 = 1.907 \times 10^{-2} \text{ ft}^2$$

$$\text{Actual } v_1 = Q/A_1 = (0.0668 \text{ ft}^3/\text{s})/(1.907 \times 10^{-2} \text{ ft}^2) = 3.50 \text{ ft/s}$$

$$A_2 = \frac{Q}{v_2} = \frac{0.0668 \text{ ft}^3/\text{s}}{7.0 \text{ ft/s}} = 9.54 \times 10^{-3} \text{ ft}^2 \text{ min.}$$

$$1 \text{ 1/2-in} \times 0.083 \text{ tube} \rightarrow A_2 = 9.706 \times 10^{-3} \text{ ft}^2$$

$$\text{Actual } v_2 = Q/A_2 = (0.0668 \text{ ft}^3/\text{s})/(9.706 \times 10^{-3} \text{ ft}^2) = 6.88 \text{ ft/s}$$

$$6.47 \quad Q_L = 1800 \text{ L/min} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 0.030 \text{ m}^3/\text{s}$$

$$A_L = \frac{Q_L}{v} = \frac{0.030 \text{ m}^3/\text{s}}{2.0 \text{ m/s}} = 0.015 \text{ m}^2 \text{ minimum; } 6\text{-in Sch 40; } A = 1.864 \times 10^{-2} \text{ m}^2$$

$$Q_H = 9500/60000 = 0.1583 \text{ m}^3/\text{s}$$

$$A_H = \frac{Q_H}{v} = \frac{0.1583}{2.0} = 7.916 \times 10^{-2} \text{ m}^2; 14\text{-in Sch 40; } A = 8.729 \times 10^{-2} \text{ m}^2$$

$$6.48 \quad \text{For } A_L = 0.015 \text{ m}^2 \text{ min; } 6\text{-in Sch 80; } A = 1.682 \times 10^{-2} \text{ m}^2$$

$$\text{For } A_H = 7.916 \times 10^{-2} \text{ m}^2 \text{ min; } 14\text{-in Sch 80; } A = 7.916 \times 10^{-2} \text{ m}^2$$

$$6.49 \quad v = \frac{Q}{A} = \frac{400 \text{ L/min}}{2.168 \times 10^{-3} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 3.075 \text{ m/s} \text{ [2-in Sch 40 pipe]}$$

$$6.50 \quad 2\text{-in Sch 80: } v = \frac{Q}{A} = \frac{400}{(1.905 \times 10^{-3})(60000)} = 3.500 \text{ m/s}$$

$$6.51 \quad v = \frac{Q}{A} = \frac{400 \text{ gal/min}}{0.0884 \text{ ft}^2} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = \mathbf{10.08 \text{ ft/s [4-in Sch 40]}}$$

$$6.52 \quad v = \frac{Q}{A} = \frac{400}{(0.07986)(449)} = \mathbf{11.16 \text{ ft/s [4-in Sch 80]}}$$

$$6.53 \quad A = \frac{Q}{v} = \frac{2.80 \text{ L/min}}{0.30 \text{ m/s}} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 1.556 \times 10^{-4} \text{ m}^2 \text{ min.}$$

**3/4 × 0.065 steel tube,  $A = 1.948 \times 10^{-4} \text{ m}^2$**

$$6.54 \quad v_{6\text{-in}} = \frac{Q_6}{A_6} = \frac{95 \text{ gal/min}}{0.2006 \text{ ft}^2} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = \mathbf{1.055 \text{ ft/s}}$$

$$v_{3\text{-in}} = \frac{Q_3}{A_3} = \frac{0.5Q_6}{A_3} = \frac{(0.5)(95)}{(0.05132)(449)} = \mathbf{2.061 \text{ ft/s}}$$

$$6.55 \quad Q = 800 \text{ gal/min}(1 \text{ ft}^3/\text{s}/449 \text{ gal/min}) = 1.782 \text{ ft}^3/\text{s}$$

Suction pipe: 5 in Sch 40;  $A_s = 0.1390 \text{ ft}^2$ ;  $v_s = Q/A = 12.82 \text{ ft/s}$   
6 in Sch 40;  $A_s = 0.2006 \text{ ft}^2$ ;  $v_s = Q/A = 8.88 \text{ ft/s}$   
Discharge pipe: 3 1/2 in Sch 40;  $A_d = 0.06868 \text{ ft}^2$ ;  $v_d = Q/A = 25.94 \text{ ft/s}$   
4 in Sch 40;  $A_d = 0.08840 \text{ ft}^2$ ;  $v_d = Q/A = 20.15 \text{ ft/s}$

$$6.56 \quad Q = 2000 \text{ gal/min}(1 \text{ ft}^3/\text{s}/449 \text{ gal/min}) = 4.454 \text{ ft}^3/\text{s}$$

Suction pipe: 6 in Sch 40;  $A_s = 0.2006 \text{ ft}^2$ ;  $v_s = Q/A = 22.21 \text{ ft/s}$   
8 in Sch 40;  $A_s = 0.3472 \text{ ft}^2$ ;  $v_s = Q/A = 12.83 \text{ ft/s}$   
Discharge pipe: 5 in Sch 40;  $A_d = 0.1390 \text{ ft}^2$ ;  $v_d = Q/A = 32.05 \text{ ft/s}$   
6 in Sch 40;  $A_d = 0.2006 \text{ ft}^2$ ;  $v_d = Q/A = 22.21 \text{ ft/s}$

$$6.57 \quad Q = 60 \text{ m}^3/\text{h}(1 \text{ h}/3600 \text{ s}) = 0.01667 \text{ m}^3/\text{s}$$

Suction pipe: 3 in Sch 40;  $A_s = 4.768 \times 10^{-3} \text{ m}^2$ ;  $v_s = Q/A = 3.73 \text{ m/s}$   
3 1/2 in Sch 40;  $A_s = 6.381 \times 10^{-3} \text{ m}^2$ ;  $v_s = Q/A = 2.61 \text{ m/s}$   
Discharge pipe: 2 in Sch 40;  $A_d = 2.168 \times 10^{-3} \text{ m}^2$ ;  $v_d = Q/A = 7.69 \text{ m/s}$   
2 1/2 in Sch 40;  $A_d = 3.090 \times 10^{-3} \text{ m}^2$ ;  $v_d = Q/A = 5.39 \text{ m/s}$

$$6.58 \quad Q = Av = (7.538 \times 10^{-3} \text{ m}^3)(3.0 \text{ m/s}) = 2.261 \times 10^{-2} \text{ m}^3/\text{s}$$

$$A = \frac{Q}{v} = \frac{2.261 \times 10^{-2} \text{ m}^3/\text{s}}{15.0 \text{ m/s}} = 1.508 \times 10^{-3} \text{ m}^2 = \pi D_i^2/4$$

$$D_i = \sqrt{4A/\pi} = \sqrt{4(1.508 \times 10^{-3} \text{ m}^2)/\pi} = 4.38 \times 10^{-2} \text{ m} \times \frac{10^3 \text{ mm}}{\text{m}} = \mathbf{43.8 \text{ mm}}$$

$$6.59 \quad v_p = \frac{Q}{A_p} = \frac{7.50 \text{ ft}^3/\text{s}}{0.9396 \text{ ft}^2} = \mathbf{7.98 \text{ ft/s in pipe}}$$

$$v_n = \frac{Q}{A_n} = \frac{7.50 \text{ ft}^3/\text{s}}{\frac{\pi(4.60 \text{ in})^2}{4} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2}} = \mathbf{65.0 \text{ ft/s in nozzle}}$$

**Bernoulli's equation**

$$6.60 \quad \frac{p_1}{\gamma_G} + z_1 + \frac{v_1^2}{2g} = \frac{p_2}{\gamma_G} + z_2 + \frac{v_2^2}{2g}; \quad z_1 = z_2$$

$$v_1 = \frac{Q}{A_1} = \frac{0.11 \text{ m}^3/\text{s}}{\pi(0.15 \text{ m})^2/4} = \frac{6.22 \text{ m}}{\text{s}}; \quad v_2 = v_1 \left( \frac{D_1}{D_2} \right)^2 = \frac{24.90 \text{ m}}{\text{s}}$$

$$p_2 = p_1 + \left[ \frac{v_1^2 - v_2^2}{2g} \right] \gamma_G = 415 \text{ kPa} + \frac{[6.22^2 - 24.90^2] \text{ m}^2/\text{s}^2}{2(9.81 \text{ m/s}^2)} \times \frac{0.67(9.81 \text{ kN})}{\text{m}^3}$$
$$= \mathbf{220 \text{ kPa}}$$

$$6.61 \quad \frac{p_A}{\gamma_w} + z_A + \frac{v_A^2}{2g} = \frac{p_B}{\gamma_w} + z_B + \frac{v_B^2}{2g}; \quad v_A = \frac{Q}{A_A} = \frac{0.37 \text{ m}^3/\text{s}}{\pi(0.3 \text{ m})^2/4} = \frac{5.23 \text{ m}}{\text{s}};$$

$$v_B = v_A \left( \frac{D_A}{D_B} \right)^2 = \frac{1.31 \text{ m}}{\text{s}}$$

$$p_B = p_A + \gamma_w \left[ (z_A - z_B) + \frac{v_A^2 - v_B^2}{2g} \right]$$
$$= 66.2 \text{ kPa} + \frac{9.81 \text{ kN}}{\text{m}^3} \left[ -4.5 + \frac{(5.23^2 - 1.31^2) \text{ m}^2/\text{s}^2}{2(9.81 \text{ m/s}^2)} \right]$$

$$p_B = 66.2 \text{ kPa} - 31.3 \text{ kPa} = \mathbf{34.9 \text{ kPa}}$$

6.62 Pt. A at gage; Pt. B outside nozzle:  $\frac{p_A}{\gamma} + z_A + \frac{v_A^2}{2g} = \frac{p_B}{\gamma} + z_B + \frac{v_B^2}{2g}$ ;  $p_B = 0$

$$\frac{v_A^2 - v_B^2}{2g} = (z_B - z_A) - \frac{p_A}{\gamma} = 3.65 \text{ m} - \frac{565 \text{ kN}}{\text{m}^2(9.81 \text{ kN/m}^3)} = -53.94 \text{ m}$$

$$v_B = v_A(A_A/A_B) = v_A(D_A/D_B)^2 = v_A(70/35)^2 = 4v_A; v_B^2 = 16v_A^2;$$

$$v_A^2 - v_B^2 = -15v_A^2$$

$$-15v_A^2 = 2g(-53.94 \text{ m})$$

$$v_A = \sqrt{\frac{2g(53.94 \text{ m})}{15}} = \sqrt{\frac{2(9.81 \text{ m/s}^2)(53.94 \text{ m})}{15}} = 8.40 \text{ m/s}$$

$$Q = A_A v_A = \frac{\pi(.070 \text{ m})^2}{4} \times 8.40 \text{ m/s} = 0.0323 \text{ m}^3/\text{s} = \mathbf{3.23 \times 10^{-2} \text{ m}^3/\text{s}}$$

6.63 Pt. A before nozzle; Pt. B outside nozzle:  $\frac{p_A}{\gamma} + z_A + \frac{v_A^2}{2g} = \frac{p_B}{\gamma} + z_B + \frac{v_B^2}{2g}$ ;  $p_B = 0, z_A = z_B$

$$p_A = \gamma \left[ \frac{v_B^2 - v_A^2}{2g} \right] = \frac{60.6 \text{ lb}}{\text{ft}^3} \left[ \frac{(75^2 - 42.19^2) \text{ ft}^2/\text{s}^2}{2(32.2 \text{ ft/s}^2)} \right] \frac{1 \text{ ft}^2}{144 \text{ in}^2} = \mathbf{25.1 \text{ psig}}$$

$$v_B = 75 \text{ ft/s}; v_A = v_B \frac{A_B}{A_A} = 75 \left( \frac{D_B}{D_A} \right)^2 = 75 \left( \frac{.75}{1.0} \right)^2 = 42.19 \text{ ft/s}$$

6.64  $Q = 10 \text{ gal/min} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = \frac{0.0223 \text{ ft}^3}{\text{s}}; v_A = \frac{Q}{A_A} = \frac{0.0223 \text{ ft}^3/\text{s}}{0.0060 \text{ ft}^2} = \frac{3.71 \text{ ft}}{\text{s}}$

$$v_B = \frac{Q}{A_B} = \frac{0.0223}{0.02333} = \frac{0.955 \text{ ft}}{\text{s}}; \frac{p_A}{\gamma_K} + z_A + \frac{v_A^2}{2g} = \frac{p_B}{\gamma_K} + z_B + \frac{v_B^2}{2g}; z_A = z_B$$

$$p_A - p_B = \gamma_K \left[ \frac{v_B^2 - v_A^2}{2g} \right] = \frac{50 \text{ lb}}{\text{ft}^3} \left[ \frac{(0.955^2 - 3.71^2) \text{ ft}^2}{2(32.2 \text{ ft/s}^2)} \right] \frac{1 \text{ ft}^2}{144 \text{ in}^2} = \mathbf{-0.0694 \text{ psi}}$$

6.65 Pt. 1 at water surface; Pt. 2 outside nozzle.

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}; p_1 = 0, v_1 = 0, p_2 = 0$$

$$v_2 = \sqrt{2g(z_1 - z_2)} = \sqrt{2(9.81 \text{ m/s}^2)(6.0 \text{ m})} = 10.85 \text{ m/s}$$

$$Q = A_2 v_2 = \frac{\pi(0.050 \text{ m})^2}{4} \times 10.85 \text{ m/s} = \mathbf{2.13 \times 10^{-2} \text{ m}^3/\text{s}}$$

$$v_A = \frac{Q}{A_A} = \frac{0.0213 \text{ m}^3/\text{s}}{\pi(.15 \text{ m})^2/4} = 1.206 \text{ m/s}; \frac{v_A^2}{2g} = \frac{1.1206^2 \text{ m}^2/\text{s}^2}{2(9.81 \text{ m/s}^2)} = 0.0741 \text{ m}$$

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} = \frac{p_A}{\gamma} + z_A + \frac{v_A^2}{2g}; p_1 = 0, v_1 = 0$$

$$p_A = \gamma_w \left[ (z_1 - z_A) - \frac{v_A^2}{2g} \right] = \frac{9.81 \text{ kN}}{\text{m}^3} [6.0 \text{ m} - 0.0741 \text{ m}] = \mathbf{58.1 \text{ kPa}}$$

6.66 Pt. 1 at oil surface; Pt. 2 outside nozzle.

$$\frac{p_1}{\gamma_o} + z_1 + \frac{v_1^2}{2g} = \frac{p_2}{\gamma_o} + z_2 + \frac{v_2^2}{2g}; \quad p_1 = 0, v_1 = 0, p_2 = 0$$

$$v_2 = \sqrt{2g(z_1 - z_2)} = \sqrt{2(9.81 \text{ m/s}^2)(3.0 \text{ m})} = 7.67 \text{ m/s}$$

$$Q = A_2 v_2 = \frac{\pi(.035 \text{ m})^2}{4} \times \frac{7.67 \text{ m}}{\text{s}} = \frac{7.38 \times 10^{-3} \text{ m}^3}{\text{s}}$$

$$v_A = v_B = \frac{Q}{A_A} = \frac{7.38 \times 10^{-3} \text{ m}^3/\text{s}}{\pi(0.10 \text{ m})^2/4} = \frac{0.940 \text{ m}}{\text{s}}; \quad \frac{v_A^2}{2g} = \frac{v_B^2}{2g} = \frac{0.94^2 \text{ m}^2/\text{s}^2}{2(9.81 \text{ m/s}^2)} = 0.0450 \text{ m}$$

$$\frac{p_1}{\gamma_o} + z_1 + \frac{v_1^2}{2g} = \frac{p_A}{\gamma_o} + z_A + \frac{v_A^2}{2g}; \quad p_1 = 0, v_1 = 0$$

$$p_A = \gamma_o \left[ (z_1 - z_A) - \frac{v_A^2}{2g} \right] = (0.85) \left( \frac{9.81 \text{ m}}{\text{s}^2} \right) [4.0 - 0.045] \text{ m} = 33.0 \text{ kPa}$$

$$\frac{p_1}{\gamma_o} + z_1 + \frac{v_1^2}{2g} = \frac{p_B}{\gamma_o} + z_B + \frac{v_B^2}{2g}; \quad p_1 = 0, v_1 = 0$$

$$p_B = \gamma_o \left[ (z_1 - z_B) - \frac{v_B^2}{2g} \right] = (0.85)(9.81)[3.0 - 0.045] = 24.6 \text{ kPa}$$

6.67  $\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$ : Pt. 1 at water surface; Pt. 2 outside nozzle;  $v_1 = 0, p_2 = 0$

$$v_2 = \sqrt{2g(p_1/\gamma + z_1 - z_2)} = \sqrt{2 \left( \frac{32.2 \text{ ft}}{\text{s}^2} \right) \left[ \frac{20 \text{ lb ft}^3}{\text{in}^2} \frac{144 \text{ in}^2}{62.4 \text{ lb ft}^2} + 8.0 \text{ ft} \right]} = 59.06 \text{ ft/s}$$

$$Q = A_2 v_2 = \frac{\pi(3 \text{ in})^2}{4} \times \frac{59.06 \text{ ft}}{\text{s}} \times \frac{\text{ft}^2}{144 \text{ in}^2} = 2.90 \text{ ft}^3/\text{s}$$

6.68  $\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$ : Pt. 1 at water surface; Pt. 2 outside nozzle;  $v_1 = 0, p_2 = 0$

$$p_1 = \gamma \left[ (z_2 - z_1) + \frac{v_2^2}{2g} \right] = \frac{62.4 \text{ lb}}{\text{ft}^3} \left[ -10 \text{ ft} + \frac{(20)^2 \text{ ft}^2/\text{s}^2}{2(32.2 \text{ ft/s}^2)} \right] \frac{1 \text{ ft}^2}{144 \text{ in}^2} = -1.64 \text{ psig}$$

6.69  $\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$ : Pt. 1 at water surface; Pt. 2 outside nozzle;

$$p_1 = p_2 = 0, v_1 = 0$$

$$v_2 = \sqrt{2g(z_1 - z_2)} = \sqrt{2(9.81 \text{ m/s}^2)(4.6 \text{ m})} = 9.50 \text{ m/s}$$

$$Q = A_2 v_2 = \frac{\pi(.025 \text{ m})^2}{4} \times 9.50 \text{ m/s} = 4.66 \times 10^{-3} \text{ m}^3/\text{s}$$

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} = \frac{p_A}{\gamma} + z_A + \frac{v_A^2}{2g}; \quad p_1 = 0, v_1 = 0, z_1 = z_A$$

$$v_A = v_B = v_2 \frac{A_2}{A_A} = v_2 \left( \frac{D_2}{D_A} \right)^2 = v_2/4 = 2.375 \text{ m/s}$$

$$p_A = \gamma \left[ \frac{-v_A^2}{2g} \right] = \frac{9.81 \text{ kN}}{\text{m}^3} \left[ \frac{-(2.375)^2 \text{ m}^2/\text{s}^2}{2(9.81 \text{ m/s}^2)} \right] = \mathbf{-2.82 \text{ kPa}}$$

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} = \frac{p_B}{\gamma} + z_B + \frac{v_B^2}{2g}; \quad p_1 = 0, v_1 = 0$$

$$p_B = \gamma \left[ (z_1 - z_B) - \frac{v_B^2}{2g} \right] = 9.81 \left[ -0.90 - \frac{(2.375)^2}{2(9.81)} \right] = \mathbf{-11.65 \text{ kPa}}$$

6.70 (See Prob. 6.69)  $v_2 = \frac{Q}{A_2} = \frac{7.1 \times 10^{-3} \text{ m}^3/\text{s}}{\pi(.025 \text{ m})^2/4} = 14.46 \text{ m/s}$

$$z_1 - z_2 = X = \frac{v_2^2}{2g} = \frac{(14.46)^2 \text{ m}^2/\text{s}^2}{2(9.81 \text{ m/s}^2)} = \mathbf{10.66 \text{ m}}$$

6.71 (See Prob. 6.69)  $v_B = \frac{Q}{A_B} = \frac{5.6 \times 10^{-3} \text{ m}^3/\text{s}}{\pi(.05 \text{ m})^2/4} = 2.85 \text{ m/s}$

Minimum pressure exists at B, highest point in system.

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} = \frac{p_B}{\gamma} + z_B + \frac{v_B^2}{2g}; \quad p_1 = 0, v_1 = 0$$

$$z_B - z_1 = Y = \frac{-p_B}{\gamma} - \frac{v_B^2}{2g} = \frac{-(-18 \text{ kN})}{\text{m}^2(9.81 \text{ kN/m}^3)} - \frac{(2.85)^2 \text{ m}^2/\text{s}^2}{2(9.81 \text{ m/s}^2)} = \mathbf{1.42 \text{ m}}$$

6.72 Analysis for  $v_2$ ,  $Q$ ,  $p_A$ ,  $p_B$  same as Prob. 6.69.

$$v_2 = \sqrt{2g(z_1 - z_2)} = \sqrt{2(9.81)(10)} = 14.01 \text{ m/s}$$

$$Q = A_2 v_2 = \frac{\pi(.025)^2}{4} \times 14.01 = 6.88 \times 10^{-3} \text{ m}^3/\text{s}$$

$$\left. \begin{aligned} v_A = v_B = v_C = v_D = v_2/4 \\ v_A = 3.502 \text{ m/s} \end{aligned} \right\}$$

$$p_A = \gamma_o \left[ \frac{-v_A^2}{2g} \right] = (0.86)(9.81) \left[ \frac{-(3.502)^2}{2(9.81)} \right] = (8.437)[-0.625] = \mathbf{-5.27 \text{ kPa}}$$

$$p_B = \gamma_o \left[ (z_1 - z_B) - \frac{v_B^2}{2g} \right] = (8.437)[-3.0 - 0.625] = \mathbf{-30.58 \text{ kPa}}$$

$$p_C = p_A = \mathbf{-5.27 \text{ kPa}}$$

$$\frac{p_1}{\gamma_o} + z_1 + \frac{v_1^2}{2g} = \frac{p_D}{\gamma_o} + z_D + \frac{v_D^2}{2g}; p_1 = 0, v_1 = 0$$

$$p_D = \gamma_o \left[ (z_1 - z_D) - \frac{v_D^2}{2g} \right] = (8.437)[10.0 - 0.625] = 79.1 \text{ kPa}$$

$$6.73 \quad \frac{p_A}{\gamma} + z_A + \frac{v_A^2}{2g} = \frac{p_B}{\gamma} + z_B + \frac{v_B^2}{2g}; z_A = z_B$$

$$\frac{v_A^2 - v_B^2}{2g} = \frac{p_B - p_A}{\gamma_w} = \frac{(42 - 50) \text{ lb ft}^3 (144 \text{ in}^2)}{\text{in}^2 (62.4 \text{ lb})\text{ft}^2} = -18.46 \text{ ft}$$

$$v_A = v_B \frac{A_B}{A_A} = v_B \left( \frac{D_B}{D_A} \right)^2 = v_B \left( \frac{1}{2} \right)^2 = 0.25v_B; v_A^2 = 0.0625 v_B^2$$

$$0.0625v_B^2 - v_B^2 = 2g(-18.46 \text{ ft})$$

$$-0.9375v_B^2 = 2g(-18.46 \text{ ft})$$

$$v_B = \sqrt{\frac{2(32.2 \text{ ft})(-18.46 \text{ ft})}{s^2(-0.9375)}} = 35.6 \text{ ft/s}$$

$$6.74 \quad \frac{p_A}{\gamma_o} + z_A + \frac{v_A^2}{2g} = \frac{p_B}{\gamma_o} + z_B + \frac{v_B^2}{2g}; z_A = z_B$$

$$\frac{v_A^2 - v_B^2}{2g} = \frac{p_B - p_A}{\gamma_o} = \frac{(28.2 - 25.6) \text{ lb ft}^3 (144 \text{ in}^2)}{\text{in}^2 (0.90)(62.4 \text{ lb})\text{ft}^2} = 6.667 \text{ ft}$$

$$v_A = v_B \frac{A_B}{A_A} = v_B \left( \frac{D_B}{D_A} \right)^2 = v_B \left( \frac{8}{5} \right)^2 = 2.56v_B; v_A^2 = 6.55v_B^2$$

$$6.55v_B^2 - v_B^2 = 2g(6.667 \text{ ft})$$

$$5.55v_B^2 = 2g(6.667 \text{ ft})$$

$$v_B = \sqrt{\frac{2(32.2)(6.667)}{5.55}} \text{ ft/s} = 8.79 \text{ ft/s}$$

$$Q = A_B v_B = \frac{\pi(8 \text{ in})^2}{4} \times \frac{8.79 \text{ ft}}{\text{s}} \times \frac{\text{ft}^2}{144 \text{ in}^2} = 3.07 \text{ ft}^3/\text{s}$$

$$6.75 \quad \frac{p_A}{\gamma_w} + z_A + \frac{v_A^2}{2g} = \frac{p_B}{\gamma_w} + z_B + \frac{v_B^2}{2g}; \quad z_A = z_B$$

$$\frac{p_A - p_B}{\gamma_w} = \frac{v_B^2 - v_A^2}{2g} = \frac{[v_A(A_A/A_B)]^2 - v_A^2}{2g} = \frac{[v_A(D_A/D_B)]^2 - v_A^2}{2g}$$

$$= \frac{16v_A^2 - v_A^2}{2g} = \frac{15v_A^2}{2g}$$

Manometer:  $p_A + \gamma_w y + \gamma_w h - \gamma_m h - \gamma_w y = p_B$  [cancel terms with  $y$ ]

$$p_A - p_B = \gamma_m h - \gamma_w h = h(\gamma_m - \gamma_w) = h(13.54\gamma_w - \gamma_w) = h(12.54\gamma_w)$$

$$\frac{p_A - p_B}{\gamma_w} = 12.54h = \frac{15v_A^2}{2g}$$

$$v_A = \sqrt{\frac{2g(12.54)(h)}{15}} = \sqrt{\frac{2(9.81 \text{ m})(12.54)(0.250 \text{ m})}{s^2(15)}} = 2.025 \text{ m/s}$$

$$Q = A_A v_A = [\pi(.050 \text{ m})^2/4](2.025 \text{ m/s}) = 3.98 \times 10^{-3} \text{ m}^3/\text{s}$$

$$6.76 \quad (\text{See Prob. 6.75}) \quad v_A = v_B \left( \frac{A_B}{A_A} \right) = v_B \left( \frac{D_B}{D_A} \right)^2 = 0.25v_B = 0.25(10) = 2.50 \text{ m/s}$$

$$12.54h = \frac{15v_A^2}{2g} = \frac{15(2.50)^2 \text{ m}^2/\text{s}^2}{2(9.81 \text{ m/s}^2)} = 4.778 \text{ m}$$

$$h = 4.778 \text{ m}/12.54 = 0.381 \text{ m}$$

$$6.77 \quad \left. \begin{array}{l} \frac{p_A}{\gamma_o} + z_A + \frac{v_A^2}{2g} = \frac{p_B}{\gamma_o} + z_B + \frac{v_B^2}{2g} \\ \frac{v_A^2 - v_B^2}{2g} = \frac{p_B - p_A}{\gamma_o} + (z_B - z_A) \end{array} \right\} \begin{array}{l} v_B = v_A \frac{A_A}{A_B} = v_A \left( \frac{D_A}{D_B} \right)^2 = v_A \left( \frac{100}{50} \right)^2 = 4v_A \\ v_B^2 = 16v_A^2 \\ v_A^2 - v_B^2 = v_A^2 - 16v_A^2 = -15v_A^2 \end{array}$$

Manometer:  $p_A + \gamma_o(0.35 \text{ m}) - \gamma_w(0.20 \text{ m}) - \gamma_o(0.75 \text{ m}) = p_B$

$$p_B - p_A = -\gamma_w(0.20 \text{ m}) - \gamma_o(0.40 \text{ m})$$

$$\frac{p_B - p_A}{\gamma_o} = \frac{-\gamma_w(0.20 \text{ m})}{\gamma_o} - 0.40 = \frac{-9.81(0.20 \text{ m})}{8.64} - 0.40 \text{ m} = -0.627 \text{ m}$$

$$z_B - z_A = 0.60$$

$$-15v_A^2 = 2g[-0.627 \text{ m} + 0.60 \text{ m}] = 2g(-0.027 \text{ m})$$

$$v_A = \sqrt{2(9.81 \text{ m/s}^2)(-0.027 \text{ m})/-15} = 0.188 \text{ m/s}$$

$$Q = A_A v_A = \frac{\pi(0.10 \text{ m})^2}{4} \times 0.188 \text{ m/s} = 1.48 \times 10^{-3} \text{ m}^3/\text{s}$$

$$6.78 \quad \frac{v_A^2 - v_B^2}{2g} = \frac{p_B - p_A}{\gamma_w} + (z_B - z_A) \quad \left| \quad v_B = v_A \left( \frac{D_A}{D_B} \right)^2 = v_A \left( \frac{200}{75} \right)^2 = 7.11 v_A \right.$$

$$z_B - z_A = 0.25 \text{ m} \quad \left| \quad v_B^2 = 50.6 v_A^2 \right.$$

$$\left. \quad v_A^2 - v_B^2 = v_A^2 - 50.6 v_A^2 = -49.6 v_A^2 \right.$$

Manometer:  $p_A + \gamma_o y + \gamma_o(0.60 \text{ m}) - \gamma_G(0.60 \text{ m}) - \gamma_o y - \gamma_o(0.25 \text{ m}) = p_B$   
 $p_B - p_A = \gamma_o(0.35 \text{ m}) - \gamma_G(0.60 \text{ m})$

$$\frac{p_B - p_A}{\gamma_o} = 0.35 - \frac{(1.40)(9.81 \text{ kN/m}^3)(0.60 \text{ m})}{(0.90)(9.81 \text{ kN/m}^3)} = -0.583 \text{ m}$$

$$-49.6 v_A^2 = 2g[-0.583 \text{ m} + 0.25 \text{ m}] = 2g(-0.333 \text{ m})$$

$$v_A = \sqrt{2(9.81 \text{ m/s}^2)(-0.333 \text{ m})/(-49.6)} = 0.363 \text{ m/s}$$

$$Q = A_A v_A = [\pi(0.20 \text{ m})^2/4](0.363 \text{ m/s}) = 1.14 \times 10^{-2} \text{ m}^3/\text{s}$$

$$6.79 \quad \frac{p_A}{\gamma_o} + z_A + \frac{v_A^2}{2g} = \frac{p_B}{\gamma_o} + z_B + \frac{v_B^2}{2g} \quad \left| \quad \text{Let } z_A - z_B = X \right.$$

$$\text{Let } y = \text{Distance from B to surface of Mercury.}$$

$$\textcircled{1} \quad \frac{p_A - p_B}{\gamma_o} + z_A - z_B = \frac{v_B^2 - v_A^2}{2g} \quad \left| \quad v_B = v_A \frac{A_A}{A_B} = v_A \left( \frac{D_A}{D_B} \right)^2 = v_A \left( \frac{4}{2} \right)^2 = 4v_A \right.$$

Manometer:  $p_B + \gamma_o y + \gamma_m h - \gamma_o h - \gamma_o y - \gamma_o X = p_A$  [cancel terms with  $y$ ]

$$\frac{p_A - p_B}{\gamma_o} = \frac{\gamma_m h}{\gamma_o} - h - X = \frac{13.54 \gamma_w \cdot h}{0.90 \gamma_w} - h - X = 14.04h - X$$

$$\text{In } \textcircled{1}: 14.04h - X + X = \frac{16v_A^2 - v_A^2}{2g} = \frac{15v_A^2}{2g}$$

$$v_A = \sqrt{\frac{2g(14.04)(h)}{15}} = \sqrt{\frac{2(32.2 \text{ ft/s}^2)(14.04)(28 \text{ in})}{15(12 \text{ in/ft})}} = 11.86 \text{ ft/s}$$

$$Q = A_A v_A = \frac{\pi(4 \text{ in})^2}{4} \times \frac{11.86 \text{ ft}}{\text{s}} \times \frac{\text{ft}^2}{144 \text{ in}^2} = 1.035 \text{ ft}^3/\text{s}$$

6.80 (See also Prob. 6.79)  $v_A = v_B/4 = 10.0 \text{ ft/s}/4 = 2.50 \text{ ft/s}$

$$14.04h = 15v_A^2 / 2g$$

$$h = \frac{15(2.50 \text{ ft/s})^2}{2(32.2 \text{ ft/s}^2)(14.04)} = 0.1037 \text{ ft} \times \frac{12 \text{ in}}{\text{ft}} = 1.24 \text{ in}$$

$$6.81 \quad \frac{p_A}{\gamma} + z_A + \frac{v_A^2}{2g} = \frac{p_B}{\gamma} + z_B + \frac{v_B^2}{2g} \quad \left| \quad v_A = \frac{Q}{A_A} = \frac{4.0 \text{ ft}^3/\text{s}}{\pi(6 \text{ in})^2/4} \cdot \frac{144 \text{ in}^2}{\text{ft}^2} = 20.37 \text{ ft/s} \right.$$

$$p_B = p_A + \gamma \left[ \frac{v_A^2 - v_B^2}{2g} \right] \quad \left. v_B = v_A \cdot \left( \frac{D_A}{D_B} \right)^2 = 4v_A = 81.49 \text{ ft/s} \right.$$

$$p_B = 60.0 \text{ psig} + (0.67) \left( \frac{62.4 \text{ lb}}{\text{ft}^3} \right) \left[ \frac{(20.37^2 - 81.49^2) \text{ ft}^2/\text{s}^2}{2(32.2 \text{ ft/s}^2)} \right] \frac{1 \text{ ft}^2}{144 \text{ in}^2} = \mathbf{31.94 \text{ psig}}$$

$$6.82 \quad \frac{p_A}{\gamma_o} + z_A + \frac{v_A^2}{2g} = \frac{p_B}{\gamma_o} + z_B + \frac{v_B^2}{2g} \quad \left| \quad v_B = v_A \cdot \frac{A_A}{A_B} = v_A \cdot \frac{0.08840 \text{ ft}^2}{0.02333 \text{ ft}^2} = 3.789v_A \right.$$

$$\textcircled{1} \quad \frac{p_A - p_B}{\gamma_o} + z_A - z_B = \frac{v_B^2 - v_A^2}{2g} \quad \left. v_B^2 - v_A^2 = (3.789v_A)^2 - v_A^2 = 13.36v_A^2 \right.$$

$$z_A - z_B = -24 \text{ in}$$

Manometer:  $p_B + \gamma_o(24 \text{ in}) + \gamma_o(6 \text{ in}) + \gamma_w(8 \text{ in}) - \gamma_o(8 \text{ in}) - \gamma_o(6 \text{ in}) = p_A$

$p_A - p_B = \gamma_o(16 \text{ in}) + \gamma_w(8 \text{ in})$

$$\frac{p_A - p_B}{\gamma_o} = 16 \text{ in} + \frac{\gamma_w}{\gamma_o}(8 \text{ in}) = 16 \text{ in} + \frac{62.4 \text{ lb/ft}^3}{55.0 \text{ lb/ft}^3}(8 \text{ in}) = 25.08 \text{ in}$$

in  $\textcircled{1}$   $25.08 \text{ in} - 24.0 \text{ in} = 13.36v_A^2/2g$

$$v_A = \sqrt{\frac{2g(1.08 \text{ in})}{13.36}} = \sqrt{\frac{2(32.2 \text{ ft/s}^2)(1.08 \text{ in})}{13.36(12 \text{ in/ft})}} = 0.659 \text{ ft/s}$$

$$Q = A_A v_A = 0.08840 \text{ ft}^2 \times \frac{0.659 \text{ ft}}{\text{s}} = \mathbf{0.0582 \text{ ft}^3/\text{s}}$$

6.83 Plot shown below. Data computed as follows.  
 Pt. 1: Tank surface - Pt. 2: Outside nozzle - Ref. level at D.

Pt. 1:  $z_1 = 10.0 \text{ m}$ ;  $\frac{v_1^2}{2g} = 0$ ;  $\frac{p_1}{\gamma} = 0$  See Problem 6.72 for data.

Pt. A:  $z_A = 10.0 \text{ m}$ ;  $\frac{v_A^2}{2g} = \frac{(3.502 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)} = +0.625 \text{ m} = \frac{v_B^2}{2g} = \frac{v_C^2}{2g} = \frac{v_D^2}{2g}$

$\frac{p_A}{\gamma} = \frac{-5.27 \text{ kN/m}^2}{8.437 \text{ kN/m}^3} = -0.625 \text{ m} = \frac{p_C}{\gamma}$

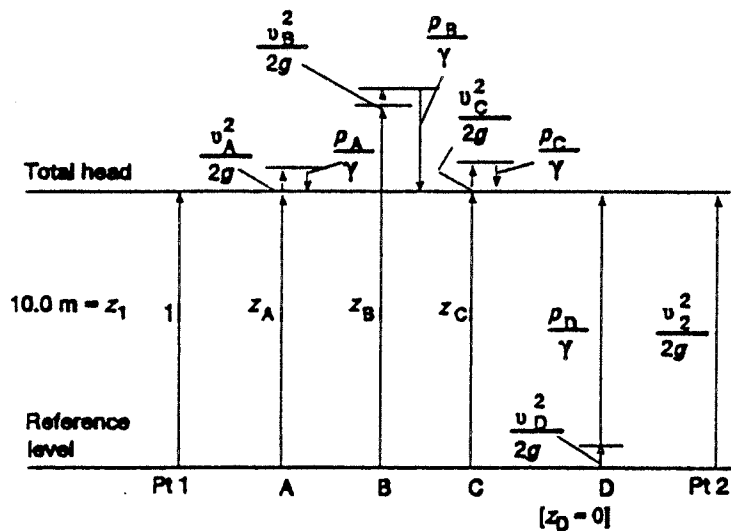
Pt. B:  $z_B = 13.0 \text{ m}$ ;  $\frac{v_B^2}{2g} = 0.625 \text{ m}$

$\frac{p_B}{\gamma} = \frac{-30.58}{8.437} = -3.625 \text{ m}$

Pt. C: Same as Pt. A

Pt. D:  $z_D = 0$ ;  $\frac{v_D^2}{2g} = 0.625 \text{ m}$ ;  $\frac{p_D}{\gamma} = \frac{79.1}{8.437} = 9.375 \text{ m}$

Pt. 2:  $z_2 = 0$ ;  $\frac{v_2^2}{2g} = \frac{(14.01)^2}{2(9.81)} \text{ m} = 10.0 \text{ m}$ ;  $\frac{p_2}{\gamma} = 0$



6.84 See Prob. 6.73 for data. Let  $z_A = z_B = 0$

$$\text{Pt. A: } \frac{p_A}{\gamma} = \frac{50.0 \text{ lb}}{\text{in}^2} \times \frac{144 \text{ in}^2}{\text{ft}^2} \times \frac{\text{ft}^3}{62.4 \text{ lb}} = 115.4 \text{ ft}$$

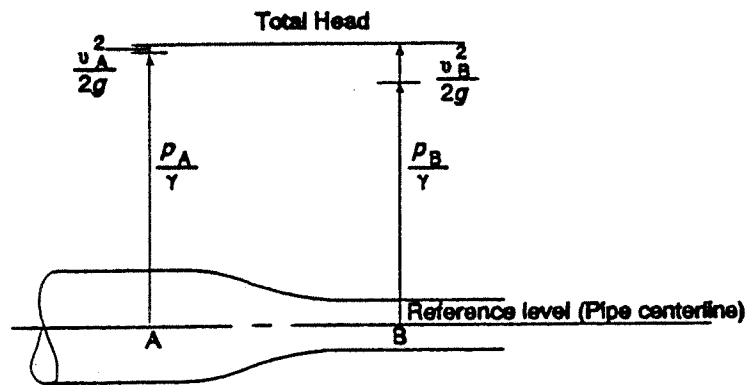
$$\frac{v_A^2}{2g} = \frac{(0.25v_B)^2}{2g} = \frac{[(0.25)(35.6 \text{ ft/s})]^2}{2(32.2 \text{ ft/s}^2)} = 1.23 \text{ ft}$$

} - Total head = 116.6 ft

$$\text{Pt. B: } \frac{p_B}{\gamma} = \frac{(42.0)(144)}{62.4} = 96.9 \text{ ft}$$

$$\frac{v_B^2}{2g} = \frac{(35.6)^2}{2(32.2)} = 19.7 \text{ ft}$$

} - Total head = 116.6 ft



$$6.85 \quad \frac{p_A}{\gamma} + z_A + \frac{v_A^2}{2g} = \frac{p_G}{\gamma} + z_G + \frac{v_G^2}{2g} \quad (\text{Neglecting energy losses}); \quad p_A = p_G = 0, \quad v_A = 0$$

$$v_G = \sqrt{2g(z_A - z_G)} = \sqrt{2(32.2 \text{ ft/s}^2)(30 \text{ ft})} = 43.95 \text{ ft/s}$$

$$A_G = \frac{\pi(1.25 \text{ in})^2}{4} \times \frac{\text{ft}^2}{144 \text{ in}^2} = 8.522 \times 10^{-3} \text{ ft}^2$$

$$\text{Velocity in 2-in Sch 40 pipe: } v_2 = v_G \times \frac{A_G}{A_2} = (43.95) \frac{8.522 \times 10^{-3}}{0.02333} = 16.06 \text{ ft/s}$$

$$\text{Velocity in 6-in Sch 40 pipe: } v_6 = v_G \times \frac{A_G}{A_6} = (43.95) \frac{8.522 \times 10^{-3}}{0.2006} = 1.867 \text{ ft/s}$$

$$v_G^2/2g = (43.95 \text{ ft/s})^2/2(32.2 \text{ ft/s}^2) = 30.0 \text{ ft}$$

$$v_2^2/2g = (16.06)^2/64.4 = 4.00 \text{ ft} = v_B^2/2g = v_D^2/2g = v_E^2/2g = v_F^2/2g$$

$$v_6^2/2g = (1.867)^2/64.4 = 0.054 \text{ ft} = v_C^2/2g$$

$$\text{Point B: } \frac{p_A}{\gamma} + z_A + \frac{v_A^2}{2g} = \frac{p_B}{\gamma} + z_B + \frac{v_B^2}{2g}; \quad p_A = 0, \quad v_A = 0$$

$$p_B = \gamma \left[ (z_A - z_B) - \frac{v_B^2}{2g} \right] = \frac{62.4 \text{ lb}}{\text{ft}^3} [15.0 \text{ ft} - 4.0 \text{ ft}] \frac{1 \text{ ft}^2}{144 \text{ in}^2} = 4.77 \text{ psig}$$

$$\frac{p_B}{\gamma} = (z_A - z_B) - \frac{v_B^2}{2g} = 15 \text{ ft} - 4.0 \text{ ft} = 11.0 \text{ ft}$$

Same values at point D.

$$\text{Point C: } \frac{p_C}{\gamma} = (z_A - z_C) - \frac{v_C^2}{2g} = 15.0 \text{ ft} - 0.054 \text{ ft} = 14.95 \text{ ft}$$

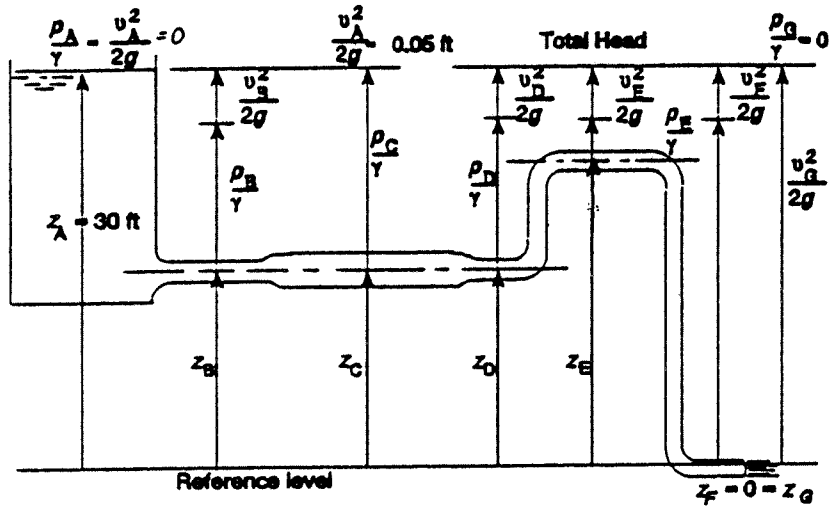
$$p_C = \gamma(14.95 \text{ ft}) = (62.4 \text{ lb/ft}^3)(14.95 \text{ ft})(1 \text{ ft}^2/144 \text{ in}^2) = 6.48 \text{ psig}$$

$$\text{Point E: } \frac{p_E}{\gamma} = (z_A - z_E) - v_E^2/2g = 9 \text{ ft} - 4.0 \text{ ft} = 5.0 \text{ ft}$$

$$p_E = \gamma(5.0 \text{ ft}) = (62.4)(5.0)/144 = 2.17 \text{ psig}$$

$$\text{Point F: } \frac{p_F}{\gamma} = (z_A - z_F) - \frac{v_F^2}{2g} = 30.0 \text{ ft} - 4.0 \text{ ft} = 26.0 \text{ ft}$$

$$p_F = \gamma(26.0 \text{ ft}) = (62.4)(26.0)/144 = 11.27 \text{ psig}$$



6.86 With Mercury at wall of throat,  $h/2 = 0.30$  m;  $h = 0.60$  m

$$\frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} = \frac{p_t}{\gamma_w} + z_t + \frac{v_t^2}{2g} \quad \left| \quad v_t = v_1 \frac{A_1}{A_t} = v_1 \left( \frac{D_1}{D_t} \right)^2 = \left( \frac{75}{25} \right)^2 = 9v_1 \right.$$

$$\frac{p_1 - p_t}{\gamma_w} = \frac{v_t^2 - v_1^2}{2g} = \frac{(9v_1)^2 - v_1^2}{2g} = \frac{80v_1^2}{2g}$$

Manometer:  $p_1 + \gamma_w(D_t/2) + \gamma_w(0.60 \text{ m}) - \gamma_m(0.60 \text{ m}) - \gamma_w(D_t/2) = p_t$

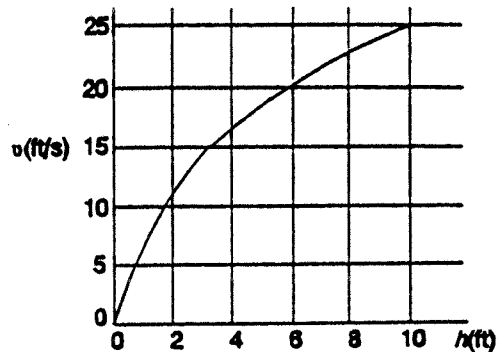
$$\frac{p_1 - p_t}{\gamma_w} = \frac{\gamma_m(0.60 \text{ m})}{\gamma_w} - 0.60 \text{ m} = 13.54(0.60) - 0.60 = 7.52 \text{ m}$$

$$v_1 = \sqrt{\frac{2g(7.52 \text{ m})}{80}} = \sqrt{\frac{2(9.81 \text{ m/s}^2)(7.52 \text{ m})}{\text{s}^2(80)}} = 1.36 \text{ m/s}$$

$$Q = A_1 v_1 = \pi(0.075 \text{ m})^2/4 \times 1.36 \text{ m/s} = 6.00 \times 10^{-3} \text{ m}^3/\text{s}$$

$$6.87 \quad \frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}; \quad v_2 = \sqrt{2g(z_1 - z_2)} = \sqrt{2gh} = \text{Velocity of jet}$$

$h(\text{ft})$	$v(\text{ft/s})$
10	25.4
8	22.7
6	19.7
4	16.1
2	11.4
1.5	9.83
1.0	8.02
0.5	5.67
0	0



$$6.88 \quad Q = 200 \text{ gal/min} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 0.445 \text{ ft}^3/\text{s}$$

$$v_j = \frac{Q}{A} = \frac{0.445 \text{ ft}^3/\text{s}}{\pi(3.00 \text{ in})^2/4(\text{ft}^2)} = \frac{9.07 \text{ ft}}{\text{s}} \sqrt{2gh} \quad (\text{See Prob 6.87})$$

$$h = \frac{v_j^2}{2g} = \frac{(9.07 \text{ ft/s})^2}{2(32.2 \text{ ft/s}^2)} = \mathbf{1.28 \text{ ft}}$$

### Torricelli's theorem

$$6.89 \quad \frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}; \quad v_2 = \sqrt{2g(z_1 - z_2)} = \sqrt{2gh}$$

Ref. Fig. 6.37; Pt. 1 at tank surface; Pt. 2 in jet outside orifice

$$6.90 \quad h = \frac{v_j^2}{2g} = \frac{(9.07)^2 \text{ ft}^2/\text{s}^2}{2(32.2 \text{ ft/s}^2)} = \mathbf{1.28 \text{ ft}}$$

6.91 To the level of the fluid surface in the tank.  
**1.675 m** above the outlet nozzle.

6.92  $h = 3.50 \text{ ft} - 1.0 \text{ ft} = 2.50 \text{ ft} = \text{Depth of fluid above nozzle.}$

$$h_{\text{total}} = h + \frac{p}{\gamma} = 2.50 \text{ ft} + \frac{12.0 \text{ lb ft}^3}{\text{in}^2} \frac{144 \text{ in}^2}{62.4 \text{ lb ft}^2} = 2.50 + 27.69 = \mathbf{30.19 \text{ ft}}$$

6.93  $28.0 \text{ ft} = h + p/\gamma = 4.50 \text{ ft} + p_1/\gamma$

$$p_1 = \gamma[28 - 4.50] = \frac{62.4 \text{ lb}}{\text{ft}^3} \times 23.5 \text{ ft} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} = \mathbf{10.18 \text{ psig}}$$

$$6.94 \quad 9.50 \text{ m} = h + p/\gamma = 1.50 \text{ m} + p_1/\gamma$$

$$p_1 = \gamma[9.50 - 1.50] = \frac{9.81 \text{ kN}}{\text{m}^3} \times 8.0 \text{ m} = 78.48 \text{ kPa}$$

**Flow due to a falling head**

$$6.95 \quad t_2 - t_1 = \frac{2(A_i / A_j)}{\sqrt{2g}} (h_1^{1/2} - h_2^{1/2}) = \frac{2(400)}{\sqrt{2(9.81)}} (2.68^{1/2} - 0) = \mathbf{296 \text{ s}} [4 \text{ min}, 56 \text{ s}]$$

$$A_i = \pi(3.00 \text{ m})^2/4 = 7.07 \text{ m}^2; A_j = \pi(.15 \text{ m})^2/4 = 0.0177 \text{ m}^2$$

$$A_i/A_j = 7.07/0.0177 = 400$$

$$6.96 \quad A_i/A_j = (D_i/D_j)^2 = (300/20)^2 = 225$$

$$t_2 - t_1 = \frac{2(225)}{\sqrt{2(9.81)}} (.055^{1/2} - 0) = \mathbf{23.8 \text{ s}}$$

$$6.97 \quad A_i/A_j = (D_i/D_j)^2 = (12/0.50)^2 = 576$$

$$t_2 - t_1 = \frac{2(576)}{\sqrt{2(32.2 \text{ ft/s}^2)}} (15.0 \text{ ft}^{1/2} - 0) = \mathbf{556 \text{ s}} (9 \text{ min}, 16 \text{ s})$$

$$6.98 \quad A_i/A_j = (D_i/D_j)^2 = (22.0/0.50)^2 = 1936$$

$$g = (32.2 \text{ ft/s}^2)(12 \text{ in/ft}) = 386 \text{ in/s}^2$$

$$t_2 - t_1 = \frac{2(A_i - A_j)}{\sqrt{2g}} (h_1^{1/2} - h_2^{1/2}) = \frac{2(1936)}{\sqrt{2(386 \text{ in/s}^2)}} (18.5^{1/2} \text{ in} - 0) = \mathbf{599 \text{ s}} (9 \text{ min}, 59 \text{ s})$$

$$6.99 \quad A_i/A_j = (D_i/D_j)^2 = (2.25 \text{ m}/0.05 \text{ m})^2 = 2025$$

$$t_2 - t_1 = \frac{2(2025)}{\sqrt{2(9.81)}} (2.68^{1/2} - 1.18^{1/2}) = \mathbf{504 \text{ s}} (8 \text{ min}, 24 \text{ s})$$

$$6.100 \quad A_i/A_j = (D_i/D_j)^2 = (1.25 \text{ m}/0.025 \text{ m})^2 = 2500$$

$$t_2 - t_1 = \frac{2(2500)}{\sqrt{2(9.81)}} (1.38^{1/2} - 1.155^{1/2}) = \mathbf{113 \text{ s}} (1 \text{ min}, 53 \text{ s})$$

$$6.101 \quad \text{See Prob. 6.98: } g = 386 \text{ in/s}^2$$

$$A_i/A_j = (D_i/D_j)^2 = \left( \frac{6.25 \text{ ft}(12 \text{ in/ft})}{0.625 \text{ in}} \right)^2 = 14400$$

$$t_2 - t_1 = \frac{2(14400)}{\sqrt{2(386)}} (38^{1/2} - 25.5^{1/2}) = \mathbf{1155 \text{ s}} (19 \text{ min}, 15 \text{ s})$$

$$6.102 \quad A_i/A_j = (D_i/D_j)^2 = \left( \frac{46.5 \text{ ft}}{8.75 \text{ in}(1 \text{ ft}/12 \text{ in})} \right)^2 = 4067$$

$$t_2 - t_1 = \frac{2(4067)}{\sqrt{2(32.2 \text{ ft/s}^2)}} (23.0^{1/2} - 2.0^{1/2}) = \mathbf{3427 \text{ s}} (57 \text{ min}, 7 \text{ s})$$

6.103 See Prob. 6.97.

$$\frac{p}{\gamma} = \frac{5.0 \text{ lb ft}^3}{\text{in}^2} \frac{144 \text{ in}^2}{62.4 \text{ lb ft}^2} = 11.54 \text{ ft}; h_1 = 15.0 \text{ ft} + 11.54 \text{ ft} = 26.54 \text{ ft}$$

$$h_2 = 11.54 \text{ ft} = \frac{p}{\gamma}$$

$$t_2 - t_1 = \frac{2(576)}{\sqrt{2(32.2)}} (26.54^{1/2} - 11.54^{1/2}) = \mathbf{252 \text{ s}} \text{ (4 min, 12 s)}$$

6.104 See Prob. 6.101.

$$\frac{p}{\gamma} = \frac{2.8 \text{ lb ft}^3}{\text{in}^2} \frac{144 \text{ in}^2}{62.4 \text{ lb ft}^2} = 6.46 \text{ ft} \times \frac{12 \text{ in}}{\text{ft}} = 77.5 \text{ in}$$

$$h_1 = 38 \text{ in} + 77.5 \text{ in} = 115.5 \text{ in}; h_2 = 25.5 \text{ in} + 77.5 \text{ in} = 100 \text{ in}$$

$$t_2 - t_1 = \frac{2(14400)}{\sqrt{2(386)}} (115.5^{1/2} - 100^{1/2}) = \mathbf{774 \text{ s}} \text{ (12 min, 54 s)}$$

6.105 See Prob. 6.96.

$$\frac{p}{\gamma} = \frac{20 \text{ kN}}{\text{m}^2} \frac{\text{m}^2}{9.81 \text{ kN}} = 2.039 \text{ m}$$

$$h_1 = 0.055 \text{ m} + 2.039 \text{ m} = 2.094 \text{ m}; h_2 = 2.039 \text{ m}$$

$$t_2 - t_1 = \frac{2(225)}{\sqrt{2(9.81)}} (2.094^{1/2} - 2.039^{1/2}) = \mathbf{1.94 \text{ s}}$$

6.106 See Prob. 6.100.

$$\frac{p}{\gamma} = \frac{35 \text{ kN}}{\text{m}^2} \frac{\text{m}^3}{9.81 \text{ kN}} = 3.57 \text{ m}$$

$$h_1 = 1.38 + 3.57 = 4.95 \text{ m}; h_2 = 1.155 \text{ m} + 3.57 \text{ m} = 4.722 \text{ m}$$

$$t_2 - t_1 = \frac{2(2500)}{\sqrt{2(9.81)}} (4.95^{1/2} - 4.722^{1/2}) = \mathbf{57.8 \text{ s}}$$

# CHAPTER SEVEN

## GENERAL ENERGY EQUATION

$$7.1 \quad \frac{p_1}{\gamma_o} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_o} + z_2 + \frac{v_2^2}{2g}; z_1 = z_2 \text{ and } v_1 = v_2$$

$$h_L = \frac{p_1 - p_2}{\gamma_o} = \frac{(74.6 - 62.2) \text{ lb}}{\text{in}^2} \times \frac{\text{ft}^3}{(0.83)(62.4 \text{ lb})} \times \frac{144 \text{ in}^2}{\text{ft}^2} = \mathbf{34.5 \text{ lb} \cdot \text{ft/lb}}$$

$$7.2 \quad \frac{p_A}{\gamma_w} + z_A + \frac{v_A^2}{2g} - h_L = \frac{p_B}{\gamma_w} + z_B + \frac{v_B^2}{2g} \quad \left| \begin{array}{l} v_B = v_A \frac{A_A}{A_B} = v_A \left( \frac{D_A}{D_B} \right)^2 \\ v_B = 10 \text{ ft/s} \left( \frac{4}{2} \right)^2 = 40 \text{ ft/s} \end{array} \right.$$

$$p_B = p_A + \gamma_w \left[ (z_A - z_B) + \frac{v_A^2 - v_B^2}{2g} - h_L \right]$$

$$p_B = 60 \text{ psig} + \frac{62.4 \text{ lb}}{\text{ft}^3} \left[ 30 \text{ ft} + \frac{(10^2 - 40^2) \text{ ft}^2/\text{s}^2}{2(32.2 \text{ ft/s}^2)} - 25 \text{ ft} \right] \frac{1 \text{ ft}^2}{144 \text{ in}^2} = \mathbf{52.1 \text{ psig}}$$

$$7.3 \quad \frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{v_2^2}{2g} \quad \left| \begin{array}{l} \text{Pt. 1 at surface of water. } v_1 = 0 \\ \text{Pt. 2 in stream outside nozzle. } p_2 = 0 \end{array} \right.$$

$$v_2 = \sqrt{2g \left[ \frac{p_1}{\gamma_w} + (z_1 - z_2) - h_L \right]} = \sqrt{\frac{2(9.81 \text{ m})}{\text{s}^2} \left[ \frac{140 \text{ kN m}^3}{\text{m}^2 9.81 \text{ kN}} + 2.4 \text{ m} - 2.0 \text{ m} \right]}$$

$$= 17.0 \text{ m/s}$$

$$Q = A_2 v_2 = \pi(0.05 \text{ m})^2/4 \times 17.0 \text{ m/s} = \mathbf{3.33 \times 10^{-2} \text{ m}^3/\text{s}}$$

$$7.4 \quad \frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{v_2^2}{2g} \quad \left| \begin{array}{l} \text{Pt. 1 at water surface.} \\ \text{Pt. 2 in stream outside pipe.} \end{array} \right.$$

$$p_1 = p_2 = 0 \text{ and } v_1 = 0$$

$$h_L = (z_1 - z_2) - \frac{v_2^2}{2g}$$

$$h_L = 10 \text{ m} - \frac{(4.56 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)} = 8.94 \text{ m} = \frac{\mathbf{8.94 \text{ N} \cdot \text{m}}}{\mathbf{N}}$$

$$v_2 = \frac{Q}{A_2} = \frac{0.085 \text{ m}^3/\text{s}}{1.864 \times 10^{-2} \text{ m}^2}$$

$$v_2 = 4.56 \text{ m/s}$$

$$7.5 \quad \frac{p_A}{\gamma_w} + z_A + \frac{v_A^2}{2g} - h_L = \frac{p_B}{\gamma_w} + z_B + \frac{v_B^2}{2g} \quad \left| \begin{array}{l} v_A = \frac{Q}{A_A} = \frac{0.20 \text{ ft}^3/\text{s}}{0.02333 \text{ ft}^2} = 8.57 \text{ ft/s} \\ v_B = \frac{Q}{A_B} = \frac{0.20}{0.0884} = 2.26 \text{ ft/s} \end{array} \right.$$

$$h_L = \frac{p_A - p_B}{\gamma_w} + (z_A - z_B) + \frac{v_A^2 - v_B^2}{2g}$$

Manometer:  $p_A + \gamma_w(10 \text{ in}) - \gamma_m(14 \text{ in}) - \gamma_w(44 \text{ in}) = p_B$   

$$\frac{p_A - p_B}{\gamma_w} = \frac{\gamma_m(14 \text{ in}) + \gamma_w(34 \text{ in})}{\gamma_w} = \frac{13.54\gamma_w(14 \text{ in}) + \gamma_w(34 \text{ in})}{\gamma_w} = 223.6 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}}$$

$$= 18.6 \text{ ft}$$

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$$h_L = 18.6 \text{ ft} + (-4.0 \text{ ft}) + \frac{(8.57^2 - 2.26^2) \text{ ft}^2/\text{s}^2}{2(32.2 \text{ ft}/\text{s}^2)} = 15.7 \text{ ft}$$

7.6 
$$\frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{v_2^2}{2g} : z_1 = z_2 \text{ and } v_1 = v_2 : h_L = \frac{p_1 - p_2}{\gamma_w}$$

Manometer:  $p_1 + \gamma_w(X) + \gamma_w(6.4 \text{ in}) - \gamma_{\text{cr}}(6.4 \text{ in}) - \gamma_w(X) = p_2$   

$$\frac{p_1 - p_2}{\gamma_w} = \frac{\gamma_{\text{cr}}(6.4 \text{ in}) - \gamma_w(6.4 \text{ in})}{\gamma_w} = \frac{1.60\gamma_w(6.4 \text{ in}) - \gamma_w(6.4 \text{ in})}{\gamma_w} = \frac{3.84 \text{ in}}{12 \text{ in}/\text{ft}}$$

$$= 0.32 \text{ ft} = h_L$$

$$h_L = K \frac{v_2^2}{2g} : K = \frac{2gh_L}{v_2^2} = \frac{2(32.2 \text{ ft}/\text{s}^2)(0.32 \text{ ft})}{(1.95 \text{ ft}/\text{s})^2} = 5.43 = K$$

$$v_2 = \frac{Q}{A_2} = \frac{0.10 \text{ ft}^3/\text{s}}{0.05132 \text{ ft}^2} = 1.95 \text{ ft}/\text{s}$$

7.7 
$$\frac{p_1}{\gamma_o} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_o} + z_2 + \frac{v_2^2}{2g} : v_1 = v_2 : h_L = \frac{p_1 - p_2}{\gamma_o} + (z_1 - z_2)$$

Manometer:  $p_1 + \gamma_o(X) + \gamma_o(0.38 \text{ m}) - \gamma_m(0.38 \text{ m}) - \gamma_o(X) - \gamma_o(1.0 \text{ m}) = p_2$   

$$\frac{p_1 - p_2}{\gamma_o} = \frac{\gamma_m(0.38 \text{ m})}{\gamma_o} + \frac{\gamma_o(0.62 \text{ m})}{\gamma_o} = \frac{13.54\gamma_w(0.38 \text{ m})}{0.90\gamma_w} + 0.62 \text{ m} = 6.337 \text{ m}$$

$$h_L = 6.337 \text{ m} + (-1.0 \text{ m}) = 5.337 \text{ m} = K \left( \frac{v_2^2}{2g} \right)$$

$$K = \frac{2gh_L}{v_2^2} = \frac{2(9.81 \text{ m}/\text{s}^2)(5.337 \text{ m})}{(1.20 \text{ m}/\text{s})^2} = 72.7$$

7.8 
$$\frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} + h_A - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{v_2^2}{2g}$$
 Ref. pts. at tank surfaces. Assume  $h_L = 0$ .

$$p_1 = 0, z_1 = z_2, \text{ and } v_1 = v_2 = 0$$

$$h_A = \frac{p_2}{\gamma_w} = \frac{500 \text{ kN}}{\text{m}^2} \frac{\text{m}^3}{9.81 \text{ kN}} = 50.97 \text{ m} \quad \left| \quad Q = \frac{2250 \text{ L}/\text{min}(1 \text{ m}^3/\text{s})}{60000 \text{ L}/\text{min}} = 0.0375 \text{ m}^3/\text{s} \right.$$

$$P_A = h_A \gamma_w Q = 50.97 \text{ m}(9.81 \text{ kN}/\text{m}^3)(0.0375 \text{ m}^3/\text{s}) = 18.75 \text{ kN}\cdot\text{m}/\text{s} = 18.75 \text{ kW}$$

7.9 
$$h_A = \frac{p_2 - p_1}{\gamma_w} = \frac{(500 - 68) \text{ kN}}{\text{m}^2 9.81 \text{ kN}/\text{m}^3} = 44.04 \text{ m}$$
 (See Prob. 7.8,  $p_1 = 68 \text{ kPa}$ )

$$P_A = h_A \gamma_w Q = (44.04)(9.81)(0.0375) = 16.20 \text{ kW}$$

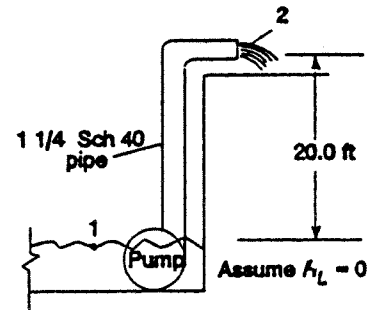
$$7.10 \quad \frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} + h_A - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{v_2^2}{2g};$$

$$p_1 = p_2 = 0; \quad v_1 = 0$$

$$h_A = (z_2 - z_1) + \frac{v_2^2}{2g} = 20 \text{ ft} + \frac{(10 \text{ ft/s})^2}{2(32.2 \text{ ft/s}^2)} = 21.55 \text{ ft}$$

$$Q = \frac{2800 \text{ gal/hr}}{60 \text{ min/hr}} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 0.1039 \text{ ft}^3/\text{s}$$

$$v_2 = \frac{Q}{A_2} = \frac{0.1039 \text{ ft}^3/\text{s}}{0.01039 \text{ ft}^2} = 10.0 \text{ ft/s}$$



$$a) \quad P_A = h_A \gamma_w Q = (21.55 \text{ ft})(62.4 \text{ lb/ft}^3)(0.1039 \text{ ft}^3/\text{s}) = 139.8 \text{ lb}\cdot\text{ft/s} \times \frac{1 \text{ hp}}{550 \text{ lb}\cdot\text{ft/s}}$$

$$= 0.254 \text{ hp}$$

$$b) \quad e_M = \frac{P_A}{P_I} = \frac{0.254 \text{ hp}}{0.50 \text{ hp}} = 0.508 = 50.8\%$$

$$7.11 \quad \frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} + h_A - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{v_2^2}{2g} \quad \left\{ \begin{array}{l} \text{Pt. 1 at well surface. } p_1 = 0 \text{ and } v_1 = 0 \\ \text{Pt. 2 at tank surface. } v_2 = 0 \end{array} \right.$$

$$h_A = \frac{p_2}{\gamma_w} + (z_2 - z_1) + h_L = \frac{40 \text{ lb ft}^3}{\text{in}^2} \frac{144 \text{ in}^2}{62.4 \text{ lb ft}^2} + 120 \text{ ft} + 10.5 \text{ ft} = 222.8 \text{ lb}\cdot\text{ft/lb}$$

$$Q = \frac{745 \text{ gal/h}}{60 \text{ min/h}} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 0.0277 \text{ ft}^3/\text{s}$$

$$a) \quad P_A = h_A \gamma_w Q = \frac{222.8 \text{ lb}\cdot\text{ft}}{\text{lb}} \times \frac{62.4 \text{ lb}}{\text{ft}^3} \times \frac{0.0277 \text{ ft}^3}{\text{s}} = \frac{348 \text{ lb}\cdot\text{ft}}{\text{lb}} \frac{1 \text{ hp}}{550 \text{ lb}\cdot\text{ft/lb}}$$

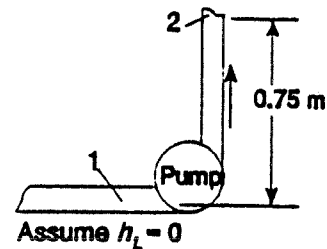
$$= 0.700 \text{ hp}$$

$$b) \quad e_M = \frac{P_A}{P_I} = \frac{0.700 \text{ hp}}{1.0 \text{ hp}} = 0.700 = 70.0\%$$

$$7.12 \quad \frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} + h_A - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{v_2^2}{2g}; \quad v_1 = v_2$$

$$h_A = \frac{p_2 - p_1}{\gamma_w} + (z_2 - z_1) = \frac{[520 - (-30)] \text{ kN}}{\text{m}^2 9.81 \text{ kN/m}^3} + 0.75 \text{ m}$$

$$= 56.82 \text{ m}$$



$$Q = 75 \text{ L/min} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 1.25 \times 10^{-3} \text{ m}^3/\text{s}$$

$$P_A = h_A \gamma_w Q = (56.82 \text{ m})(9.81 \text{ kN/m}^3)(1.25 \times 10^{-3} \text{ m}^3/\text{s}) = 0.697 \text{ kN}\cdot\text{m/s} = 0.697 \text{ kW}$$

$$7.13 \quad \frac{p_A}{\gamma_o} + z_A + \frac{v_A^2}{2g} + h_A - h_L = \frac{p_B}{\gamma_o} + z_B + \frac{v_B^2}{2g}$$

$$h_A = \frac{p_B - p_A}{\gamma_o} + (z_B - z_A) + \frac{v_B^2 - v_A^2}{2g} + h_L$$

$$h_L = 2.5 \left( \frac{v_B^2}{2g} \right)$$

$$h_A = \frac{[275 - (-20)] \text{ kN}}{\text{m}^2 (0.85)(9.81 \text{ kN/m}^3)} + 1.20 \text{ m} + \frac{(2.243^2 - 0.577^2) \text{ m}^2/\text{s}^2}{2(9.81 \text{ m/s}^2)} + 2.5 \frac{(2.243 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)}$$

$$Q = 75 \text{ L/min} = 1.25 \times 10^{-3} \text{ m}^3/\text{s} \quad (\text{Prob. 7.12})$$

$$v_A = \frac{Q}{A_A} = \frac{1.25 \times 10^{-3}}{2.168 \times 10^{-3}} = 0.577 \text{ m/s}$$

$$v_B = \frac{Q}{A_B} = \frac{1.25 \times 10^{-3}}{5.574 \times 10^{-4}} = 2.243 \text{ m/s}$$

$$h_A = 35.38 \text{ m} + 1.20 \text{ m} + 0.24 \text{ m} + 0.64 \text{ m} = \mathbf{37.46 \text{ m}}$$

$$P_A = h_A \gamma_o Q + (37.46 \text{ m})(0.85)(9.81 \text{ kN/m}^3)(1.25 \times 10^{-3} \text{ m}^3/\text{s}) = 0.39 \text{ kN}\cdot\text{m/s}$$

$$= \mathbf{0.390 \text{ kW}}$$

$$7.14 \quad \text{a) } \frac{p_A}{\gamma_w} + z_A + \frac{v_A^2}{2g} - h_{Ls} = \frac{p_B}{\gamma_o} + z_B + \frac{v_B^2}{2g}$$

$$p_B = \gamma_w \left[ (z_A - z_B) - \frac{v_B^2}{2g} - h_L \right]$$

$$p_B = \frac{62.4 \text{ lb}}{\text{ft}^3} \left[ -10 \text{ ft} - \frac{(9.97 \text{ ft/s})^2}{2(32.2 \text{ ft/s}^2)} - 6 \text{ ft} \right] \frac{1 \text{ ft}^2}{144 \text{ in}^2} = \mathbf{-7.60 \text{ psig}}$$

Pt. A at lower tank surface. $p_A = 0$
Pt. B at pump inlet. $v_A = 0$
$v_B = \frac{Q}{A_B} = \frac{2.0 \text{ ft}^3/\text{s}}{0.2006 \text{ ft}^2} = 9.97 \text{ ft/s}$

$$\text{b) } \frac{p_C}{\gamma_w} + z_C + \frac{v_C^2}{2g} - h_{Ld} = \frac{p_D}{\gamma_w} + z_D + \frac{v_D^2}{2g}$$

$$p_C = \gamma_w \left[ (z_D - z_C) - \frac{v_C^2}{2g} + h_{Ld} \right]$$

Pt. C at pump outlet. $p_D = 0$
Pt. D at upper tank surface. $v_D = 0$
$v_C = v_B = 9.97 \text{ ft/s}$

$$p_D = 0$$

$$v_D = 0$$

$$p_C = \frac{62.4 \text{ lb}}{\text{ft}^3} [40 \text{ ft} - 1.54 \text{ ft} + 12 \text{ ft}] \frac{1 \text{ ft}^2}{144 \text{ in}^2} = \mathbf{21.9 \text{ psig}}$$

$$\text{c) } \frac{p_A}{\gamma_w} + z_A + \frac{v_A^2}{2g} + h_A - h_{Ls} - h_{Ld} = \frac{p_D}{\gamma} + z_D + \frac{v_D^2}{2g}; \quad p_A = p_D = 0; \quad v_A = v_D = 0$$

$$h_A = z_D - z_A + h_{Ls} + h_{Ld} = 50 \text{ ft} + 6 \text{ ft} + 12 \text{ ft} = \mathbf{68.0 \text{ ft}}$$

$$\text{d) } P_A = h_A \gamma_w Q = (68.0 \text{ ft})(62.4 \text{ lb/ft}^3)(2.0 \text{ ft}^3/\text{s}) = \frac{8486 \text{ lb}\cdot\text{ft}}{\text{lb}} \frac{\text{hp}}{550 \text{ lb}\cdot\text{ft}/\text{lb}} = \mathbf{15.4 \text{ hp}}$$

7.15 (See Prob. 7.14)

$$\text{a) } p_B = \gamma_w \left[ (z_A - z_B) - \frac{v_B^2}{2g} - h_L \right] = \frac{62.4 \text{ lb}}{\text{ft}^3} [+10 \text{ ft} - 1.54 \text{ ft} - 6 \text{ ft}] \frac{1 \text{ ft}^2}{144 \text{ in}^2}$$

- b)  $p_C = 21.8 \text{ psig}$  (same as Prob. 7.14)  
 c)  $h_A = (z_D - z_A) + h_{L_s} + h_{L_D} = 30 \text{ ft} + 6 \text{ ft} + 12 \text{ ft} = 48 \text{ ft}$   
 d)  $P_A = h_A \gamma_w Q = (48 \text{ ft})(62.4 \text{ lb/ft}^3)(20.0 \text{ ft}^3/\text{s})/550 = 10.9 \text{ hp}$

7.16 a)  $\frac{p_1}{\gamma_o} + z_1 + \frac{v_1^2}{2g} + h_A - h_L = \frac{p_2}{\gamma_o} + z_2 + \frac{v_2^2}{2g} \left| \begin{array}{l} \text{Pt. 1 at lower tank surface. } p_1 = 0 \\ \text{Pt. 2 at upper tank surface. } v_1 = v_2 = 0 \end{array} \right.$

$$h_A = \frac{p_2}{\gamma_o} + (z_2 - z_1) + h_L = \frac{825 \text{ kN m}^3}{\text{m}^2 (0.85)(9.81 \text{ kN})} + 14.5 \text{ m} + 4.2 \text{ m} = 117.6 \text{ m}$$

$$P_A = h_A \gamma_o Q = (117.6 \text{ m})(0.85) \left( \frac{9.81 \text{ kN}}{\text{m}^3} \right) \frac{840 \text{ L/min}(1 \text{ m}^3/\text{s})}{60000 \text{ L/min}} = \frac{13.73 \text{ kN} \cdot \text{m}}{\text{s}}$$

$$= 13.73 \text{ kW}$$

b)  $\frac{p_1}{\gamma_o} + z_1 + \frac{v_1^2}{2g} - h_{L_s} = \frac{p_3}{\gamma_o} + z_3 + \frac{v_3^2}{2g} \left| \text{Pt. 3 at pump inlet.} \right.$

$$p_3 = \gamma_o \left[ (z_1 - z_3) - \frac{v_3^2}{2g} - h_{L_s} \right]$$

$$= \frac{(0.85)(9.81 \text{ kN})}{\text{m}^3} \left[ -3.0 \text{ m} - \frac{(4.53 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)} - \frac{1.4 \text{ N} \cdot \text{m}}{\text{N}} \right] = -45.4 \text{ kPa}$$

$$v_3 = \frac{Q}{A_3} = \frac{840 \text{ L/min}(1 \text{ m}^3/\text{s})}{60000 \text{ L/min}} \cdot \frac{1}{3.090 \times 10^{-3} \text{ m}^2} = 4.53 \text{ m/s}$$

7.17  $\frac{p_1}{\gamma_f} + z_1 + \frac{v_1^2}{2g} + h_A - h_L = \frac{p_2}{\gamma_f} + z_2 + \frac{v_2^2}{2g} \left| \begin{array}{l} \text{Pt. 1 at lower pump surface. } p_1 = 0 \\ \text{Pt. 2 outside pipe at cutter. } v_1 = 0 \\ p_2 = 0 \end{array} \right.$

$$h_A = (z_2 - z_1) + \frac{v_2^2}{2g} + h_L = 1.25 \text{ m} + \frac{(2.91 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)} + 3.0 \text{ m} = 4.68 \text{ m}$$

$$v_2 = \frac{Q}{A_2} = \frac{60 \text{ L/min}(1 \text{ m}^3/\text{s})}{60000 \text{ L/min}} \times \frac{1}{3.437 \times 10^{-4} \text{ m}^2} = 2.91 \text{ m/s}$$

$$P_A = h_A \gamma_f Q = (4.68 \text{ m})(0.95) \left( \frac{9.81 \text{ kN}}{\text{m}^3} \right) \left( \frac{60 \text{ m}^3}{60000 \text{ s}} \right)$$

$$= \frac{0.0436 \text{ kN} \cdot \text{m}}{\text{s}} \times \frac{10^3 \text{ N}}{\text{kN}} = \frac{43.6 \text{ N} \cdot \text{m}}{\text{s}} = 43.6 \text{ W}$$

7.18 Tub Volume =  $(\pi D^2/4)(d) = [\pi(0.525 \text{ m})^2/4](0.25 \text{ m}) = 0.0541 \text{ m}^3$   
 $Q = V/t = 0.0541 \text{ m}^3/90 \text{ s} = 6.013 \times 10^{-4} \text{ m}^3/\text{s}$

Outlet  $v_2 = \frac{Q}{A_2} = \frac{6.013 \times 10^{-4} \text{ m}^3/\text{s}}{\pi(0.18 \text{ m})^2/4} = 2.36 \text{ m/s} \left| \begin{array}{l} \text{Pt. 1 at tub surface.} \\ \text{Pt. 2 in outlet stream.} \\ p_1 = p_2 = 0; v_1 = 0 \end{array} \right.$

$$\frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} + h_A - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$$

$$h_A = (z_2 - z_1) + \frac{v_2^2}{2g} + h_L = (1.00 - 0.375) \text{ m} + \frac{(2.36 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)} + 0.22 \text{ m} = 1.13 \text{ m}$$

7.19 Weight Flow Rate =  $W = w/t = 556 \text{ lb}/10 \text{ s} = 55.6 \text{ lb/s}$

$$Q = \frac{W}{\gamma_w} = \frac{55.6 \text{ lb/s}}{62.4 \text{ lb/ft}^3} = 0.891 \text{ ft}^3/\text{s}; \quad v_A = \frac{Q}{A_A} = \frac{0.891 \text{ ft}^3/\text{s}}{\pi(4/12)^2/4 \text{ ft}^2} = 10.21 \text{ ft/s}$$

$$v_B = v_A \left( \frac{D_A}{D_B} \right)^2 = 10.21 \text{ ft/s} \left( \frac{4}{3} \right)^2 = 18.15 \text{ ft/s at outlet of upper pipe (Pt. B)}$$

$$\frac{p_A}{\gamma_w} + z_A + \frac{v_A^2}{2g} + h_A - h_L = \frac{p_B}{\gamma_w} + z_B + \frac{v_B^2}{2g}; \quad h_L = 0 \text{ and } p_B = 0$$

$$h_A = (z_B - z_A) + \frac{v_B^2 - v_A^2}{2g} - \frac{p_A}{\gamma_w} = 20 \text{ ft} + \frac{(18.15^2 - 10.21^2) \text{ ft}^2/\text{s}^2}{2(32.2 \text{ ft/s}^2)} - \frac{-2.0 \text{ lb ft}^3}{\text{in}^2(62.4 \text{ lb})} \frac{144 \text{ in}^2}{\text{ft}^2}$$

$$h_A = 20 \text{ ft} + 3.50 \text{ ft} + 4.62 \text{ ft} = 28.11 \text{ ft}$$

$$P_A = h_A W = 28.11 \text{ ft}(55.6 \text{ lb/s}) = \frac{1563 \text{ ft} \cdot \text{lb/s}(1 \text{ hp})}{550 \text{ ft} \cdot \text{lb/s}} = \mathbf{2.84 \text{ hp}}$$

7.20  $Q = \frac{9.1 \text{ gal/min}(1 \text{ ft}^3/\text{s})}{449 \text{ gal/min}} = 0.0203 \text{ ft}^3/\text{s}$

$$P_A = h_A \gamma_o Q = (257 \text{ ft})(0.90)(62.4 \text{ lb/ft}^3)(0.0203 \text{ ft}^3/\text{s}) = 292.5 \text{ ft} \cdot \text{lb/s}/550 = 0.532 \text{ hp}$$

$$e_M = \frac{P_A}{P_i} = \frac{0.532 \text{ hp}}{0.850 \text{ hp}} = 0.626 = \mathbf{62.6\%}$$

7.21  $Q = \frac{V}{t} = \frac{1.0 \text{ L}}{40 \text{ s}} \times \frac{1 \text{ m}^3}{10^3 \text{ L}} = 2.50 \times 10^{-5} \text{ m}^3/\text{s}$

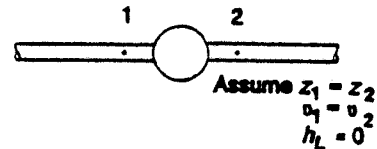
$$p_1 = \gamma_m h = \frac{133.4 \text{ kN}}{\text{m}^3} \times (-0.15 \text{ m}) = -20.0 \text{ kPa}$$

$$\frac{p_1}{\gamma_g} + z_1 + \frac{v_1^2}{2g} + h_A - h_L = \frac{p_2}{\gamma_g} + z_2 + \frac{v_2^2}{2g}$$

$$h_A = \frac{p_2 - p_1}{\gamma_g} = \frac{[30 - (-20)] \text{ kN/m}^2}{6.67 \text{ kN/m}^3} = 7.50 \text{ m}$$

$$P_A = h_A \gamma_g Q = (7.50 \text{ m})(6.67 \text{ kN/m}^3)(2.50 \times 10^{-5} \text{ m}^3/\text{s})(10^3 \text{ N/kN}) = 1.25 \text{ N} \cdot \text{m/s}$$

$$P_i = \frac{P_A}{e_M} = \frac{1.25 W}{0.60} = \mathbf{2.08 W}$$



7.22 a)  $Q = A_{\text{cyl}} \times \frac{\text{stroke}}{\text{time}} = \frac{\pi(5.0 \text{ in})^2(1 \text{ ft}^2)}{4(144 \text{ in}^2)} \times \frac{20 \text{ in}}{15 \text{ s}} \frac{\text{ft}}{12 \text{ in}} = \mathbf{0.01515 \text{ ft}^3/\text{s}}$

b)  $p_{\text{cyl}} = \frac{F}{A_{\text{cyl}}} = \frac{11000 \text{ lb}}{\pi(5.0)^2/(4) \text{ in}^2} = (\mathbf{560 \text{ lb/in}^2})(144 \text{ in}^2/\text{ft}^2) = 80672 \text{ lb/ft}^2$

$$c) \quad \frac{p_B}{\gamma_o} + z_B + \frac{v_B^2}{2g} - h_{L_D} = \frac{p_C}{\gamma_o} + z_C + \frac{v_C^2}{2g}$$

$$p_B = p_C + \gamma_o \left[ (z_C - z_B) + \frac{v_C^2 - v_B^2}{2g} + h_{L_D} \right]$$

Pt. A at tank surface.  
Pt. B at pump outlet.  
Pt. C in cylinder.

$$v_C = \frac{20 \text{ in}}{15 \text{ s}} \times \frac{\text{ft}}{12 \text{ in}} = 0.1111 \frac{\text{ft}}{\text{s}}; \quad v_B = \frac{Q}{A_B} = \frac{0.01515 \text{ ft}^3/\text{s}}{0.000976 \text{ ft}^2} = 15.52 \text{ ft/s}$$

$$p_B = 560 \text{ psig} + 0.90 \frac{(62.4 \text{ lb})}{\text{ft}^3} \left[ 10 \text{ ft} + \frac{(0.1111^2 - 15.52^2)}{2(32.2)} + 35.0 \text{ ft} \right] \frac{1 \text{ ft}^2}{144 \text{ in}^2}$$

$$= 576.1 \text{ psig}$$

$$d) \quad \frac{p_A}{\gamma_o} + z_A + \frac{v_A^2}{2g} - h_{L_S} = \frac{p_D}{\gamma_o} + z_D + \frac{v_D^2}{2g}; \quad \text{Pt. D at pump inlet.}$$

$$p_A = 0, v_A = 0$$

$$p_D = \gamma_o \left[ z_A - z_D - \frac{v_D^2}{2g} - h_{L_S} \right]$$

$$v_D = v_B = 15.52 \text{ ft/s}$$

$$p_D = \frac{(0.90)(62.4 \text{ lb})}{\text{ft}^3} \left[ -5.0 \text{ ft} - \frac{(15.52 \text{ ft/s})^2}{2(32.2 \text{ ft/s}^2)} - 11.5 \text{ ft} \right] \frac{1 \text{ ft}^2}{144 \text{ in}^2}$$

$$p_D = -4.98 \text{ psig}$$

$$e) \quad \frac{p_A}{\gamma_o} + z_A + \frac{v_A^2}{2g} + h_A - h_{L_S} - h_{L_D} = \frac{p_C}{\gamma_o} + z_C + \frac{v_C^2}{2g}; \quad p_A = 0, v_A = 0$$

$$h_A = \frac{p_C}{\gamma_o} + (z_C - z_A) + \frac{v_C^2}{2g} + h_{L_S} + h_{L_D} = \frac{80672 \text{ lb} \cdot \text{ft}^3}{\text{ft}^2(0.9)(62.4 \text{ lb})} + 15 \text{ ft} + \frac{(1111)^2}{2g} + 11.5 \text{ ft} + 35 \text{ ft}$$

$$h_A = 1498 \text{ ft}$$

$$P_A = h_A \gamma_o Q = (1498 \text{ ft})(0.90)(62.4 \text{ lb/ft}^3)(0.01515 \text{ ft}^3/\text{s}) = \frac{1275 \text{ ft} \cdot \text{lb/s}}{550} = 2.32 \text{ hp}$$

$$7.23 \quad \frac{p_A}{\gamma_o} + z_A + \frac{v_A^2}{2g} - h_R - h_L = \frac{p_B}{\gamma_o} + z_B + \frac{v_B^2}{2g} \quad \left| \quad v_A = v_B \cdot \frac{A_B}{A_A} = 1.5 \frac{1.772 \times 10^{-3} \text{ m}^2}{3.835 \times 10^{-4} \text{ m}^2} \right.$$

$$h_R = \frac{p_A - p_B}{\gamma_o} + (z_A - z_B) + \frac{v_A^2 - v_B^2}{2g} \quad \left| \quad v_A = 6.93 \text{ m/s; assume } h_L = 0 \right.$$

$$h_R = \frac{(6.8 - 3.4)(10^6 \text{ N/m}^2)}{0.90(9810 \text{ N/m}^3)} + 3.0 \text{ m} + \frac{(6.93^2 - 1.50^2) \text{ m}^2/\text{s}^2}{2(9.81 \text{ m/s}^2)} = 390 \text{ m}$$

$$P_R = h_R \gamma_o Q = h_R \gamma_o A_B v_B = (390 \text{ m})(0.90)(9.81 \text{ kN/m}^3)(1.772 \times 10^{-3} \text{ m}^2)(1.5 \text{ m/s})$$

$$= 9.15 \text{ kW}$$

$$7.24 \quad \frac{p_A}{\gamma_w} + z_A + \frac{v_A^2}{2g} - h_R - h_L = \frac{p_B}{\gamma_w} + z_B + \frac{v_B^2}{2g} \quad \left| \quad \begin{aligned} v_A &= \frac{Q}{A_A} = \frac{7.57 \text{ ft}^3/\text{s}}{0.7771 \text{ ft}^2} = 9.74 \text{ ft/s} \\ v_B &= \frac{Q}{A_B} = \frac{7.57}{2.792} = 2.71 \text{ ft/s} \\ h_L &= 2.0 \frac{v_A^2}{2g} = \frac{2.0(9.74)^2}{2(32.2)} = 2.95 \text{ ft} \end{aligned} \right.$$

$$h_R = \frac{p_A - p_B}{\gamma_w} + (z_A - z_B) + \frac{v_A^2 - v_B^2}{2g} - h_L$$

$$Q = \frac{3400 \text{ gal/min}(1 \text{ ft}^3/\text{s})}{449 \text{ gal/min}} = 7.57 \text{ ft}^3/\text{s}$$

$$h_R = \frac{[21.4 - (-5)] \text{ lb} \cdot \text{ft}^3 (144 \text{ in}^2)}{\text{in}^2 (62.4 \text{ lb}) 1 \text{ ft}^2} + 3 \text{ ft} + \frac{(9.74^2 - 2.74^2)}{2(32.2)} \text{ ft} - 2.95 \text{ ft} = 62.3 \text{ ft}$$

$$P_R = h_R \gamma_w Q = (62.3 \text{ ft})(62.4 \text{ lb/ft}^3)(7.57 \text{ ft}^3/\text{s}) = \frac{29454 \text{ ft} \cdot \text{lb/s}}{(550 \text{ ft} \cdot \text{lb/s})/\text{hp}} = \mathbf{53.6 \text{ hp}}$$

$$7.25 \quad \frac{p_1}{\gamma_o} + z_1 + \frac{v_1^2}{2g} - h_R - h_L = \frac{p_2}{\gamma_o} + z_2 + \frac{v_2^2}{2g} \quad \left| \quad \begin{aligned} \text{Pt. 1 at oil surface. } p_1 &= 0 \text{ and } v_1 = 0 \\ \text{Pt. 2 in outlet stream. } p_2 &= 0 \end{aligned} \right.$$

$$h_R = (z_1 - z_2) - \frac{v_2^2}{2g} - h_L = 10 \text{ m} - 0.638 \text{ m} - 1.40 \text{ m} = 7.96 \text{ m}$$

$$v_2 = \frac{Q}{A_2} = \frac{0.25 \text{ m}^3/\text{s}}{\pi(0.30 \text{ m})^2/4} = 3.54 \text{ m/s}; \quad \frac{v_2^2}{2g} = \frac{3.54^2 \text{ m}^2/\text{s}^2}{2(9.81) \text{ m/s}^2} = 0.638 \text{ m}$$

$$P_R = h_R \gamma_o Q = (7.96 \text{ m})(0.86)(9.81 \text{ kN/m}^3)(0.25 \text{ m}^3/\text{s}) = 16.79 \text{ kN} \cdot \text{m/s} = \mathbf{16.79 \text{ kW}}$$

$$P_o = P_R \cdot e_M = 16.79 \text{ kW} \times 0.75 = \mathbf{12.60 \text{ kW}}$$

$$7.26 \quad \frac{p_1}{\gamma_f} + z_1 + \frac{v_1^2}{2g} - h_A - h_L = \frac{p_2}{\gamma_f} + z_2 + \frac{v_2^2}{2g} \quad \left| \quad \begin{aligned} Q &= 40 \text{ gal/min}/449 = 0.0891 \text{ ft}^3/\text{s} \\ v_1 &= \frac{Q}{A_1} = \frac{0.0891 \text{ ft}^3/\text{s}}{0.05132 \text{ ft}^2} = 1.74 \text{ ft/s} \\ v_2 &= \frac{Q}{A_2} = \frac{0.0891}{0.02333} = 3.82 \text{ ft/s} \end{aligned} \right.$$

$$h_A = \frac{p_2 - p_1}{\gamma_f} + (z_2 - z_1) + \frac{v_2^2 - v_1^2}{2g} + h_L$$

$$h_A = \frac{[50.0 - (-2.30)] \text{ lb} \cdot \text{ft}^3 144 \text{ in}^2}{\text{in}^2 (60.0 \text{ lb}) \text{ft}^2} + 25 \text{ ft} + \frac{(3.82^2 - 1.74^2) \text{ ft}^2}{2(32.2 \text{ ft/s}^2) \text{s}^2} + 3.4 \text{ ft} = 154.1 \text{ ft}$$

$$P_A = h_A \gamma_f Q = (154.1 \text{ ft})(60.0 \text{ lb/ft}^3)(0.0891 \text{ ft}^3/\text{s})(1 \text{ hp}/550 \text{ lb} \cdot \text{ft/s}) = \mathbf{1.50 \text{ hp}}$$

$$7.27 \quad P_I = P_A/e_M = 1.50 \text{ hp}/0.75 = \mathbf{2.00 \text{ hp}}$$

$$7.28 \quad \frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g} \quad \left| \quad \begin{aligned} \text{Pt. 1 at water surface. } p_1 &= 0, v_1 = 0 \\ \text{Pt. 2 in outlet stream. } p_2 &= 0 \end{aligned} \right.$$

$$h_L = (z_1 - z_2) - \frac{v_2^2}{2g} = 4.0 \text{ m} - (5.14 \text{ m/s})^2/2(9.81 \text{ m/s}^2) = \mathbf{2.65 \text{ m}}$$

$$v_2 = \frac{Q}{A_2} = \frac{600 \text{ L/min}(1 \text{ m}^3/\text{s})}{60000 \text{ L/min } 1.945 \times 10^{-3} \text{ m}^2} = 5.14 \text{ m/s}$$

$$7.29 \quad \frac{p_1}{\gamma_K} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_B}{\gamma_K} + z_B + \frac{v_B^2}{2g} \quad \left| \begin{array}{l} \text{Pt. 1 at tank surface. } p_1 = 0, v_1 = 0 \\ v_B = \frac{Q}{A_B} = \frac{0.060 \text{ m}^3/\text{s}}{4.768 \times 10^{-3} \text{ m}^2} = 12.58 \text{ m/s} \end{array} \right.$$

$$p_B = \gamma_K \left[ (z_1 - z_B) - \frac{v_B^2}{2g} - h_L \right]$$

$$p_B = (0.823)(9.81 \text{ kN/m}^3) \left[ 17.0 \text{ m} - \frac{(12.58 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)} - 4.60 \text{ m} \right] = 35.0 \text{ kN/m}^2 = \mathbf{35.0 \text{ kPa}}$$

$$7.30 \quad \frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} - h_R - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{v_2^2}{2g} \quad \left| \begin{array}{l} \text{Pt. 1 at reservoir surface. } p_1 = 0, v_1 = 0 \\ \text{Pt. 2 in outlet stream. } p_2 = 0 \end{array} \right.$$

$$h_L = (z_1 - z_2) - \frac{v_2^2}{2g} - h_R$$

$$v_2 = \frac{Q}{A_2} = \frac{1000 \text{ gal/min}}{0.3472 \text{ ft}^2} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 6.41 \text{ ft/s}$$

$$h_L = 165 \text{ ft} - \frac{(6.41 \text{ ft/s})^2}{2(32.2 \text{ ft/s}^2)} - 146.4 \text{ ft} = 17.9 \text{ ft} = \mathbf{17.9 \text{ ft}\cdot\text{lb/lb}}$$

$$h_R = \frac{P_R}{\gamma_w Q} = \frac{37.0 \text{ hp}(550 \text{ ft}\cdot\text{lb/s})}{1 \text{ hp}(62.4 \text{ lb/ft}^3)(2.227 \text{ ft}^3/\text{s})} = 146.4 \text{ ft}$$

$$7.31 \quad \frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} - h_{L_s} = \frac{p_A}{\gamma_w} + z_A + \frac{v_A^2}{2g} \quad \text{Pt. 1 at reservoir surface. } p_1 = 0, v_1 = 0$$

$$h = (z_1 - z_A) = \frac{p_A}{\gamma_w} + \frac{v_A^2}{2g} + h_L$$

$$Q = 1500 \text{ gal/min} \times 1 \text{ ft}^3/\text{s}/449 \text{ gal/min} = 3.341 \text{ ft}^3/\text{s}$$

$$v_A = \frac{Q}{A_A} = \frac{3.341 \text{ ft}^3/\text{s}}{0.5479 \text{ ft}^2} = 6.10 \text{ ft/s}$$

$$h = \frac{5.0 \text{ lb}(\text{ft}^3)(144 \text{ in}^2)}{\text{in}^2(62.4 \text{ lb})(\text{ft}^2)} + \frac{(6.10 \text{ ft/s})^2}{2(32.2 \text{ ft/s}^2)} + 0.65 \text{ ft} = \mathbf{12.8 \text{ ft}}$$

$$7.32 \quad \frac{p_A}{\gamma_w} + z_A + \frac{v_A^2}{2g} + h_A - h_{L_D} = \frac{p_B}{\gamma_w} + z_B + \frac{v_B^2}{2g} \quad \left| \begin{array}{l} v_B = \frac{Q}{A_B} = \frac{3.341 \text{ ft}^3/\text{s}}{0.3472 \text{ ft}^2} = 9.62 \text{ ft/s} \end{array} \right.$$

$$h_A = \frac{p_B - p_A}{\gamma_w} + (z_B - z_A) + \frac{v_B^2 - v_A^2}{2g} + h_{L_D} = \frac{(85 - 5) \text{ lb}(\text{ft}^3)144 \text{ in}^2}{\text{in}^2(62.4 \text{ lb})\text{ft}^2} + 25 \text{ ft}$$

$$+ \frac{(9.62^2 - 6.10^2) \text{ ft}^2/\text{s}^2}{2(32.2 \text{ ft/s}^2)} + 28 \text{ ft} = 238.5 \text{ ft}$$

$$P_A = h_A \gamma_w Q = (238.5 \text{ ft})(62.4 \text{ lb/ft}^3)(3.341 \text{ ft}^3/\text{s})/550 = \mathbf{90.4 \text{ hp}}$$

$$7.33 \quad \frac{p_1}{\gamma_K} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_K} + z_2 + \frac{v_2^2}{2g} \quad \left| \begin{array}{l} \text{Pt. 1 at tank surface. } v_1 = 0 \\ \text{Pt. 2 in outlet stream. } p_2 = 0 \end{array} \right.$$

$$h_L = \frac{p_1}{\gamma_K} + (z_1 - z_2) - \frac{v_2^2}{2g} = \frac{103.4 \text{ kN/m}^2}{8.07 \text{ kN/m}^3} - 5.0 \text{ m} - \frac{(4.28 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)} = \mathbf{6.88 \text{ m}}$$

$$\underbrace{\hspace{10em}}_{= 0.936 \text{ m}}$$

$$v_2 = \frac{Q}{A_2} = \frac{500 \text{ L/min}}{1.945 \times 10^{-3} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 4.28 \text{ m/s}$$

$$p_1 = 15.0 \text{ psi} \times 6895 \text{ Pa/psi} = 1.034 \times 10^5 \text{ N/m}^2 \times 1 \text{ kN}/10^3 \text{ N} = \mathbf{103.4 \text{ kN/m}^2}$$

$$7.34 \quad (\text{See Prob. 7.33}) \quad v_2 = 2(4.28 \text{ m/s}) = 8.56 \text{ m/s}$$

$$\frac{v_2^2}{2g} = \frac{(8.56 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)} = 3.74 \text{ m}; \text{ Then } h_L = 6.88 \text{ m} \times \frac{3.74 \text{ m}}{0.936 \text{ m}} = 27.52 \text{ m}$$

$$p_1 = \gamma_K \left[ (z_2 - z_1) + \frac{v_2^2}{2g} + h_L \right] = \frac{8.07 \text{ kN}}{\text{m}^3} [5.0 + 3.74 + 27.52] \text{ m} = 292.6 \text{ kPa}$$

$$p_1 = 292.6 \text{ kPa} \times 1.0 \text{ psi}/6.895 \text{ kPa} = \mathbf{42.4 \text{ psig}}$$

**General data for Problems 7.35 through 7.40:**

$$\gamma_o = \text{sg}_o \gamma_w = 0.93(62.4 \text{ lb/ft}^3) = 58.03 \text{ lb/ft}^3$$

$$Q = 175 \text{ gal/min} \times 1 \text{ ft}^3/\text{s}/449 \text{ gal/min} = 0.390 \text{ ft}^3/\text{s}$$

$$P_A = P_{in} \times e_M = 28.4 \text{ hp}(0.80) = 22.7 \text{ hp} \times 550 \text{ ft}\cdot\text{lb/s}/\text{hp} = 12496 \text{ ft}\cdot\text{lb/s}$$

$$7.35 \quad \frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_{L_{1-6}} + h_A - h_R = \frac{p_6}{\gamma} + z_6 + \frac{v_6^2}{2g}; \quad p_1 = p_6 = 0, \quad v_1 = 0$$

$$h_R = (z_1 - z_6) - \frac{v_6^2}{2g} - h_{L_{1-6}} + h_A$$

$$z_1 - z_6 = -1.0 \text{ ft}$$

$$v_6 = \frac{Q}{A_6} = \frac{0.390 \text{ ft}^3/\text{s}}{0.03326 \text{ ft}^2} = 11.72 \text{ ft/s} = v_3 = v_4 = v_5$$

$$\frac{v_6^2}{2g} = \frac{(11.72)^2}{2(32.2)} = 2.13 \text{ ft}$$

$$h_{L_{1-6}} = 2.80 + 28.50 + 3.50 = 34.8 \text{ ft}$$

$$P_A = h_A \gamma Q; \quad h_A = \frac{P_A}{\gamma Q} = \frac{12496 \text{ ft}\cdot\text{lb/s}}{(58.03 \text{ lb/ft}^3)(0.390 \text{ ft}^3/\text{s})} = 552.5 \text{ ft}$$

$$h_R = -1.0 - 2.13 - 34.8 + 552.5 = 514.5 \text{ ft}$$

$$P_R = h_R \gamma Q = \frac{(514.5 \text{ ft})(58.03 \text{ lb/ft}^3)(0.390 \text{ ft}^3/\text{s})}{550 \text{ ft}\cdot\text{lb/s}/\text{hp}} = \mathbf{21.16 \text{ hp}}$$

$$7.36 \quad \frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_{L_{1-2}} = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}; \quad p_1 = 0, v_1 = 0$$

$$p_2 = \gamma \left[ (z_1 - z_2) - \frac{v_2^2}{2g} - h_{L_{1-2}} \right]$$

$$v_2 = \frac{Q}{A_2} = \frac{0.390 \text{ ft}^3/\text{s}}{0.05132 \text{ ft}^2} = 7.59 \text{ ft/s}$$

$$\frac{v_2^2}{2g} = \frac{(7.59)^2}{2(32.2)} = 0.896 \text{ ft}$$

$$p_2 = 58.03 \frac{\text{lb}}{\text{ft}^3} [-4.0 \text{ ft} - 0.896 \text{ ft} - 2.80 \text{ ft}] \frac{1 \text{ ft}^2}{144 \text{ in}^2} = -3.10 \text{ psig}$$

$$7.37 \quad \frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_{L_{1-2}} + h_A = \frac{p_3}{\gamma} + z_3 + \frac{v_3^2}{2g}; \quad p_1 = 0, v_1 = 0$$

$$p_3 = \gamma \left[ (z_1 - z_3) - \frac{v_3^2}{2g} - h_{L_{1-2}} + h_A \right] = 58.03 \frac{\text{lb}}{\text{ft}^3} [-4.0 - 2.13 - 2.80 + 552.5] \frac{\text{ft} \cdot \text{ft}^2}{144 \text{ in}^2}$$

$$p_3 = 219.1 \text{ psig}$$

$$7.38 \quad \frac{p_3}{\gamma} + z_3 + \frac{v_3^2}{2g} - h_{L_{3-4}} = \frac{p_4}{\gamma} + z_4 + \frac{v_4^2}{2g}; \quad v_3 = v_4$$

$$z_3 = z_4$$

$$p_4 = p_3 - \gamma h_{L_{3-4}} = 219.1 \text{ psig} - 58.03 \frac{\text{lb}}{\text{ft}^3} (28.5 \text{ ft}) \frac{1 \text{ ft}^2}{144 \text{ in}^2} = 207.6 \text{ psig}$$

$$7.39 \quad \frac{p_5}{\gamma} + z_5 + \frac{v_5^2}{2g} - h_{L_{5-6}} = \frac{p_6}{\gamma} + z_6 + \frac{v_6^2}{2g}; \quad v_5 = v_6, p_6 = 0$$

$$p_5 = \gamma \left[ (z_6 - z_5) + h_{L_{5-6}} \right] = 58.03 \frac{\text{lb}}{\text{ft}^3} [-1.0 \text{ ft} + 3.50 \text{ ft}] \frac{1 \text{ ft}^2}{144 \text{ in}^2} = 1.01 \text{ psig}$$

7.40 For  $Q = 175 \text{ gal/min}$ , Fig. 6.2 suggests using either a 2 1/2-in or 3-in Schedule 40 steel pipe for the suction line. The given 3-in pipe is satisfactory. However, noting that the pressure at the inlet to the pump is  $-3.10 \text{ psig}$ , a larger pipe may be warranted to decrease the energy losses in the suction line and increase the pump inlet pressure. See Chapters 9–13, especially Section 13.12 on net positive suction head (NPSH).

Fig. 6.2 suggests either a 2-in or 2 1/2-in pipe for the discharge line. The given 2 1/2-in pipe size is satisfactory.

$$7.41 \quad \frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g} : p_2 = 0$$

$$p_1 = \gamma \left[ (z_2 - z_1) - \frac{v_2^2 - v_1^2}{2g} + h_L \right]$$

$$\gamma = 0.76(62.4 \text{ lb/ft}^3) = 47.42 \text{ lb/ft}^3$$

$$z_2 - z_1 = -22 \text{ in}(1 \text{ ft}/12 \text{ in}) = -1.833 \text{ ft}$$

$$Q = \frac{40 \text{ gal}}{8 \text{ s}} \times \frac{\text{ft}^3}{7.48 \text{ gal}} = 0.668 \text{ ft}^3/\text{s}$$

$$v_2 = \frac{Q}{A_2} = \frac{0.668 \text{ ft}^3/\text{s}}{\pi(2.0 \text{ in})^2/4} \times \frac{144 \text{ in}^2}{\text{ft}^2} = 30.64 \text{ ft/s}$$

$$v_1 = \frac{Q}{A_1} = \frac{0.668 \text{ ft}^3/\text{s}}{\pi(18.0 \text{ in})^2/4} \times \frac{144 \text{ in}^2}{\text{ft}^2} = 0.378 \text{ ft/s}$$

$$p_1 = 47.42 \frac{\text{lb}}{\text{ft}^3} \left[ -1.833 \text{ ft} + \frac{(30.64^2 - 0.378^2) \text{ft}^2/\text{s}^2}{2(32.2 \text{ ft/s}^2)} + 4.75 \text{ ft} \right] \frac{1 \text{ ft}^2}{144 \text{ in}^2}$$

$$p_1 = \mathbf{5.76 \text{ psig}}$$

$$7.42 \quad \frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L + h_A = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g} \quad \begin{array}{l} \text{Pt. 1 at creek surface. } p_1 = 0, v_1 = 0 \\ \text{Pt. 2 at tank surface. } v_2 = 0 \end{array}$$

$$h_A = \frac{p_2}{\gamma} + (z_2 - z_1) + h_L = \frac{30 \text{ lb}}{\text{in}^2} \frac{\text{ft}^3}{62.4 \text{ lb}} \frac{144 \text{ in}^2}{\text{ft}^2} + 220 \text{ ft} + 15.5 \text{ ft} = 304.7 \text{ ft}$$

$$P_A = h_A \gamma Q = 304.7 \text{ ft} \times \frac{62.4 \text{ lb}}{\text{ft}^3} \times \frac{40 \text{ gal/min}}{449 \text{ gal/min}} \frac{(1 \text{ ft}^3/\text{s}) \text{hp}}{550 \text{ ft} \cdot \text{lb/s}} = \mathbf{3.08 \text{ hp}}$$

$$7.43 \quad P_I = \frac{P_A}{e_M} = \frac{3.08 \text{ hp}}{0.72} = \mathbf{4.28 \text{ hp}}$$

$$7.44 \quad \frac{p_1}{\gamma_o} + z_1 + \frac{v_1^2}{2g} - h_R = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}; \quad z_1 = z_2$$

$$h_R = \frac{p_1 - p_2}{\gamma_o} + \frac{v_1^2 - v_2^2}{2g}$$

$$\text{Manometer: } p_1 + \gamma_o y + \gamma_o(38.5 \text{ in}) - \gamma_m(38.5 \text{ in}) - \gamma_o y = p_2$$

$$p_1 - p_2 = \gamma_m(38.5 \text{ in}) - \gamma_o(38.5 \text{ in})$$

$$\frac{p_1 - p_2}{\gamma_o} = \frac{\gamma_m}{\gamma_o}(38.5 \text{ in}) - 38.5 \text{ in} = \frac{13.54\gamma_w}{0.9\gamma_w}(38.5 \text{ in}) - 38.5 \text{ in}$$

$$\frac{p_1 - p_2}{\gamma_o} = 540.7 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}} = 45.06 \text{ ft}$$

$$v_1 = \frac{Q}{A_1} = \frac{135 \text{ gal/min}}{0.01227 \text{ ft}^2} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = \frac{0.3007 \text{ ft}^3/\text{s}}{0.01227 \text{ ft}^2} = 24.50 \text{ ft/s}$$

$$v_2 = \frac{Q}{A_2} = \frac{0.3007 \text{ ft}^3/\text{s}}{0.02944 \text{ ft}^2} = 10.21 \text{ ft/s}$$

$$h_R = 45.06 \text{ ft} + \frac{(24.5^2 - 10.21^2) \text{ ft}^2/\text{s}^2}{2(32.2 \text{ ft/s}^2)} = 52.76 \text{ ft}$$

$$P_R = h_R \gamma Q = (52.76 \text{ ft})(0.90)(62.4 \text{ lb/ft}^3)(0.3007 \text{ ft}^3/\text{s}) = 891.0 \text{ ft}\cdot\text{lb/s}$$

$$P_R = 891.0 \text{ ft}\cdot\text{lb/s} \times \frac{1 \text{ hp}}{550 \text{ ft}\cdot\text{lb/s}} = \mathbf{1.62 \text{ hp}}$$

$$7.45 \quad P_o = P_R \times e_M = 1.62 \text{ hp} \times 0.78 = \mathbf{1.26 \text{ hp}}$$

## CHAPTER EIGHT

# REYNOLDS NUMBER, LAMINAR FLOW, TURBULENT FLOW, AND ENERGY LOSSES DUE TO FRICTION

$$8.1 \quad v = \frac{Q}{A} = \frac{0.20 \text{ ft}^3/\text{s}}{\pi(4.0 \text{ in})^2/4} \times \frac{144 \text{ in}^2}{\text{ft}^2} = 2.29 \text{ ft/s}; D = 4.0 \text{ in}(1 \text{ ft}/12 \text{ in}) = 0.333 \text{ ft}$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(2.29)(0.333)(1.26)(1.94)}{7.5 \times 10^{-3}} = 249 \text{ Laminar}$$

└ from App. D

$$8.2 \quad \text{Let } N_R = 4000 = vD/v: v = 4.38 \times 10^{-6} \text{ ft}^2/\text{s} \text{—App. A; } D = (2/12) \text{ ft}$$

$$v = \frac{N_R v}{D} = \frac{4000(4.38 \times 10^{-6})}{2/12} = 0.105 \frac{\text{ft}}{\text{s}} \times \frac{0.3048 \text{ m}}{\text{ft}} = 0.03204 \frac{\text{m}}{\text{s}}$$

$$8.3 \quad \text{Let } N_R = 2000 = vD\rho/\mu$$

$$v_{\max} = \frac{N_R \mu}{D\rho} = \frac{2000(4.0 \times 10^{-2})}{(0.10)(0.895)(1000)} = 0.894 \text{ m/s}$$

$$Q = Av = \frac{\pi(0.10 \text{ m})^2}{4} \times 0.894 \text{ m/s} = 7.02 \times 10^{-3} \text{ m}^3/\text{s}$$

$$8.4 \quad v = Q/A = \frac{0.25 \text{ ft}^3/\text{s}}{0.02333 \text{ ft}^2} = 10.72 \text{ ft/s}; D = 0.1723 \text{ ft}$$

$$a) \quad N_R = \frac{vD}{\nu} = \frac{(10.72)(0.1723)}{1.21 \times 10^{-5}} = 1.53 \times 10^5 \text{ (} \nu \text{ from App. A)}$$

$$b) \quad N_R = \frac{vD\rho}{\mu} = \frac{(10.72)(0.1723)(1.53)}{6.60 \times 10^{-6}} = 4.28 \times 10^5 \text{ (} \rho, \mu \text{ from App. B)}$$

$$c) \quad N_R = \frac{vD\rho}{\mu} = \frac{(10.72)(0.1723)(1.86)}{1.36 \times 10^{-2}} = 253 \text{ (} \rho, \mu \text{ from App. B)}$$

$$d) \quad N_R = \frac{vD\rho}{\nu} = \frac{(10.72)(0.1723)(0.87)(1.94)}{9.5 \times 10^{-5}} = 3.28 \times 10^4 \text{ (} \mu \text{ from App. D)}$$

$$8.5 \quad N_R = \frac{vD\rho}{\mu} = \frac{QD\rho}{A\mu} = \frac{QD\rho}{\pi D^2/4 \mu} = \frac{4Q\rho}{\pi\mu D}; D_{\min} = \frac{4Q\rho}{\pi\mu N_R} = \frac{4Q}{\pi N_R \nu}$$

$$Q = 4.0 \text{ L/min} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 6.667 \times 10^{-5} \text{ m}^3/\text{s}; \text{ Let } N_R = 2000$$

$$a) D_{\min} = \frac{4(6.667 \times 10^{-5})}{\pi(2000)(\nu)} = \frac{4.244 \times 10^{-8}}{\nu} = \frac{4.244 \times 10^{-8}}{6.56 \times 10^{-7}} = 0.0647 \text{ m} = 64.7 \text{ mm}$$

**3-in Type K copper tube— $D = 73.8 \text{ mm}$**

$$b) D_{\min} = \frac{4.244 \times 10^{-8}(680)}{2.87 \times 10^{-4}} = 0.101 \text{ m; } \mathbf{5\text{-in tube, } D = 122 \text{ mm}}$$

$$c) D_{\min} = \frac{4.244 \times 10^{-8}(790)}{1.8 \times 10^{-3}} = 0.0186 \text{ m; } \frac{3}{4}\text{-in tube, } D = 18.9 \text{ mm}$$

$$d) D_{\min} = \frac{4.244 \times 10^{-8}(906)}{1.07 \times 10^{-1}} = 3.59 \times 10^{-4} \text{ m; } \frac{1}{8}\text{-in tube, } D = 4.57 \text{ mm}$$

Smallest listed

$$8.6 \quad N_R = \frac{\nu D \rho}{\mu}; \quad \mu = \frac{\nu D \rho}{N_R} = \frac{(2.97)(0.0779)(890)}{5 \times 10^4} = 4.12 \times 10^{-3} \text{ Pa}\cdot\text{s}$$

$$\nu = \frac{Q}{A} = \frac{8.50 \text{ L/min}}{4.768 \times 10^{-3} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 2.97 \text{ m/s}$$

From App. D, oil must be heated to **100°C** for SAE 10 oil.

8.7

**Auto. Hydraulic Oil**

**Medium Hydraulic Oil**

$$\text{At } 212^\circ\text{F} \quad N_R = \frac{\nu D}{\nu} = \frac{(10)(0.4011)}{7.85 \times 10^{-5}} = \mathbf{5.11 \times 10^4 \text{ turb.}} \quad N_R = \frac{10(0.4011)}{7.85 \times 10^{-5}} = \mathbf{5.11 \times 10^4 \text{ turb.}}$$

$$\text{At } 104^\circ\text{F} \quad N_R = \frac{(10)(0.4011)}{4.30 \times 10^{-4}} = \mathbf{9328 \text{ turb.}} \quad N_R = \frac{10(0.4011)}{7.21 \times 10^{-4}} = \mathbf{5563 \text{ turb.}}$$

$$8.8 \quad N_R = \frac{\nu D}{\nu} = \frac{(3.06)(0.0475)}{1.30 \times 10^{-6}} = \mathbf{1.12 \times 10^5 \text{ Turbulent}}$$

$$\nu = \frac{Q}{A} = \frac{325 \text{ L/min}}{1.772 \times 10^{-3} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 3.06 \text{ m/s}$$

$$8.9 \quad N_R = \frac{\nu D \rho}{\mu} = \frac{(0.899)(0.0243)(860)}{3.95 \times 10^{-4}} = \mathbf{4.76 \times 10^4 \text{ Turbulent}}$$

$$\nu = \frac{Q}{A} = \frac{25 \text{ L/min}}{4.636 \times 10^{-4} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 0.899 \text{ m/s}$$

$$8.10 \quad N_R = \frac{\nu D}{\nu} = \frac{(1.78)(0.0134)}{3.60 \times 10^{-7}} = \mathbf{6.62 \times 10^4 \text{ Turbulent}}$$

$$\nu = \frac{Q}{A} = \frac{15.0 \text{ L/min}}{1.407 \times 10^{-4} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 1.78 \text{ m/s}$$

$$8.11 \quad N_R = \frac{vD}{\nu} = \frac{(8.59)(1.563)}{1.40 \times 10^{-5}} = \mathbf{9.59 \times 10^5}$$

$$v = \frac{Q}{A} = \frac{16.5 \text{ ft}^3/\text{s}}{1.920 \text{ ft}^2} = 8.59 \text{ ft/s}$$

$$8.12 \quad v = \frac{Q}{A} = \frac{0.40 \text{ gal}}{\text{hr}} \times \frac{\text{ft}^3}{7.48 \text{ gal}} \times \frac{1 \text{ hr}}{3600 \text{ s}} \times \frac{1}{2.029 \times 10^{-5} \text{ ft}^2} = 0.732 \text{ ft/s}$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(0.732)(0.00508)(0.88)(1.94)}{6.2 \times 10^{-3}} = \mathbf{1.02 \text{ Laminar}}$$

$$8.13 \quad N_R = \frac{vD\rho}{\mu} = \frac{(0.732)(0.00508)(0.88)(1.94)}{1.90 \times 10^{-4}} = \mathbf{33.4 \text{ Laminar}}$$

Note: sg of oil may be slightly lower at 160°F.

$$8.14 \quad N_R = \frac{vD\rho}{\mu}; v = \frac{N_R\mu}{D\rho} = \frac{(4000)(4.01 \times 10^{-5})}{(0.2423)(1.56)} = \mathbf{0.424 \text{ ft/s}}$$

$$Q = Av = 4.609 \times 10^{-2} \text{ ft}^2 \times 0.424 \text{ ft/s} = \mathbf{1.96 \times 10^{-2} \text{ ft}^3/\text{s}}$$

$$8.15 \quad v = \frac{Q}{A} = \frac{45 \text{ L/min}}{2.812 \times 10^{-4} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 2.67 \text{ m/s}$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(2.67)(0.01892)(0.89)(1000)}{8 \times 10^{-3}} = \mathbf{5.61 \times 10^3 \text{ Turbulent}}$$

Note:  $\mu$  from App. D.

$$8.16 \quad N_R = \frac{vD\rho}{\mu} = \frac{(2.67)(0.01892)(890)}{3.0} = \mathbf{15.0 \text{ very low—Laminar}}$$

$$8.17 \quad v = \frac{Q}{A} = \frac{45 \text{ L/min}}{1.772 \times 10^{-3} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 0.423 \text{ m/s}$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(0.423)(0.0475)(890)}{8 \times 10^{-3}} = \mathbf{2237 \text{ Critical Zone}}$$

$$8.18 \quad N_R = \frac{vD\rho}{\mu} = \frac{(0.423)(0.0475)(890)}{3.0} = \mathbf{5.97 \text{ very low—Laminar}}$$

$$8.19 \quad v = \frac{Q}{A} = \frac{1.65 \text{ gal/min}}{2.509 \times 10^{-4} \text{ ft}^2} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 14.65 \text{ ft/s}$$

$$N_R = \frac{vD}{\nu} = \frac{(14.65)(0.01788)}{2.37 \times 10^{-4}} = \mathbf{1105 \text{ Laminar}}$$

$$8.20 \quad N_R = \frac{vD}{\nu} = \frac{(14.65)(0.01788)}{4.20 \times 10^{-5}} = \mathbf{6237 \text{ Turbulent}}$$

Changing from laminar flow, through critical zone, into turbulent flow could cause erratic performance. Also,  $v = 14.65$  ft/s is quite high, causing large pressure drops through the system.

$$8.21 \quad A = \frac{Q}{v} = \frac{500 \text{ gal/min}}{10.0 \text{ ft/s}} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 0.1114 \text{ ft}^2 \Rightarrow 5\text{-in Sch. 40 pipe}$$

$$A = 0.1390 \text{ ft}^2, D = 0.4026 \text{ ft}$$

$$\text{Actual } v = \frac{Q}{A} = \frac{(500/499) \text{ ft}^3/\text{s}}{0.1390 \text{ ft}^2} = 8.01 \text{ ft/s}$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(8.01)(0.4026)(2.13)}{3.38 \times 10^{-4}} = 2.12 \times 10^4$$

$$8.22 \quad v_1 = \frac{N_R \nu}{D} = \frac{2000(1.21 \times 10^{-5} \text{ ft}^2/\text{s})}{0.0621 \text{ ft}} = 0.3897 \text{ ft/s}$$

$$\text{For } N_R = 4000, v_2 = 2(0.3897 \text{ ft/s}) = 0.7794 \text{ ft/s}$$

$$Q_1 = Av_1 = (3.027 \times 10^{-3} \text{ ft}^2)(0.3897 \text{ ft/s})$$

$$= 1.180 \times 10^{-3} \text{ ft}^3/\text{s} \times \frac{449 \text{ gal/min}}{1 \text{ ft}^3/\text{s}}$$

$$Q_1 = 0.530 \text{ gal/min—Lower Limit}$$

$$Q_2 = 2Q_1 = 1.060 \text{ gal/min—Upper Limit}$$

8.23 (See Prob. 8.22)

$$v_1 = \frac{N_R \nu}{D} = \frac{(2000)(3.84 \times 10^{-6})}{0.0621} = 0.1237 \text{ ft/s}; v_2 = 2v_1 = 0.2473 \text{ ft/s}$$

$$Q_1 = Av_1 = (3.027 \times 10^{-3} \text{ ft}^2)(0.1237 \text{ ft/s}) \times \frac{449 \text{ gal/min}}{1 \text{ ft}^3/\text{s}} = 0.1681 \text{ gal/min}$$

$$Q_2 = 2Q_1 = 0.3362 \text{ gal/min}$$

$$8.24 \quad v = 1.30 \text{ cs} \times \frac{1.076 \times 10^{-5} \text{ ft}^2/\text{s}}{1 \text{ cs}} = 1.40 \times 10^{-5} \text{ ft}^2/\text{s}$$

$$Q = 45 \text{ gal/min} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 0.1002 \text{ ft}^3/\text{s}$$

$$v = \frac{Q}{A} = \frac{0.1002 \text{ ft}^3/\text{s}}{6.842 \times 10^{-3} \text{ ft}^2} = 14.65 \text{ ft/s}$$

$$N_R = \frac{vD}{\nu} = \frac{(14.65)(0.0933)}{1.40 \times 10^{-5}} = 9.78 \times 10^4$$

$$8.25 \quad \nu = 17.0 \text{ cs} \times \frac{10^{-6} \text{ m}^2/\text{s}}{1 \text{ cs}} = 1.7 \times 10^{-5} \text{ m}^2/\text{s}$$

$$v = \frac{Q}{A} = \frac{215 \text{ L/min}}{5.017 \times 10^{-4} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 7.142 \text{ m/s}$$

$$N_R = \frac{vD}{\nu} = \frac{(7.142)(0.0253)}{1.70 \times 10^{-5}} = 1.06 \times 10^4$$

$$8.26 \quad \nu = 1.20 \text{ cs} \times \frac{10^{-6} \text{ m}^2/\text{s}}{1 \text{ cs}} = 1.20 \times 10^{-6} \text{ m}^2/\text{s}$$

$$v = \frac{Q}{A} = \frac{200 \text{ L/min}}{3.835 \times 10^{-4} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 8.69 \text{ m/s}$$

$$N_R = \frac{vD}{\nu} = \frac{(8.69)(0.0221)}{1.20 \times 10^{-6}} = \mathbf{1.60 \times 10^5}$$

$$8.27 \quad \frac{p_1}{\gamma_o} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_o} + z_2 + \frac{v_2^2}{2g}; \quad v_1 = v_2$$

$$p_1 - p_2 = \gamma_o [z_2 - z_1 + h_L]$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(0.64)(0.0243)(0.86)(1000)}{1.70 \times 10^{-2}} = 787 \text{ (Laminar)}; \quad f = \frac{64}{N_R} = 0.0813$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = 0.0813 \times \frac{60}{0.0243} \times \frac{(0.64)^2}{2(9.81)} = 4.19 \text{ m}$$

$$p_1 - p_2 = (0.86)(9.82 \text{ kN/m}^3)[-60 \text{ m} + 4.19 \text{ m}] = -471 \text{ kN/m}^2 = \mathbf{-471 \text{ kPa}}$$

$$8.28 \quad \frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{v_2^2}{2g}; \quad v_1 = v_2; \quad z_1 = z_2; \quad p_1 - p_2 = \gamma_w h_L$$

$$v = \frac{Q}{A} = \frac{12.9 \text{ L/min}}{1.407 \times 10^{-4} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 1.528 \text{ m/s}$$

$$N_R = \frac{vD}{\nu} = \frac{(1.528)(0.0134)}{3.83 \times 10^{-7}} = 5.35 \times 10^4 \text{ (turbulent)}$$

$$D/\epsilon = 0.0134/1.50 \times 10^{-6} = 8933; \text{ Then } f = 0.0205$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = (0.0205) \cdot \frac{45}{0.0134} \cdot \frac{(1.528)^2}{2(9.81)} = 8.19 \text{ m}$$

$$p_1 - p_2 = \gamma_w h_L = 9.56 \text{ kN/m}^3 \times 8.19 \text{ m} = 78.3 \text{ kN/m}^2 = \mathbf{78.3 \text{ kPa}}$$

$$8.29 \quad \text{Let } N_R = 2000; \quad f = 64/N_R = 0.032; \quad N_R = \frac{vD\rho}{\mu}$$

$$v = \frac{N_R \mu}{D\rho} = \frac{(2000)(8.3 \times 10^{-4})}{(0.3355)(0.895)(1.94)} = 2.85 \text{ ft/s}$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = (0.032) \cdot \frac{100}{0.3355} \cdot \frac{(2.85)^2}{2(32.2)} \text{ ft} = 1.20 \text{ ft} = \mathbf{1.20 \text{ ft}\cdot\text{lb/lb}}$$

$$8.30 \quad \frac{p_A}{\gamma_o} + z_A + \frac{v_A^2}{2g} - h_L = \frac{p_B}{\gamma_o} + z_B + \frac{v_B^2}{2g} : v_A = v_B$$

$$p_B = p_A + \gamma_o [z_A - z_B - h_L]$$

$$v = \frac{N_R \mu}{D \rho} = \frac{(800)(4 \times 10^{-4})}{(0.2557)(0.90)(1.94)} = 0.717 \text{ ft/s}$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = \frac{64}{800} \cdot \frac{5000}{0.2557} \cdot \frac{(0.717)^2}{2(32.2)} = 12.5 \text{ ft}$$

$$p_B = 50 \text{ psig} + (0.90)(62.4 \text{ lb/ft}^3)[-20 \text{ ft} - 12.5 \text{ ft}] \frac{1 \text{ ft}^2}{144 \text{ in}^2} = \mathbf{37.3 \text{ psig}}$$

$$8.31 \quad \frac{p_1}{\gamma_b} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_b} + z_2 + \frac{v_2^2}{2g} : z_1 = z_2 : v_1 = v_2 : p_1 - p_2 = \gamma_b h_L = \gamma_b f \frac{L}{D} \frac{v^2}{2g}$$

$$v = \frac{Q}{A} = \frac{20 \text{ L/min}}{4.636 \times 10^{-4} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 0.719 \text{ m/s}$$

$$\rho = \frac{\gamma}{g} = \frac{8.62 \text{ kN}}{\text{m}^3} \times \frac{\text{s}^2}{9.81 \text{ m}} \times \frac{10^3 \text{ N}}{\text{kN}} \times \frac{1 \text{ kg} \cdot \text{m/s}^2}{\text{N}} = 879 \text{ kg/m}^3$$

$$N_R = \frac{v D \rho}{\mu} = \frac{(0.719)(0.0243)(879)}{3.95 \times 10^{-4}} = 3.89 \times 10^4$$

$$D/\varepsilon = 0.0243/4.6 \times 10^{-5} = 528; \text{ Then } f = 0.027$$

$$p_1 - p_2 = 8.62 \text{ kN/m}^3 \times 0.027 \times \frac{100}{0.0243} \times \frac{(0.719)^2}{2(9.81)} \text{ m} = 25.2 \text{ kN/m}^2 = \mathbf{25.2 \text{ kPa}}$$

$$8.32 \quad \text{From Prob. 8.31, } p_1 - p_2 = \gamma_w h_L; h_L = p_1 - p_2 / \gamma_w$$

$$h_L = \frac{(1035 - 669) \text{ kN/m}^2}{9.81 \text{ kN/m}^3} = 37.3 \text{ m} = f \frac{L}{D} \frac{v^2}{2g}$$

$$f = \frac{h_L D 2g}{L v^2} = \frac{(37.3)(0.03388)(2)(9.81)}{(30)(4.16)^2} = 0.048$$

$$v = \frac{Q}{A} = \frac{225 \text{ L/min}}{9.017 \times 10^{-4} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 4.16 \text{ m/s}$$

$$N_R = \frac{v D}{\nu} = \frac{(4.16)(0.03388)}{1.30 \times 10^{-6}} = 1.08 \times 10^5; \text{ Then } \frac{D}{\varepsilon} = 55 \text{ for } f = 0.048$$

$$\varepsilon = D/55 = 0.03388/55 = \mathbf{6.16 \times 10^{-4} \text{ m}}$$

8.33  $\frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{v_2^2}{2g}$  | Pt. 1 at tank surface.  $p_1 = 0, v_1 = 0$   
 Pt. 2 in outlet stream.  $p_2 = 0$   
 $D = 0.5054 \text{ ft}$   
 $A = 0.2006 \text{ ft}^2$

$$h = z_1 - z_2 = h_L + \frac{v_2^2}{2g}$$

$$v = \frac{Q}{A} = \frac{2.50 \text{ ft}^3/\text{s}}{0.2006 \text{ ft}^2} = 12.46 \text{ ft/s}$$

$$N_R = \frac{vD}{\nu} = \frac{(12.46)(0.5054)}{9.15 \times 10^{-6}} = 6.88 \times 10^5; \quad \frac{D}{\epsilon} = \frac{0.5054}{1.5 \times 10^{-4}} = 3369; \quad f = 0.0165$$

$$h = f \frac{L}{D} \frac{v^2}{2g} + \frac{v^2}{2g} = 0.0165 \times \frac{550}{0.5054} \times \frac{(12.46)^2}{2(32.2)} + \frac{(12.46)^2}{2(32.2)} = 45.7 \text{ ft}$$

8.34 From Prob. 8.31,  $p_1 - p_2 = \gamma_w h_L = \gamma_w f \frac{L}{D} \frac{v^2}{2g}$

$$v = \frac{Q}{A} = \frac{15.0 \text{ ft}^3/\text{s}}{\pi(1.50 \text{ ft})^2/4} = 8.49 \text{ ft/s}$$

$$N_R = \frac{vD}{\nu} = \frac{(8.49)(1.50)}{1.40 \times 10^{-5}} = 9.09 \times 10^5; \quad \frac{D}{\epsilon} = \frac{1.50}{4 \times 10^{-4}} = 3750; \quad f = 0.0158$$

$$p_1 - p_2 = \gamma_w f \frac{L}{D} \frac{v^2}{2g} = \frac{62.4 \text{ lb}}{\text{ft}^3} \times 0.0158 \times \frac{5280 \text{ ft}}{1.50 \text{ ft}} \times \frac{(8.49)^2 \text{ ft}^2/\text{s}^2}{2(32.2 \text{ ft/s}^2)} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} = 30.5 \text{ psi}$$

8.35  $Q = 1500 \text{ gal/min} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 3.34 \text{ ft}^3/\text{s}$

$$v_A = \frac{Q}{A_A} = \frac{3.34 \text{ ft}^3/\text{s}}{0.5479 \text{ ft}^2} = 6.097 \text{ ft/s}; \quad \frac{v_A^2}{2g} = \frac{(6.097)^2}{2(32.2)} = 0.577 \text{ ft}$$

a)  $\frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} - h_{L_s} = \frac{p_A}{\gamma_w} + z_A + \frac{v_A^2}{2g}$  | Pt. 1 at tank surface.  $p_1 = 0, v_1 = 0$

$$z_1 - z_A = h = \frac{p_A}{\gamma_w} + \frac{v_A^2}{2g} + h_L$$

$$N_R = \frac{v_A D}{\nu} = \frac{(6.097)(0.835)}{1.21 \times 10^{-5}} = 4.21 \times 10^5; \quad \frac{D}{\epsilon} = \frac{0.835}{1.5 \times 10^{-4}} = 5567; \quad f = 0.0155$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = (0.0155) \times \frac{45}{0.835} \times 0.577 \text{ ft} = 0.482 \text{ ft}$$

$$h = \frac{5.0 \text{ lb} \cdot \text{ft}^3}{\text{in}^2 62.4 \text{ lb}} \frac{144 \text{ in}^2}{\text{ft}^2} + 0.577 + 0.482 = 12.60 \text{ ft}$$

$$\begin{aligned}
 \text{b) } \quad \frac{p_A}{\gamma} + z_A + \frac{v_A^2}{2g} - h_{L_d} + h_A &= \frac{p_B}{\gamma} + z_B + \frac{v_B^2}{2g} \\
 v_B &= \frac{Q}{A_B} = \frac{3.34 \text{ ft}^3/\text{s}}{0.3472 \text{ ft}^2} = 9.62 \text{ ft/s} \\
 h_A &= \frac{p_B - p_A}{\gamma_w} + (z_B - z_A) + \frac{v_B^2 - v_A^2}{2g} + h_{L_d} = \frac{(85 - 5) \text{ lb ft}^3 (144 \text{ in}^2)}{\text{in}^2 (62.4 \text{ lb})\text{ft}^2} + 25 \\
 &\quad + \frac{(9.62^2 - 6.097^2) \text{ ft}^2/\text{s}^2}{2(32.2 \text{ ft/s}^2)} + 89.9 = 300.4 \text{ ft} \\
 N_{R_b} &= \frac{v_B D_B}{\nu} = \frac{(9.62)(0.6651)}{1.21 \times 10^{-5}} = 5.29 \times 10^5 \\
 D/\varepsilon &= \frac{0.6651}{1.5 \times 10^{-4}} = 4434; \quad f = 0.016 \\
 h_{L_d} &= f \frac{L}{D} \frac{v^2}{2g} = (0.016) \times \frac{2600}{0.6651} \times \frac{(9.62)^2}{2(32.2)} = 89.9 \text{ ft} \\
 P_A &= h_A \gamma_w Q = 300.4 \text{ ft} \times \frac{62.4 \text{ lb}}{\text{ft}^3} \times \frac{3.34 \text{ ft}^3}{\text{s}} \frac{\text{hp}}{550 \text{ ft} \cdot \text{lb/s}} = \mathbf{113.8 \text{ hp}}
 \end{aligned}$$

$$8.36 \quad \frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} + h_A - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$$

Pt. 1 at well surface ( $p_1 = 0$  psig).  
 Pt. 2 at tank surface.  
 $v_1 = v_2 = 0$

$$\begin{aligned}
 h_A &= \frac{p_2}{\gamma_w} + (z_2 - z_1) + h_L \\
 Q &= \frac{745 \text{ gal}}{\text{h}} \times \frac{1 \text{ h}}{60 \text{ min}} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 0.0277 \text{ ft}^3/\text{s} \\
 v &= \frac{Q}{A} = \frac{0.0277 \text{ ft}^3/\text{s}}{0.0060 \text{ ft}^2} = 4.61 \text{ ft/s in pipe} \\
 N_R &= \frac{vD}{\nu} = \frac{(4.61)(0.0874)}{1.21 \times 10^{-5}} = 3.33 \times 10^4; \quad \frac{D}{\varepsilon} = \frac{0.0874}{1.5 \times 10^{-4}} = 583; \quad f = 0.0275 \\
 h_L &= f \frac{L}{D} \frac{v^2}{2g} = (0.0275) \frac{140}{0.0874} \times \frac{(4.61)^2}{2(32.2)} \text{ ft} = 14.54 \text{ ft} \\
 h_A &= \frac{(40 \text{ lb})\text{ft}^3 (144 \text{ in}^2)}{\text{in}^2 (62.4 \text{ lb})\text{ft}^2} + 120 + 14.54 = 226.8 \text{ ft} \\
 P_A &= h_A \gamma_w Q = (226.8 \text{ ft})(62.4 \text{ lb/ft}^3)(0.0277 \text{ ft}^3/\text{s})/550 \text{ ft} \cdot \text{lb/s/hp} = \mathbf{0.713 \text{ hp}}
 \end{aligned}$$

$$8.37 \quad \frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{v_2^2}{2g} \quad \left| \begin{array}{l} \text{Pt. 1 at tank surface. } v_1 = 0 \\ \text{Pt. 2 in outlet stream. } p_2 = 0 \end{array} \right.$$

$$p_1 = \gamma_w \left[ (z_2 - z_1) + \frac{v_2^2}{2g} + h_L \right]$$

$$v_2 = \frac{Q}{A_2} = \frac{75 \text{ gal/min}}{0.01414 \text{ ft}^2} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 11.8 \text{ ft/s}; \quad \frac{v^2}{2g} = \frac{(11.8)^2}{2(32.2)} = 2.167 \text{ ft}$$

$$N_{Rr} = \frac{vD}{\nu} = \frac{(11.8)(0.1342)}{1.21 \times 10^{-5}} = 1.31 \times 10^5; \quad \frac{D}{\epsilon} = \frac{0.1342}{1.5 \times 10^{-4}} = 895; \quad f = 0.0225$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = (0.0225) \frac{300}{0.1342} (2.167 \text{ ft}) = 109.0 \text{ ft}$$

$$p_1 = \frac{62.4 \text{ lb}}{\text{ft}^3} [-3 \text{ ft} + 2.167 \text{ ft} + 109.0 \text{ ft}] \frac{1 \text{ ft}^2}{144 \text{ in}^2} = \mathbf{46.9 \text{ psi}}$$

$$8.38 \quad \frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} + h_A - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g} \quad \left| \begin{array}{l} \text{Pt. 1 at tank surface. } p_1 = 0; v_1 = 0 \\ \text{Pt. 2 in hose at nozzle.} \\ \text{Pt. 3 in hose at pump outlet.} \\ v_3 = v_2 \end{array} \right.$$

$$a) \quad h_A = \frac{p_2}{\gamma} + (z_2 - z_1) + \frac{v_2^2}{2g} + h_L$$

$$v = \frac{Q}{A} = \frac{95 \text{ L/min}}{\pi(0.025 \text{ m})^2/4} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 3.23 \text{ m/s}; \quad \frac{v^2}{2g} = \frac{(3.23)^2}{2(9.81)} = 0.530 \text{ m}$$

$$N_{Rr} = \frac{vD\rho}{\mu} = \frac{(3.23)(0.025)(1100)}{2.0 \times 10^{-3}} = 4.44 \times 10^4; \quad f = 0.021 \text{ (smooth)}$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = (0.021) \frac{85}{0.025} (0.530) \text{ m} = 37.86 \text{ m}$$

$$h_A = \frac{140 \text{ kN/m}^2}{(1.10)(9.81 \text{ kN/m}^3)} + 7.3 \text{ m} + 0.530 + 37.86 \text{ m} = 58.67 \text{ m}$$

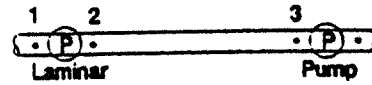
$$P_A = h_A \gamma Q = (58.67 \text{ m})(1.10)(9.81 \text{ kN/m}^3)(95/60000) \text{ m}^3/\text{s} = 1.00 \text{ kN}\cdot\text{m/s} = \mathbf{1.00 \text{ kW}}$$

$$b) \quad \frac{p_3}{\gamma} + z_3 + \frac{v_3^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}; \quad p_3 = p_2 + [(z_2 - z_3) + h_L]\gamma$$

$$p_3 = 140 \text{ kPa} + (1.10)(9.81 \text{ kN/m}^3)[8.5 \text{ m} + 37.86 \text{ m}] = \mathbf{640 \text{ kPa}}$$

$$8.39 \quad Q = 1200 \text{ L/min} \times 1 \text{ m}^3/\text{s}/60000 \text{ L/min} = 0.02 \text{ m}^3/\text{s}$$

$$v = \frac{Q}{A} = \frac{0.02 \text{ m}^3/\text{s}}{1.682 \times 10^{-2} \text{ m}^2} = 1.189 \text{ m/s}$$



$$a) \quad p_2 - p_3 = \gamma_o h_L = \gamma_o f \frac{L}{D} \frac{v^2}{2g}$$

$$N_R = \frac{vD\rho}{\mu} = \frac{1.189(0.1463)(930)}{0.15} = 1079 \text{ Laminar}$$

$$p_2 - p_3 = \gamma_o h_L = (0.93)(9.81 \text{ kN/m}^3) \left( \frac{64}{1079} \right) \left( \frac{3200}{0.1463} \right) \frac{(1.189)^2}{2(9.81)} \text{ m} = 853 \text{ kPa}$$

$$b) \quad \frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} + h_A - h_L = \frac{p_3}{\gamma} + z_3 + \frac{v_3^2}{2g} : p_1 = p_3, v_1 = v_3, z_1 = z_3$$

$$h_A = h_L = \frac{853 \text{ kN/m}^2}{(0.93)(9.81 \text{ kN/m}^3)} = 93.5 \text{ m}$$

$$P_A = h_A \gamma Q = (93.5 \text{ m})(0.93)(9.81 \text{ kN/m}^3)(0.02 \text{ m}^3/\text{s}) = 17.1 \text{ kN}\cdot\text{m/s} = 17.1 \text{ kW}$$

$$8.40 \quad \text{At } 100^\circ\text{C}, \mu = 7.9 \times 10^{-3} \text{ Pa}\cdot\text{s}$$

a) With pumping stations 3.2 km apart:

$$N_R = \frac{vD\rho}{\mu} = \frac{(1.189)(0.1463)(930)}{7.9 \times 10^{-3}} = 2.05 \times 10^4 \text{ turbulent}$$

$$D/\epsilon = 0.1463 \text{ m}/4.6 \times 10^{-5} \text{ m} = 3180; f = 0.026$$

$$h_A = h_L = f \frac{L}{D} \frac{v^2}{2g} = (0.026) \frac{3200}{0.1463} \frac{(1.189)^2}{2(9.81)} \text{ m} = 40.98 \text{ m}$$

$$P_A = h_A \gamma Q = (40.98)(0.93)(9.81)(0.02) = 7.48 \text{ kW}$$

$$b) \quad \text{Let } h_L = 93.5 \text{ m (from Prob. 9.13): } h_L = f \frac{L}{D} \frac{v^2}{2g}$$

$$L = \frac{h_L D (2g)}{f v^2} = \frac{(93.5 \text{ m})(0.1463 \text{ m})(2)(9.81 \text{ m/s}^2)}{(0.026)(1.189 \text{ m/s})^2} = 8682 \text{ m} = 8.68 \text{ km}$$

$$8.41 \quad \frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_B}{\gamma_w} + z_B + \frac{v_B^2}{2g} \quad \left| \begin{array}{l} \text{Pt. 1 at tank surface. } p_1 = 0, v_1 = 0 \\ Q = \frac{900 \text{ L/min}}{60000 \text{ L/min}} = 0.015 \text{ m}^3/\text{s} \\ v = \frac{Q}{A} = \frac{0.015 \text{ m}^3/\text{s}}{7.538 \times 10^{-3} \text{ m}^2} = 1.99 \text{ m/s} \end{array} \right.$$

$$p_B = \gamma_w \left[ (z_1 - z_B) - \frac{v_B^2}{2g} - h_L \right]$$

$$N_R = \frac{vD}{\nu} = \frac{(1.99)(0.098)}{1.30 \times 10^{-6}} = 1.50 \times 10^5; \quad \frac{D}{\epsilon} = \frac{0.098}{1.5 \times 10^{-6}} = 65333; \quad f = 0.0165$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = (0.0165) \frac{80.5}{0.098} \times \frac{(1.99)^2}{2(9.81)} = 2.735 \text{ m}$$

$$p_B = 9.81 \text{ kN/m}^3 \left[ 12 - \frac{(1.99)^2}{2(9.81)} - 2.735 \right] \text{ m} = \mathbf{89.9 \text{ kPa}}$$

$$8.42 \quad Q = 50 \text{ gal/min} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 0.1114 \text{ ft}^3/\text{s}; \quad v = \frac{Q}{A} = \frac{0.1114 \text{ ft}^3/\text{s}}{0.0060 \text{ ft}^2} = 18.56 \text{ ft/s}$$

$$\frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} + h_A - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{v_2^2}{2g}; \quad p_1 = 0, v_1 = v_2 = 0$$

$$h_A = \frac{p_2}{\gamma_w} + (z_2 - z_1) + h_L$$

$$N_R = \frac{vD}{\nu} = \frac{(18.56)(0.0874)}{1.21 \times 10^{-5}} = 1.34 \times 10^5; \quad \frac{D}{\epsilon} = \frac{0.0874}{1.5 \times 10^{-4}} = 583; \quad f = 0.0243$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = (0.0243) \frac{225}{0.0874} \times \frac{(18.56)^2}{2(32.2)} \text{ ft} = 335 \text{ ft}$$

$$h_A = \frac{(40 \text{ lb})\text{ft}^3}{\text{in}^2} \times \frac{144 \text{ in}^2}{62.4 \text{ lb}} + 220 \text{ ft} + 335 \text{ ft} = 647 \text{ ft}$$

$$P_A = h_A \gamma_w Q = (647 \text{ ft})(62.4 \text{ lb/ft}^3)(0.1114 \text{ ft}^3/\text{s})/550 = \mathbf{8.18 \text{ hp}}$$

(b) Increase the pipe size to 1 1/2-in Schedule 40. Results:  $v = 7.88 \text{ ft/s}$ ;  $N_R = 8.74 \times 10^4$ ;  $D/\epsilon = 895$ ;  $f = 0.0232$ ; Then,  $h_L = 37.5 \text{ ft}$ ;  $h_A = 349.8 \text{ ft}$ ; **Power =  $P_A = 4.42 \text{ hp}$ .**

$$8.43 \quad \frac{p_1}{\gamma_o} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_o} + z_2 + \frac{v_2^2}{2g}; \quad p_1 - p_2 = \gamma_o h_L$$

$$v = \frac{Q}{A} = \frac{60 \text{ gal/min}}{0.01414 \text{ ft}^2} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 9.45 \text{ ft/s}$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(9.45)(0.1342)(0.94)(1.94)}{8.5 \times 10^{-3}} = 272 \text{ Laminar}$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = \frac{64}{272} \times \frac{40}{0.1342} \times \frac{(9.45)^2}{2(32.2)} \text{ ft} = 97.23 \text{ ft}$$

$$p_1 - p_2 = \gamma_o h_L = (0.94) \frac{(62.4 \text{ lb})}{\text{ft}^3} (97.23 \text{ ft}) \frac{1 \text{ ft}^2}{144 \text{ in}^2} = \mathbf{39.6 \text{ psi}}$$

$$8.44 \quad \frac{p_A}{\gamma} + z_A + \frac{v_A^2}{2g} + h_A - h_L = \frac{p_B}{\gamma} + z_B + \frac{v_B^2}{2g}$$

$$h_A = \frac{p_B - p_A}{\gamma} + z_B - z_A + \frac{v_B^2 - v_A^2}{2g} + h_L$$

$$v_A = \frac{Q}{A_A} = \frac{0.50 \text{ ft}^3/\text{s}}{0.06868 \text{ ft}^2} = 7.28 \text{ ft/s}; \quad v_B = \frac{Q}{A_B} = \frac{0.50}{0.03326} = 15.03 \text{ ft/s}$$

$$N_{R_B} = \frac{v_B D \rho}{\mu} = \frac{(15.03)(0.2058)(1.026)(1.94)}{4.0 \times 10^{-5}} = 1.54 \times 10^5$$

$$\frac{D}{\varepsilon} = \frac{0.2058}{1.5 \times 10^{-4}} = 1372; \quad f = 0.020$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = (0.020) \frac{80}{0.2058} \times \frac{(15.03)^2}{2(32.2)} \text{ ft} = 27.28 \text{ ft}$$

$$h_A = \frac{[25.0 - (-3.50)] \text{ lb ft}^3}{\text{in}^2 (1.026)(62.4 \text{ lb}) \text{ ft}^2} + 80 \text{ ft} + \frac{(15.03)^2 - (7.28)^2 \text{ ft}^2/\text{s}^2}{2(32.2 \text{ ft}/\text{s}^2)} + 27.28 \text{ ft} = 174.1 \text{ ft}$$

$$P_A = h_A \gamma Q = (174.1 \text{ ft})(1.026)(62.4 \text{ lb}/\text{ft}^3)(0.50 \text{ ft}^3/\text{s})/550 = \mathbf{10.13 \text{ hp}}$$

$$8.45 \quad N_R = \frac{v D \rho}{\mu} = \frac{Q D \rho}{A \mu} = \frac{Q D \rho}{\frac{\pi D^2}{4} \mu} = \frac{4 Q \rho}{\pi D \mu}; \quad D_{\min} = \frac{4 Q \rho}{\pi N_R \mu}$$

$$D_{\min} = \frac{4(0.90 \text{ ft}^3/\text{s})(1.24)(1.94 \text{ lb} \cdot \text{s}^2/\text{ft}^4)}{\pi(300)(5.0 \times 10^{-2} \text{ lb} \cdot \text{s}/\text{ft}^2)} = 0.184 \text{ ft}$$

2 1/2-in Type K Copper Tube:  $D = 0.2029 \text{ ft}$ ;  $A = 0.03234 \text{ ft}^2$

$$v = \frac{Q}{A} = \frac{0.90 \text{ ft}^3/\text{s}}{0.03234 \text{ ft}^2} = 27.8 \text{ ft/s}$$

$$N_R = \frac{v D \rho}{\mu} = \frac{(27.8)(0.2029)(1.24)(1.94)}{5.0 \times 10^{-2}} = 272$$

$$p_1 - p_2 = \gamma_g h_L = \gamma_g f \frac{L}{D} \frac{v^2}{2g} = (1.24)(62.4) \frac{64}{272} \times \frac{55}{0.2029} \times \frac{(27.8)^2 \text{ lb}}{2(32.2) \text{ ft}^2} \frac{1 \text{ ft}^2}{144 \text{ in}^2}$$

$$= \mathbf{411 \text{ psi}}$$

$$8.46 \quad \frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{v_2^2}{2g}$$

$$p_1 = \gamma_w \left[ (z_2 - z_1) - \frac{v_1^2}{2g} + h_L \right]$$

$$N_R = \frac{v D}{\nu} = \frac{(11.52)(0.6651)}{1.21 \times 10^{-5}} = 6.33 \times 10^5; \quad \frac{D}{\varepsilon} = \frac{0.6651}{1.5 \times 10^{-4}} = 4434; \quad f = 0.0155$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = (0.0155) \cdot \frac{2500}{0.6651} \cdot \frac{(11.52)^2}{2(32.2)} \text{ ft} = 120.1 \text{ ft}$$

$$p_1 = \frac{62.4 \text{ lb}}{\text{ft}^3} \left[ 210 - \frac{(11.52)^2}{2(32.2)} + 120.1 \right] \frac{\text{ft} \cdot \text{ft}^2}{144 \text{ in}^2} = \mathbf{142.1 \text{ psi}}$$

Pt. 1 at pump outlet in pipe.

Pt. 2 at reservoir surface.  $p_2 = 0$ ,  $v_2 = 0$

$$v = \frac{Q}{A} = \frac{4.00 \text{ ft}^3/\text{s}}{0.3472 \text{ ft}^2} = 11.52 \text{ ft/s}$$

$$8.47 \quad \frac{p_0}{\gamma_w} + z_0 + \frac{v_0^2}{2g} + h_A = \frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g}$$

$$h_A = \frac{p_1 - p_0}{\gamma_w} = \frac{[142.1 - (-2.36)] \text{ lb}}{(62.4 \text{ lb/ft}^3)(\text{in}^2)(1 \text{ ft}^2/144 \text{ in}^2)}$$

$$h_A = 333.5 \text{ ft} \cdot \text{lb/lb}$$

$$P_A = h_A \gamma Q = \frac{333.5 \text{ ft} \cdot \text{lb}}{\text{lb}} \cdot \frac{62.4 \text{ lb}}{\text{ft}^3} \cdot \frac{4.00 \text{ ft}^3}{\text{s}} \cdot \frac{1 \text{ hp}}{550 \text{ ft} \cdot \text{lb/s}} = \mathbf{151 \text{ hp}}$$

Pt. 0 at pump inlet.

Pt. 1 at pump outlet.

Assume  $z_0 = z_1, v_0 = v_1$

$$8.48 \quad \frac{p_A}{\gamma_g} + z_A + \frac{v_A^2}{2g} - h_L = \frac{p_B}{\gamma} + z_B + \frac{v_B^2}{2g}$$

$$p_A = p_B + \gamma_g [(z_B - z_A) + h_L]$$

$$N_R = \frac{v D \rho}{\mu} = \frac{(7.76)(0.8350)(1.32)}{7.2 \times 10^{-6}} = 1.19 \times 10^6$$

$$\frac{D}{\varepsilon} = \frac{0.8350}{1.5 \times 10^{-4}} = 5567; f = 0.0145$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = 0.0145 \cdot \frac{3200}{0.8350} \times \frac{(7.76)^2}{2(32.2)} = 51.9 \text{ ft}$$

$$p_A = 40.0 \text{ psig} + \frac{42.4 \text{ lb}}{\text{ft}^3} [85 + 51.9] \frac{\text{ft} \cdot 1 \text{ ft}^2}{144 \text{ in}^2} = 80.3 \text{ psig}$$

$$v = \frac{Q}{A} = \frac{4.25 \text{ ft}^3/\text{s}}{0.5479 \text{ ft}^2} = 7.76 \text{ ft/s}$$

Assume  $sg = 0.68$

$\mu$  From App. D.

$$8.49 \quad \frac{p_1}{\gamma_o} + z_1 + \frac{v_1^2}{2g} + h_A - h_L = \frac{p_2}{\gamma_o} + z_2 + \frac{v_2^2}{2g}$$

$$h_A = (z_2 - z_1) + \frac{v_2^2}{2g} + h_L$$

$$v_4 = \frac{Q}{A_4} = \frac{0.668 \text{ ft}^3/\text{s}}{0.08840 \text{ ft}^2} = 7.56 \text{ ft/s}$$

$$v_3 = \frac{Q}{A_3} = \frac{0.668 \text{ ft}^3/\text{s}}{0.05132 \text{ ft}^2} = 13.02 \text{ ft/s} = v_2$$

$$h_L = h_{L_3} + h_{L_4} = f_3 \frac{L_3}{D_3} \frac{v_3^2}{2g} + f_4 \frac{L_4}{D_4} \frac{v_4^2}{2g}$$

$$N_{R_3} = \frac{v_3 D_3}{\nu} = \frac{(13.02)(0.2557)}{2.15 \times 10^{-3}} = 1548 \text{ (Laminar)}; f_3 = \frac{64}{N_R} = 0.0413$$

$$N_{R_4} = \frac{v_4 D_4}{\nu} = \frac{(7.56)(0.3355)}{2.15 \times 10^{-3}} = 1180 \text{ (Laminar)}; f_4 = \frac{64}{N_R} = 0.0543$$

$$h_L = 0.0413 \cdot \frac{75}{0.2557} \cdot \frac{(13.02)^2}{2(32.2)} + 0.0543 \cdot \frac{25}{0.3355} \cdot \frac{(7.56)^2}{2(32.2)} = 35.5 \text{ ft}$$

$$h_A = 1.0 \text{ ft} + \frac{(13.02)^2}{2(32.2)} \text{ ft} + 35.5 \text{ ft} = 39.1 \text{ ft}$$

$$P_A = h_A \gamma_o Q = (39.1 \text{ ft})(0.890) \frac{(62.4 \text{ lb})}{\text{ft}^3} \frac{(0.668 \text{ ft}^3)}{\text{s}} \frac{1 \text{ hp}}{550 \text{ ft} \cdot \text{lb/s}} = \mathbf{2.64 \text{ hp}}$$

Pt. 1 at tank surface.  $p_1 = 0, v_1 = 0$

Pt. 2 in outlet stream from 3-in pipe.  $p_2 = 0$

$$Q = \frac{300 \text{ gal/min} \cdot 1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 0.668 \text{ ft}^3/\text{s}$$

oil- App. C

$$8.50 \quad \frac{p_1}{\gamma_o} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_o} + z_2 + \frac{v_2^2}{2g}; \quad v_1 = v_2$$

$$p_1 - p_2 = \gamma_o[(z_2 - z_1) + h_L]$$

$$N_R = \frac{\nu D \rho}{\mu} = \frac{(3.65)(0.0189)(930)}{3.31 \times 10^{-2}} = 1938 \text{ (Laminar)}; f = \frac{64}{N_R} = 0.0330$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = (0.0330) \frac{17.5}{0.0189} \cdot \frac{(3.65)^2}{2(9.81)} = 20.76 \text{ m}$$

$$p_1 - p_2 = 9.12 \text{ kN/m}^3[-1.88 \text{ m} + 20.76 \text{ m}] = \mathbf{172 \text{ kPa}}$$

$$8.51 \quad p_1 - p_2 = \gamma_g[(z_2 - z_1) + h_L] \text{ (From 9.24)}$$

$$N_R = \frac{\nu D \rho}{\mu} = \frac{(0.701)(0.0738)(1258)}{0.960}$$

$$N_R = 67.8 \text{ (Laminar)}; f = \frac{64}{N_R} = 0.944$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = (0.944) \cdot \frac{25.8}{0.0738} \cdot \frac{(0.701)^2}{2(9.81)} = 8.27 \text{ m}$$

$$p_1 - p_2 = 12.34 \text{ kN/m}^3[0.68 \text{ m} + 8.27 \text{ m}] = \mathbf{110 \text{ kPa}}$$

$$Q = \frac{180 \text{ L/min} \cdot 1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 0.003 \text{ m}^3/\text{s}$$

$$v = \frac{Q}{A} = \frac{0.003}{4.282 \times 10^{-3}} = 0.701 \text{ m/s}$$

**NOTE:** For problems 8.52 through 8.62 the objective is to compute the value of the friction factor,  $f$ , from the Swamee-Jain equation (8-7) from Section 8.8, shown below:

(8-7)

$$f = \frac{0.25}{\left[ \log \left( \frac{1}{3.7(D/\varepsilon)} + \frac{5.74}{N_R^{0.9}} \right) \right]^2}$$

For each problem, the calculation of the Reynolds number and the relative roughness are shown followed by the result of the calculation for  $f$ .

$$8.52 \quad \text{Water at } 75^\circ\text{C}; \nu = 3.83 \times 10^{-7} \text{ m}^2/\text{s}$$

$$v = \frac{Q}{A} = \frac{12.9 \text{ L/min}}{60000 \text{ L/min}} \cdot \frac{1 \text{ m}^3/\text{s}}{1.407 \times 10^{-4} \text{ m}^2} = 1.528 \text{ m/s}$$

$$N_R = \frac{\nu D}{\mu} = \frac{(1.528)(0.0134)}{3.83 \times 10^{-7}} = 5.34 \times 10^4$$

$$D/\varepsilon = 0.0134/1.5 \times 10^{-6} = 8933; f = \mathbf{0.0209}$$

$$8.53 \quad \text{Benzene at } 60^\circ\text{C}: \rho = 0.88(1000) = 880 \text{ kg/m}^3; \mu = 3.95 \times 10^{-4} \text{ Pa}\cdot\text{s}$$

$$v = \frac{Q}{A} = \frac{20 \text{ L/min}}{60000 \text{ L/min}} \cdot \frac{1 \text{ m}^3/\text{s}}{4.636 \times 10^{-4} \text{ m}^2} = 0.719 \text{ m/s}$$

$$N_R = \frac{\nu D \rho}{\mu} = \frac{(0.719)(0.0243)(880)}{3.95 \times 10^{-4}} = 3.89 \times 10^4$$

$$D/\varepsilon = 0.0243/4.6 \times 10^{-5} = 528; f = \mathbf{0.0273}$$

8.54 Water at 80°F:  $\nu = 9.15 \times 10^{-6} \text{ ft}^2/\text{s}$

$$D = 0.512 \text{ ft}; A = 0.2056 \text{ ft}^2$$

$$v = \frac{Q}{A} = \frac{2.50 \text{ ft}^3/\text{s}}{0.2056 \text{ ft}^2} = 12.16 \text{ ft/s}$$

$$N_R = \frac{vD}{\nu} = \frac{(12.16)(0.512)}{9.15 \times 10^{-6}} = 6.80 \times 10^5; D/\epsilon = \frac{0.512}{4 \times 10^{-4}} = 1280$$

$$f = \mathbf{0.0191}$$

8.55 Water at 50°F:  $\nu = 1.40 \times 10^{-5} \text{ ft}^2/\text{s}$

$$D = 18 \text{ in}(1 \text{ ft}/12 \text{ in}) = 1.50 \text{ ft}; A = \frac{\pi D^2}{4} = 1.767 \text{ ft}^2$$

$$v = \frac{Q}{A} = \frac{15.0 \text{ ft}^3/\text{s}}{1.767 \text{ ft}^2} = 8.49 \text{ ft/s}$$

$$N_R = \frac{vD}{\nu} = \frac{(8.49)(1.50)}{1.40 \times 10^{-5}} = 9.09 \times 10^5; D/\epsilon = \frac{1.50}{4 \times 10^{-4}} = 3750$$

$$f = \mathbf{0.0155}$$

8.56 Water at 60°F:  $\nu = 1.21 \times 10^{-5} \text{ ft}^2/\text{s}$

$$v = \frac{Q}{A} = \frac{1500 \text{ gal}/\text{min}}{0.5479 \text{ ft}^2} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal}/\text{min}} = 6.097 \text{ ft/s}$$

$$N_R = \frac{vD}{\nu} = \frac{(6.097)(0.835)}{1.21 \times 10^{-5}} = 4.21 \times 10^5; D/\epsilon = \frac{0.835}{1.5 \times 10^{-4}} = 5567$$

$$f = \mathbf{0.0156}$$

8.57  $A = \pi D^2/4 = \pi(0.025)^2/4 = 4.909 \times 10^{-4} \text{ m}^2$

$$v = \frac{Q}{A} = \frac{95 \text{ L}/\text{min}}{4.909 \text{ ft}^2 \times 10^{-4} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L}/\text{min}} = 3.23 \text{ m/s}$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(3.23)(0.025)(1.10)(1000)}{2.0 \times 10^{-3}} = 4.44 \times 10^4; D/\epsilon = \text{Smooth [Large } D/\epsilon]$$

$$f = \mathbf{0.0213}$$

8.58 Crude oil ( $\text{sg} = 0.93$ ) at 100°C

$$\rho = (0.93)(1000 \text{ kg}/\text{m}^3) = 930 \text{ kg}/\text{m}^3; \mu = 7.8 \times 10^{-3} \text{ Pa}\cdot\text{s}$$

$$v = \frac{Q}{A} = \frac{1200 \text{ L}/\text{min}}{1.682 \times 10^{-2} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L}/\text{min}} = 1.19 \text{ m/s}$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(1.19)(0.1463)(9.30)}{7.8 \times 10^{-3}} = 2.07 \times 10^4$$

$$D/\epsilon = \frac{0.1463}{4.6 \times 10^{-5}} = 3180; f = \mathbf{0.0264}$$

8.59 Water at 65°C;  $\nu = 4.39 \times 10^{-7} \text{ m}^2/\text{s}$   
 $D = 0.0409 \text{ m}$

$$N_R = \frac{\nu D}{\nu} = \frac{(10)(0.0409)}{4.39 \times 10^{-7}} = 9.32 \times 10^5$$

$$D/\varepsilon = \frac{0.0409}{4.6 \times 10^{-5}} = 889; \mathbf{f = 0.0206}$$

8.60 Propyl alcohol at 25°C;  $\rho = 802 \text{ kg/m}^3$   
 $\mu = 1.92 \times 10^{-3} \text{ Pa}\cdot\text{s}$

$$\nu = \frac{Q}{A} = \frac{0.026 \text{ m}^3/\text{s}}{4.282 \times 10^{-3} \text{ m}^2} = 6.07 \text{ m/s}$$

$$N_R = \frac{\nu D \rho}{\mu} = \frac{(6.07)(0.0738)(802)}{1.92 \times 10^{-3}} = 1.87 \times 10^5$$

$$D/\varepsilon = \frac{(0.0738)}{1.5 \times 10^{-6}} = 49200; \mathbf{f = 0.0159}$$

8.61 Water at 70°F;  $\nu = 1.05 \times 10^{-5} \text{ ft}^2/\text{s}$

$$\nu = \frac{Q}{A} = \frac{3.0 \text{ ft}^3/\text{s}}{0.7854 \text{ ft}^2} = 3.82 \text{ ft/s}$$

$$N_R = \frac{\nu D}{\nu} = \frac{(3.82)(1.00)}{1.05 \times 10^{-5}} = 3.64 \times 10^5$$

$$D/\varepsilon = \frac{1.00}{4.0 \times 10^{-4}} = 2500; \mathbf{f = 0.0175}$$

8.62 Heavy fuel oil at 77°F;  $\rho = 1.76 \text{ slugs/ft}^3$   
 $\mu = 2.24 \times 10^{-3} \text{ lb}\cdot\text{s/ft}^2$

$$\nu = 12 \text{ ft/s}; D = 0.5054 \text{ ft}$$

$$N_R = \frac{\nu D \rho}{\mu} = \frac{(12.0)(0.5054)(1.76)}{2.24 \times 10^{-3}} = 4.77 \times 10^3$$

$$D/\varepsilon = \frac{0.5054}{1.5 \times 10^{-4}} = 3369; \mathbf{f = 0.0388}$$

### Hazen-Williams Formula

8.63  $Q = 1.5 \text{ ft}^3/\text{s}$ ,  $L = 550 \text{ ft}$ ,  $D = 0.5/2 \text{ ft}$ ,  $A = 0.2056 \text{ ft}^2$   
 $R = D/4 = 0.128 \text{ ft}$ ,  $C_h = 140$

$$h_L = L \left[ \frac{Q}{1.32 A C_h R^{0.63}} \right]^{1.852}$$

$$h_L = 550 \left[ \frac{1.50}{(1.32)(0.2056)(140)(0.128)^{0.63}} \right]^{1.852} = \mathbf{15.22 \text{ ft}}$$

$$8.64 \quad Q = 1000 \text{ L/min} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 0.0167 \text{ m}^3/\text{s}; L = 45 \text{ m}$$

4-in type K copper tube;  $D = 97.97 \text{ mm} = 0.09797 \text{ m}$ ,  $A = 7.538 \times 10^{-3} \text{ m}^2$   
 $R = D/4 = 0.0245 \text{ m}$ ,  $C_h = 130$

$$h_L = L \left[ \frac{Q}{0.85 A C_h R^{0.63}} \right]^{1.852}$$

$$= 45 \left[ \frac{0.0167}{0.85(7.538 \times 10^{-3})(130)(0.0245)^{0.63}} \right]^{1.852}$$

$$h_L = \mathbf{2.436 \text{ m}}$$

$$8.65 \quad Q = 7.50 \text{ ft}^3/\text{s}; L = 5280 \text{ ft}, D = 18 \text{ in} = 1.50 \text{ ft}, A = 1.767 \text{ ft}^2$$

$$R = D/4 = 0.375 \text{ ft}; C_h = 100$$

$$h_L = 5280 \left[ \frac{7.50}{(1.32)(1.767)(100)(0.375)^{0.63}} \right]^{1.852} = \mathbf{28.51 \text{ ft}}$$

$$8.66 \quad Q = 1500 \text{ gal/min} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 3.341 \text{ ft}^3/\text{s}; L = 1500 \text{ ft}$$

$D = 10.02 \text{ in} = 0.835 \text{ ft}$ ;  $A = 0.5479 \text{ ft}^2$   
 $C_h = 100$ ;  $R = D/4 = 0.2088$

$$h_L = 1500 \left[ \frac{3.341}{(1.32)(0.5479)(100)(0.2088)^{0.63}} \right]^{1.852}$$

$$h_L = \mathbf{31.38 \text{ ft}}$$

$$8.67 \quad Q = 900 \text{ L/min} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 0.015 \text{ m}^3/\text{s}; L = 80 \text{ m}$$

$D = 97.97 \text{ mm} = 0.09797 \text{ m}$ ;  $A = 7.538 \times 10^{-3} \text{ m}^2$   
 $R = D/4 = 0.0245 \text{ m}$ ;  $C_h = 130$

$$h_L = 80 \left[ \frac{0.015}{(0.85)(7.538 \times 10^{-3})(130)(0.0245)^{0.63}} \right]^{1.852} = \mathbf{3.56 \text{ m}}$$

$$8.68 \quad Q = 0.20 \text{ ft}^3/\text{s}; D = 2.469 \text{ in} = 0.2058 \text{ ft}; A = 0.03326 \text{ ft}^2$$

$$C_h = 100; R = D/4 = 0.0515 \text{ ft}$$

$v = Q/A = 6.01 \text{ ft/s}$  (OK)

$$h_L = 80 \left[ \frac{0.20}{(1.32)(0.03326)(100)(0.0515)^{0.63}} \right]^{1.852} = \mathbf{8.35 \text{ ft}}$$

8.69  $Q = 2.0 \text{ ft}^3/\text{s}; L = 2500 \text{ ft}$

a) 8-in Schedule 40 steel pipe;  $D = 0.6651 \text{ ft}; A = 0.3472 \text{ ft}^2$   
 $R = D/4 = 0.1663 \text{ ft}; C_h = 100$

$$h_L = 2500 \left[ \frac{2.0}{(1.32)(0.3472)(100)(0.1663)^{0.63}} \right]^{1.852} = \mathbf{61.4 \text{ ft}}$$

b) Cement lined 8-in ductile iron pipe  
 $D = 8.23 \text{ in} = 0.686 \text{ ft}; A = 0.3694 \text{ ft}^2; C_h = 140$   
 $R = D/4 = 0.1715 \text{ ft}$

$$h_L = 2500 \left[ \frac{2.0}{(1.32)(0.3694)(140)(0.1715)^{0.63}} \right]^{1.852} = \mathbf{28.3 \text{ ft}}$$

8.70 Specify a new Schedule 40 steel pipe size. Use  $C_h = 130$

$$Q = 300 \text{ gal/min} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 0.668 \text{ ft}^3/\text{s}$$

$$s = 10 \text{ ft}/1200 \text{ ft} = 0.00833 \text{ ft/ft}$$

$$D = \left[ \frac{2.31(0.668)}{(130)(0.00833)^{0.54}} \right]^{0.380} = 0.495 \text{ ft}$$

**6-in Schedule 40 steel pipe;  $D = 0.5054 \text{ ft}$**

Actual  $h_L$  for 6-in pipe

$$D = 0.5054 \text{ ft}; R = D/4 = 0.1264 \text{ ft}$$

$$A = 0.2006 \text{ ft}^2$$

$$h_L = L \left[ \frac{Q}{1.32 A C_h R^{0.63}} \right]^{1.852}$$

$$h_L = 1200 \left[ \frac{0.668}{(1.32)(0.2006)(130)(0.1264)^{0.63}} \right]^{1.852} = \mathbf{9.05 \text{ ft}}$$

8.71 **From 8.70**

$$Q = 0.668 \text{ ft}^3/\text{s}$$

$$D = 0.5054 \text{ ft} = 6.065 \text{ in}; A = 0.2006 \text{ ft}^2$$

$$R = D/4 = 0.1264 \text{ ft}; C_h = 100$$

$$h_L = 1200 \left[ \frac{0.668}{1.32(0.2006)(100)(0.1264)^{0.63}} \right]^{1.852}$$

$$h_L = \mathbf{14.72 \text{ ft}}$$

8.72  $Q = 100 \text{ gal/min} \times 1 \text{ ft}^3/\text{s}/449 \text{ gal/min} = 0.2227 \text{ ft}^3/\text{s}$   
 $L = 1000 \text{ ft}; C_h = 130 \text{ (New steel)}$

a) 2-in pipe:  $D = 2.067 \text{ in} = 0.1723 \text{ ft}; A = 0.02333 \text{ ft}^2$   
 $R = D/4 = 0.0431 \text{ ft}$

$$h_L = 1000 \text{ ft} \left[ \frac{0.2227}{(1.32)(0.02333)(130)(0.0431)^{0.63}} \right]^{1.852}$$

$h_L = 186 \text{ ft}$

b) 3-in pipe:  $D = 3.068 \text{ in} = 0.2557 \text{ ft}; A = 0.05132 \text{ ft}^2$   
 $R = D/4 = 0.0639 \text{ ft}$

$$h_L = 1000 \left[ \frac{0.2227}{(1.32)(0.05132)(130)(0.0639)^{0.63}} \right]^{1.852}$$

$h_L = 27.27 \text{ ft}$

# CHAPTER NINE

## VELOCITY PROFILES FOR CIRCULAR SECTIONS AND FLOW IN NONCIRCULAR SECTIONS

- 9.1 Local velocity:  $U = 2v[1 - (r/r_o)^2]$  for laminar flow  
 2-in Sch 40 steel pipe;  $D = 2.067 \text{ in} = 0.1723 \text{ ft}$ ;  $r_o = D/2 = 1.034 \text{ in}$ ;  $A = 0.02333 \text{ ft}^2$   
 $v = Q/A = 0.25 \text{ ft}^3/\text{s} / 0.02333 \text{ ft}^2 = 10.72 \text{ ft/s}$   
 $N_R = vD\rho/\eta = vD/\nu = (10.72)(0.1723) / 7.31 \times 10^{-3} = 253 \text{ Laminar}$   
 See spreadsheet listing for results for  $U$  as a function of radius.
- 9.2 Local velocity:  $U = 2v[1 - (r/r_o)^2]$ ;  $Q = 0.50 \text{ gal/min} = 0.001113 \text{ ft}^3/\text{s}$   
 3/4-in Type K copper tube;  $D = 0.745 \text{ in} = 0.0621 \text{ ft}$ ;  $r_o = D/2 = 0.373 \text{ in}$ ;  
 $A = 0.02333 \text{ ft}^2$ ;  $v = Q/A = 0.001113 \text{ ft}^3/\text{s} / 0.003027 \text{ ft}^2 = 0.3679 \text{ ft/s}$   
 $N_R = vD\rho/\eta = vD/\nu = (0.3679)(0.0621) / 1.21 \times 10^{-5} = 1888 \text{ Laminar}$   
 See spreadsheet listing for results for  $U$  as a function of radius.

### Problem 9.1

Average velocity	10.72 ft/s
Full radius	1.0338 in
<b>Radius (in)</b>	<b>Velocity, U</b>
0.00	21.44 ft/s
0.20	20.64 ft/s
0.40	18.23 ft/s
0.60	14.22 ft/s
0.80	8.60 ft/s
1.00	1.38 ft/s
1.0338	0.00 ft/s

### Problem 9.2

Average velocity	0.3679 ft/s
Full radius	0.3725 in
<b>Radius (in)</b>	<b>Velocity, U</b>
0.00	0.7358 ft/s
0.05	0.7225 ft/s
0.10	0.6828 ft/s
0.15	0.6165 ft/s
0.20	0.5237 ft/s
0.25	0.4044 ft/s
0.30	0.2585 ft/s
0.35	0.0862 ft/s
0.3725	0.0000 ft/s

- 9.3 Local velocity:  $U = 2v[1 - (r/r_o)^2]$ ;  $Q = 3.0 \text{ L/min} = 5.0 \times 10^{-5} \text{ m}^3/\text{s}$   
 4-in Type K copper tube;  $D = 97.97 \text{ mm} = 0.09797 \text{ m}$ ;  $r_o = D/2 = 48.99 \text{ mm}$   
 $A = 7.538 \times 10^{-3} \text{ m}^2$ ;  $v = Q/A = 5.0 \times 10^{-5} \text{ m}^3/\text{s} / 7.538 \times 10^{-3} \text{ m}^2 = 6.633 \times 10^{-3} \text{ m/s}$   
 $N_R = vD\rho/\eta = vD/\nu = (6.633 \times 10^{-3})(0.09797) / 4.22 \times 10^{-7} = 1540 \text{ Laminar}$   
 See spreadsheet listing for results for  $U$  as a function of radius.
- 9.4 Local velocity:  $U = 2v[1 - (r/r_o)^2]$ ;  $Q = 25.0 \text{ L/min} = 4.167 \times 10^{-4} \text{ m}^3/\text{s}$   
 2-in drawn steel tube;  $D = 47.50 \text{ mm} = 0.0475 \text{ m}$ ;  $r_o = D/2 = 23.75 \text{ mm}$   
 $A = 1.772 \times 10^{-3} \text{ m}^2$ ;  $v = Q/A = 4.167 \times 10^{-4} \text{ m}^3/\text{s} / 1.772 \times 10^{-3} \text{ m}^2 = 0.2352 \text{ m/s}$   
 $N_R = vD\rho/\eta = vD/\nu = (0.2352)(0.0475) / 7.9 \times 10^{-3} = 1258 \text{ Laminar}$   
 See spreadsheet listing for results for  $U$  as a function of radius.

**Problem 9.3**

Average velocity	6.63E-03 m/s
Full radius	48.985 mm
<b>Radius (in)</b>	<b>Velocity, U</b>
0.00	0.01327 m/s
8.00	0.01291 m/s
16.00	0.01185 m/s
24.00	0.01008 m/s
32.00	0.00760 m/s
40.00	0.00442 m/s
48.00	0.00053 m/s
48.99	0.00000 m/s

**Problem 9.4**

Average velocity	0.2352 m/s
Full radius	23.75 mm
<b>Radius (mm)</b>	<b>Velocity, U</b>
0.000	0.470 m/s
4.00	0.457 m/s
8.00	0.417 m/s
12.00	0.350 m/s
16.00	0.257 m/s
20.00	0.137 m/s
23.75	0.000 m/s

9.5 (See Section 9.4)  $U =$  Local Velocity

$$U = 2v[1 - (r/r_o)^2]$$

If  $U = v =$  average velocity

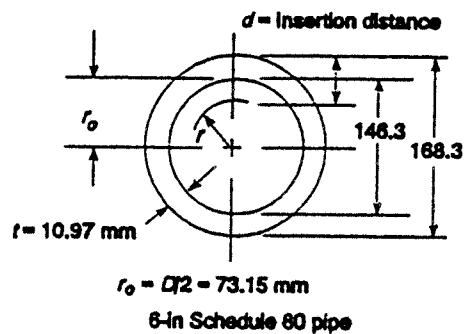
$$v = 2v[1 - (r/r_o)^2]$$

$$\frac{1}{2} = 1 - (r/r_o)^2$$

$$(r/r_o)^2 = 0.5$$

$$r = \sqrt{0.5} r_o = 0.707 r_o = 0.707(73.15 \text{ mm}) = 51.72 \text{ mm}$$

$$d = (r_o - r) + t = (73.15 - 51.72) + 10.97 = 32.40 \text{ mm}$$



9.6 If probe is inserted 5.0 mm too far:

$$r = 51.72 \text{ mm} - 5.0 \text{ mm} = 46.72 \text{ mm}$$

$$r/r_o = 46.72/73.15 = 0.6387$$

$$U = 2v[1 - (0.6387)^2] = 1.184 v \quad \mathbf{18.4\% \text{ high}}$$

If probe is inserted 5.0 mm too little:

$$r = 51.72 \text{ mm} + 5.0 \text{ mm} = 56.72 \text{ mm}$$

$$r/r_o = 56.72/73.15 = 0.7754$$

$$U = 2v[1 - (0.7754)^2] = 0.798 v \quad \mathbf{20.2\% \text{ low}}$$

9.7 Center of pipe is  $D_o/2$  from outside surface

$$\frac{D_o}{2} = \frac{168.3 \text{ mm}}{2} = 84.15 \text{ mm}; \text{ at this position, } r = 0, U = 2v$$

$$\text{With } r = 5.0 \text{ mm, } r/r_o = 5.0/73.15 = 0.06835$$

$$U = 2v[1 - (r/r_o)^2] = 2v[1 - (0.06835)^2] = 1.9907 v$$

If  $v$  is expected to be  $U/2$ ,

$$\frac{U}{2} = \frac{1.9907 v}{2} = 0.9953 v \quad \mathbf{0.47\% \text{ low}}$$

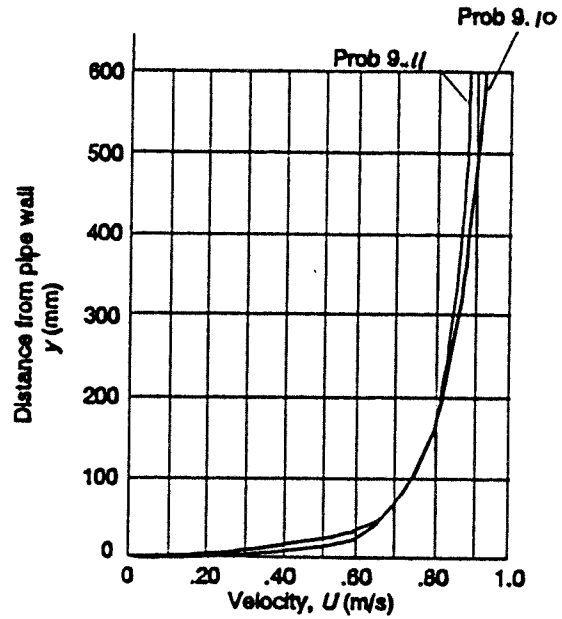
9.8  $U = 2.48 \text{ m/s}$ ;  $d = 60.0 \text{ mm}$  (See Prob. 8.27)  
 $d = r_o - r + t$ ;  $r = r_o + t - d = 73.15 + 10.97 - 60.0 = 24.12 \text{ mm}$   
 $r/r_o = 24.12/73.15 = 0.3297$   
 $U = 2v[1 - (r/r_o)^2] = 2v[1 - (0.3297)^2] = 1.783 v$   
 $v = \frac{U}{1.783} = \frac{2.48 \text{ m/s}}{1.783} = \mathbf{1.39 \text{ m/s average velocity}}$   
 $\nu = 850 \text{ cs} \times 1.0 \times 10^{-6} \text{ m}^2/\text{s}/\text{cs} = 8.50 \times 10^{-4} \text{ m}^2/\text{s}$   
 $N_R = \frac{vD}{\nu} = \frac{(1.39)(0.1463)}{8.50 \times 10^{-4}} = \mathbf{239 \text{ Laminar OK}}$

**Velocity profile for turbulent flow**

9.9  $v = \frac{Q}{A} = \frac{12.9 \text{ L/min}}{1.407 \times 10^{-4} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 1.53 \text{ m/s}$   
 $N_R = \frac{vD}{\nu} = \frac{(1.53)(0.0134)}{3.83 \times 10^{-7}} = 5.35 \times 10^4$   
 $\frac{D}{\varepsilon} = \frac{0.0134}{1.5 \times 10^{-6}} = 8933$ ;  $f = 0.0205$   
 $U_{\max} = v(1 + 1.43\sqrt{f}) = 1.53(1 + 1.43\sqrt{0.0205}) = \mathbf{1.84 \text{ m/s}}$

9.10 SAE 10 oil:  $sg = 0.87$ ;  $\rho = 0.87(1000) = 870 \text{ kg/m}^3$   
 $\mu = 2.20 \times 10^{-2} \text{ Pa}\cdot\text{s}$  (App. D) at  $40^\circ\text{C}$   
 $v = \frac{N_R \mu}{D \rho} = \frac{(3.60 \times 10^4)(2.20 \times 10^{-2})}{(1.20)(870)} = 0.759 \text{ m/s}$   
 $Q = Av = \frac{\pi(1.20 \text{ m})^2}{4} \times 0.759 \text{ m/s} = \mathbf{0.858 \text{ m}^3/\text{s}}$   
 $\frac{D}{\varepsilon} = \frac{1.20}{4.6 \times 10^{-5}} = 26000$ ;  $f = 0.0222$   
 $U_{\max} = v(1 + 1.43\sqrt{f}) = 0.759(1 + 1.43\sqrt{0.0222}) = \mathbf{0.920 \text{ m/s}}$   
 At other points:  $U = v[1 + 1.43\sqrt{f} + 2.15\sqrt{f} \log_{10}(y/r_o)]$   
 $U = 0.759 \text{ m/s} [1 + 1.43\sqrt{0.0222} + 2.15\sqrt{0.0222} \log_{10}(y/r_o)]$   
 $U = 0.759 [1.213 + 0.320 \log_{10}(y/r_o)] \text{ m/s}$   
 $r_o = D/2 = 1200 \text{ mm}/2 = 600 \text{ mm}$

$y(\text{mm})$	$y/r_o$	$U(\text{m/s})$	
0	0	0	0
10	0.0167	0.488	0.530
20	0.0333	0.561	0.592
30	0.050	0.604	0.628
40	0.0667	0.634	0.654
50	0.0833	0.658	0.674
100	0.1667	0.731	0.735
300	0.50	0.847	0.833
500	0.833	0.901	0.879
600	1.00	0.920	0.895
		Prob. 9.10	Prob. 9.11



9.11 Oil at 100°C:  $\mu = 4.2 \times 10^{-3} \text{ Pa}\cdot\text{s}$

$$N_R = \frac{\nu D \rho}{\mu} = \frac{(0.759)(1.20)(870)}{4.20 \times 10^{-3}} = 1.89 \times 10^5; f = 0.0158$$

$$U_{\max} = \nu \left[ 1 + 1.43\sqrt{f} \right] = 0.759 \left[ 1 + 1.43\sqrt{0.0158} \right] = 0.895 \text{ m/s}$$

$$U = 0.759 \left[ 1 + 1.43\sqrt{0.0158} + 2.15\sqrt{0.0158} \log_{10}(y/r_o) \right]$$

$$U = 0.759 \left[ 1.180 + 0.270 \log_{10}(y/r_o) \right]$$

Results included with Prob. 9.10.

The lower friction factor for the hot oil results in a 3% lower maximum velocity. But the velocity in the boundary layer ( $y < 100 \text{ mm}$ ) is slightly higher.

9.12 
$$U = \nu \left[ 1 + 1.43\sqrt{f} + 2.15\sqrt{f} \log_{10}(y/r_o) \right]$$

Let  $U = \nu$ , divide both sides by  $\nu$

$$1 = 1 + 1.43\sqrt{f} + 2.15\sqrt{f} \log_{10}(y/r_o)$$

Subtract 1.0 from both sides

$$0 = 1.43\sqrt{f} + 2.15\sqrt{f} \log_{10}(y/r_o)$$

Divide by  $\sqrt{f}$

$$0 = 1.43 + 2.15 \log_{10}(y/r_o)$$

$$\log_{10}(y/r_o) = \frac{-1.43}{2.15} = -0.665$$

$$y/r_o = 10^{-0.665} = 0.216 \text{ or } y = 0.216 r_o$$

9.13  $y = 0.216 r_o = 0.216(D/2) = 0.216(22.626 \text{ in}/2) = 2.44 \text{ in}$

$$v_{\text{avg}} = \frac{Q}{A} = \frac{16.75 \text{ ft}^3/\text{s}}{2.792 \text{ ft}^2} = \mathbf{6.00 \text{ ft/s}} \text{ at } y = 2.44 \text{ in}$$

At  $y_1 = 2.44 \text{ in} + 0.50 \text{ in} = 2.94 \text{ in}$ ;  $y/r_o = 2.94/11.313 = 0.260$

At  $y_2 = 2.44 \text{ in} - 0.50 \text{ in} = 1.94 \text{ in}$ ;  $y/r_o = 1.94/11.313 = 0.172$

$$N_R = \frac{vD}{\nu} = \frac{(6.00)(1.886)}{1.40 \times 10^{-5}} = 8.08 \times 10^5; \quad \frac{D}{\varepsilon} = \frac{1.886}{1.5 \times 10^{-4}} = 12570;$$

$$f = 0.0137$$

$$U_1 = 6.00 \text{ ft/s} \left[ 1 + 1.43\sqrt{0.0137} + 2.15\sqrt{0.0137} \log_{10}(0.260) \right]$$

$$U_1 = \mathbf{6.12 \text{ ft/s}} \text{ (2.0\% higher than } v_{\text{avg}})$$

$$U_2 = 6.00 \left[ 1 + 1.43\sqrt{0.0137} + 2.15\sqrt{0.0137} \log_{10}(0.172) \right]$$

$$U_2 = \mathbf{5.85 \text{ ft/s}} \text{ (2.50\% lower than } v_{\text{avg}})$$

9.14  $U_{\text{max}} = v(1 + 1.43\sqrt{f})$ ;  $v/U_{\text{max}} = 1/(1 + 1.43\sqrt{f})$

Smooth pipes

$N_R$	$f$	$v/U_{\text{max}}$
$4 \times 10^3$	0.040	0.778
$1 \times 10^4$	0.031	0.799
$1 \times 10^5$	0.0175	0.841
$1 \times 10^6$	0.0118	0.866

9.15  $U_{\text{max}} = v(1 + 1.43\sqrt{f})$ ;  $v/U_{\text{max}} = 1/(1 + 1.43\sqrt{f})$

Concrete pipe:  $D = (8/12) \text{ ft} = 0.667 \text{ ft}$ ;  $D/\varepsilon = 0.667/4 \times 10^{-4} = 1670$

$N_R$	$f$	$v/U_{\text{max}}$
$4 \times 10^3$	0.041	0.775
$1 \times 10^4$	0.032	0.796
$1 \times 10^5$	0.021	0.828
$1 \times 10^6$	0.0185	0.837

9.16  $v = \frac{Q}{A} = \frac{400 \text{ gal/min}}{0.0884 \text{ ft}^2} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 10.08 \text{ ft/s}$

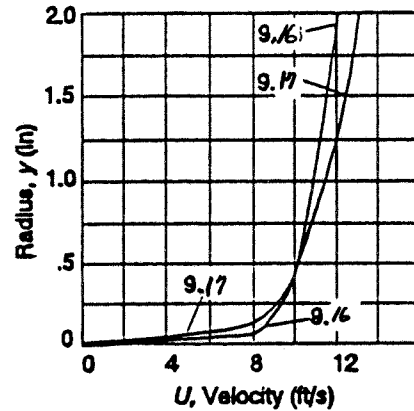
$$N_R = \frac{vD}{\nu} = \frac{(10.08)(0.3355)}{1.40 \times 10^{-5}} = 2.42 \times 10^5; \quad \frac{D}{\varepsilon} = \frac{0.3355}{1.5 \times 10^{-4}} = 2237; \quad f = 0.0182$$

$$U = v \left[ 1 + 1.43\sqrt{0.0182} + 2.15\sqrt{0.0182} \log_{10}(y/r_o) \right]$$

$$U = 10.08 \left[ 1.193 + 0.290 \log_{10}(y/r_o) \right]$$

$$r_o = D/2 = 4.026 \text{ in}/2 = 2.013 \text{ in}$$

$y(\text{in})$	$y/r_o$	$U(\text{ft/s})$	$U$ (Prob. 9.17)
0	0	0	0
0.05	0.025	7.33	5.83
0.10	0.050	8.21	7.19
0.15	0.075	8.72	7.98
0.20	0.099	9.09	8.55
0.50	0.248	10.25	10.35
1.00	0.497	11.13	11.71
1.50	0.745	11.65	12.51
2.013	1.000	12.02	13.09



$$9.17 \quad \frac{D}{\varepsilon} = \frac{0.3355}{5.0 \times 10^{-3}} = 67.1; N_R = 2.42 \times 10^5; f = 0.0436$$

$$U = 10.08 \left[ 1 + 1.43\sqrt{0.0436} + 2.15\sqrt{0.0436} \log_{10}(y/r_o) \right]$$

$$U = 10.08 \left[ 1.299 + 0.449 \log_{10}(y/r_o) \right] \quad (\text{See results for 9.16})$$

$$9.18 \quad \Delta p = \gamma h_L$$

$$\text{Prob. 9.16:} \quad h_L = f \frac{L}{D} \frac{v^2}{2g} = \frac{(0.0182)(250)(10.08)^2}{(0.3355)(2)(32.2)} = 21.39 \text{ ft}$$

$$\Delta p = (62.4 \text{ lb/ft}^3)(21.39 \text{ ft})(1 \text{ ft}^2/144 \text{ in}^2) = \mathbf{9.27 \text{ psi}}$$

$$\text{Prob. 9.17:} \quad h_L = \frac{(0.0436)(250)(10.08)^2}{(0.3355)(2)(32.2)} = 51.24 \text{ ft}$$

$$\Delta p = \gamma h_L = (62.4)(51.24)/144 = \mathbf{22.2 \text{ psi}}$$

$$9.19 \quad Q_s = A_s v_s; Q_t = A_t v_t; \text{ But } v_s = v_t \text{ specified}$$

$$\frac{Q_s}{Q_t} = \frac{A_s v_s}{A_t v_t} = \frac{A_s}{A_t}$$

$$A_t = 8.189 \times 10^{-5} \text{ m}^2$$

$$A_s = 3.059 \times 10^{-4} \text{ m}^2 - \pi(0.0127 \text{ m})^2/4 = 1.792 \times 10^{-4} \text{ m}^2$$

$$\frac{Q_s}{Q_t} = \frac{A_s}{A_t} = \frac{1.792 \times 10^{-4}}{8.189 \times 10^{-5}} = \mathbf{2.19}$$

$$9.20 \quad v_{\text{pipe}} = \frac{Q}{A} = \frac{450 \text{ L/min}}{1.864 \times 10^{-2} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = \mathbf{0.402 \text{ m/s}}$$

$$Q_{\text{duct}} = A_D v_D = (0.0355 \text{ m}^2)(0.402 \text{ m/s}) = 0.0143 \text{ m}^3/\text{s} \times \frac{60000 \text{ L/min}}{1 \text{ m}^3/\text{s}}$$

$$A_D = (0.40 \text{ m})(0.20 \text{ m}) - 2(\pi)(0.1683 \text{ m})^2/4 = 0.0355 \text{ m}^2$$

$$Q_{\text{duct}} = \mathbf{857 \text{ L/min}}$$

$$\begin{aligned}
9.21 \quad Q_T &= A_T v = (0.01414 \text{ ft}^2)(25 \text{ ft/s}) = \mathbf{0.3535 \text{ ft}^3/\text{s}} \\
Q_S &= A_S v = (0.0799 \text{ ft}^2)(25 \text{ ft/s}) = \mathbf{1.998 \text{ ft}^3/\text{s}} \\
A_S &= 0.1390 \text{ ft}^2 - \frac{3\pi(1.900 \text{ in})^2}{4} \times \frac{\text{ft}^2}{144 \text{ in}^2} = 0.0799 \text{ ft}^2
\end{aligned}$$

**Noncircular cross sections**

$$\begin{aligned}
9.22 \quad A &= (0.05 \text{ m})^2 + (0.5)(0.05 \text{ m})^2 - \pi(0.025 \text{ m})^2/4 = 3.259 \times 10^{-3} \text{ m}^2 \\
WP &= 0.05 + 0.05 + 0.10 + \sqrt{.05^2 + .05^2} + \pi(0.025) = 0.3493 \text{ m} \\
R &= \frac{A}{WP} = \frac{3.259 \times 10^{-3} \text{ m}^2}{0.3493 \text{ m}} = 9.33 \times 10^{-3} \text{ m} \\
v &= \frac{Q}{A} = \frac{150 \text{ m}^3}{\text{hr}} \times \frac{1 \text{ hr}}{3600 \text{ s}} \times \frac{1}{3.259 \times 10^{-3} \text{ m}^2} = 12.78 \text{ m/s} \\
\rho &= \frac{\gamma}{g} = \frac{12.5 \text{ N} \cdot \text{s}^2}{\text{m}^3 9.81 \text{ m}} \times \frac{1 \text{ kg} \cdot \text{m}/\text{s}^2}{\text{in}} = 1.274 \text{ kg/m}^3 \\
N_R &= \frac{v(4R)\rho}{\mu} = \frac{(12.78)(4)(9.33 \times 10^{-3})(1.274)}{2.0 \times 10^{-5}} = \mathbf{3.04 \times 10^4}
\end{aligned}$$

$$\begin{aligned}
9.23 \quad A &= (12 \text{ in})(6 \text{ in}) - 2\pi(4.0 \text{ in})^2/4 = 46.87 \text{ in}^2(1 \text{ ft}^2/144 \text{ in}^2) = 0.3255 \text{ ft}^2 \\
WP &= 2(6 \text{ in}) + 2(12 \text{ in}) + 2\pi(4.0 \text{ in}) = 61.13 \text{ in}(1 \text{ ft}/12 \text{ in}) = 5.094 \text{ ft} \\
R &= \frac{A}{WP} = \frac{0.3255 \text{ ft}^2}{5.094 \text{ ft}} = 0.0639 \text{ ft} \\
v &= \frac{Q}{A} = \frac{200 \text{ ft}^3}{\text{min}} \times \frac{1 \text{ min}}{60 \text{ s}} \times \frac{1}{0.3255 \text{ ft}^2} = 10.24 \text{ ft/s} \\
\rho &= \frac{\gamma}{g} = \frac{0.114 \text{ lb} \cdot \text{s}^2}{\text{ft}^3 (32.2 \text{ ft})} \times \frac{1 \text{ slug}}{1 \text{ lb} \cdot \text{s}^2/\text{ft}} = 0.00354 \text{ slugs/ft}^3 \\
N_R &= \frac{v(4R)\rho}{\mu} = \frac{(10.24)(4)(0.0639)(0.00354)}{3.34 \times 10^{-7}} = \mathbf{2.77 \times 10^4}
\end{aligned}$$

$$\begin{aligned}
9.24 \quad A &= (10 \text{ in})^2 - \pi(6.625 \text{ in})^2/4 = 65.53 \text{ in}^2(1 \text{ ft}^2/144 \text{ in}^2) = 0.455 \text{ ft}^2 \\
WP &= 4(10 \text{ in}) + \pi(6.625 \text{ in}) = 60.81 \text{ in}(1 \text{ ft}/12 \text{ in}) = 5.067 \text{ ft} \\
R &= A/WP = 0.455 \text{ ft}^2/5.067 \text{ ft} = 0.0898 \text{ ft} \\
v &= \frac{Q}{A} = \frac{4.00 \text{ ft}^3/\text{s}}{0.455 \text{ ft}^2} = 8.79 \text{ ft/s} \\
N_R &= \frac{v 4 R}{\nu} = \frac{(8.79)(4)(0.0898)}{8.29 \times 10^{-6}} = \mathbf{3.808 \times 10^5}
\end{aligned}$$

$$\begin{aligned}
9.25 \quad \text{Tube: } D &= 10.21 \text{ mm} = 0.01021 \text{ m}; A = 8.189 \times 10^{-5} \text{ m}^2 \\
Q &= 4.75 \text{ gal/min} \times \frac{6.309 \times 10^{-5} \text{ m}^3/\text{s}}{1 \text{ gal/min}} = 3.00 \times 10^{-4} \text{ m}^3/\text{s} \\
v &= \frac{Q}{A} = \frac{3.00 \times 10^{-4} \text{ m}^3/\text{s}}{8.189 \times 10^{-5} \text{ m}^2} = 3.66 \text{ m/s} \\
N_R &= \frac{vD}{\nu} = \frac{(3.66)(0.01021)}{3.04 \times 10^{-7}} = \mathbf{1.23 \times 10^5}
\end{aligned}$$

**Shell:**  $A = 3.059 \times 10^{-4} \text{ m}^2 - \pi(0.0127 \text{ m})^2/4 = 1.792 \times 10^{-4} \text{ m}^2$

$$WP = \pi(0.01974 \text{ m}) + \pi(0.0127 \text{ m}) = 0.1019 \text{ m}$$

$$R = A/WP = 0.00176 \text{ m} = 1.76 \times 10^{-3} \text{ m}$$

$$Q = 30.0 \text{ gal/min} \times \frac{6.309 \times 10^{-5} \text{ m}^3/\text{s}}{1 \text{ gal/min}} = 1.89 \times 10^{-3} \text{ m}^3/\text{s}$$

$$v = \frac{Q}{A} = \frac{1.89 \times 10^{-3} \text{ m}^3/\text{s}}{1.792 \times 10^{-4} \text{ m}^2} = 10.56 \text{ m/s}$$

$$N_R = \frac{v(4R)(\rho)}{\mu} = \frac{(10.56)(4)(1.76 \times 10^{-3})(1100)}{1.62 \times 10^{-2}} = 5.049 \times 10^3 = \mathbf{5049} \text{ Turbulent}$$

9.26 **Pipe:**  $Q = \frac{450 \text{ L/min} \times 1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 0.00750 \text{ m}^3/\text{s}$

$$v = \frac{Q}{A} = \frac{0.00750 \text{ m}^3/\text{s}}{1.864 \times 10^{-2} \text{ m}^2} = 0.402 \text{ m/s}$$

$$N_R = \frac{vD}{\nu} = \frac{(0.402)(0.1541)}{1.02 \times 10^{-6}} = 6.08 \times 10^4$$

└─ Water at 20°C

**Duct:** Benzene at 70°C:  $\rho = \text{sg}(\rho_w) = 0.862(1000) = 862 \text{ kg/m}^3$

$$\mu = 3.5 \times 10^{-4} \text{ Pa}\cdot\text{s (App. D)}$$

$$A = (0.40 \text{ m})(0.20 \text{ m}) - 2(\pi)(0.1683 \text{ m})^2/4 = 0.0355 \text{ m}^2$$

$$WP = 2(0.40) + 2(0.20) + 2(\pi)(0.1683) = 2.257 \text{ m}$$

$$R = \frac{A}{WP} = \frac{0.0355 \text{ m}^2}{2.257 \text{ m}} = 0.0157 \text{ m}$$

$$N_R = \frac{v(4R)(\rho)}{\mu}; v = \frac{N_R \mu}{4R \rho} = \frac{(6.08 \times 10^4)(3.5 \times 10^{-4})}{4(0.0157)(862)} = 0.392 \text{ m/s}$$

$$Q = Av = (0.0355 \text{ m}^2)(0.392 \text{ m/s}) = \mathbf{1.39 \times 10^{-2} \text{ m}^3/\text{s}}$$

9.27 **Inside Pipes:**  $N_R = \frac{vD}{\nu} = \frac{(25)(0.1342)}{3.35 \times 10^{-6}} = \mathbf{1.00 \times 10^6}$

**Shell:**  $A = 0.1390 \text{ ft}^2 - 3(\pi)(0.1583 \text{ ft})^2/4 = 0.0799 \text{ ft}^2$

$$D_o = 1.900 \text{ in}(1 \text{ ft}/12 \text{ in}) = 0.1583 \text{ ft} = \text{Outside dia. of } 1 \frac{1}{2} \text{ in pipe.}$$

$$WP = \pi(0.4206 \text{ ft}) + 3\pi(0.1583 \text{ ft}) = 2.813 \text{ ft}$$

$$R = \frac{A}{WP} = \frac{0.0799 \text{ ft}^2}{2.813 \text{ ft}} = 0.0284 \text{ ft}$$

$$N_R = \frac{v(4R)}{\nu} = \frac{(25)(4)(0.0284)}{1.21 \times 10^{-5}} = \mathbf{2.35 \times 10^5}$$

$$9.28 \quad Q = 850 \text{ L/min} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 0.01417 \text{ m}^3/\text{s}$$

$$A = A_{\text{shell}} - 3A_{\text{tube-D}_o} = 1.945 \times 10^{-3} \text{ m}^2 - 3\pi(0.0127 \text{ m})^2/4 = 1.565 \times 10^{-3} \text{ m}^2$$

$$WP = \pi(0.04976 \text{ m}) + 3\pi(0.0127 \text{ m}) = 0.2760 \text{ m}$$

$$R = \frac{A}{WP} = \frac{1.565 \times 10^{-3} \text{ m}^2}{0.2760 \text{ m}} = 5.670 \times 10^{-3} \text{ m}$$

$$v = \frac{Q}{A} = \frac{0.01417 \text{ m}^3/\text{s}}{1.565 \times 10^{-3} \text{ m}^2} = 9.05 \text{ m/s}$$

$$N_R = \frac{v4R}{\nu} = \frac{(9.05)(4)(5.670 \times 10^{-3})}{1.30 \times 10^{-6}} = 1.58 \times 10^5$$

$$9.29 \quad A = (0.25 \text{ in})(1.75 \text{ in}) + 4(0.25 \text{ in})(0.50 \text{ in}) = 0.9375 \text{ in}^2 (1 \text{ ft}^2/144 \text{ in}^2) = 0.00651 \text{ ft}^2$$

$$WP = (1.75 \text{ in}) + 7(0.25 \text{ in}) + 2(0.75 \text{ in}) + 6(0.50 \text{ in})$$

$$WP = 8.00 \text{ in} (1 \text{ ft}/12 \text{ in}) = 0.667 \text{ ft}$$

$$R = A/WP = 0.00651 \text{ ft}^2/0.667 \text{ ft} = 9.77 \times 10^{-3} \text{ ft}$$

$$N_R = \frac{v4R\rho}{\mu}; v = \frac{N_R\mu}{4R\rho} = \frac{(1500)(3.38 \times 10^{-4})}{4(9.77 \times 10^{-3})(2.13)} = 6.09 \text{ ft/s}$$

$$Q = Av = (0.00651 \text{ ft}^2)(6.09 \text{ ft/s}) = 3.97 \times 10^{-2} \text{ ft}^3/\text{s}$$

9.30 Air flows in cross-hatched area.

$$A = [4(5.30) + 2(5.65)](50) = 1625 \text{ mm}^2$$

$$WP = 12(50) + 4(5.65) + 8(5.30) = 665 \text{ mm}$$

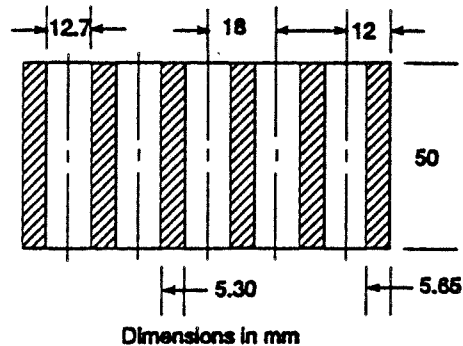
$$R = \frac{A}{WP} = \frac{1625 \text{ mm}^2}{665 \text{ mm}} = 2.444 \text{ mm}$$

$$v = \frac{Q}{A}$$

$$= \frac{50 \text{ m}^3}{\text{h}} \cdot \frac{1}{1625 \text{ mm}^2} \cdot \frac{10^6 \text{ mm}^2}{\text{m}^2} \cdot \frac{1 \text{ h}}{3600 \text{ s}}$$

$$v = 8.55 \text{ m/s}$$

$$N_R = \frac{v(4R)(\rho)}{\mu} = \frac{(8.55)(4)(0.00244)(1.15)}{1.63 \times 10^{-5}} = 5.90 \times 10^3$$



$$9.31 \quad A = (0.45)(0.30) + \pi(0.30)^2/4 - 2(0.15)^2 = 0.1607 \text{ m}^2$$

$$WP = 2(0.45) + \pi(0.30) + 8(0.15) = 3.042 \text{ m}$$

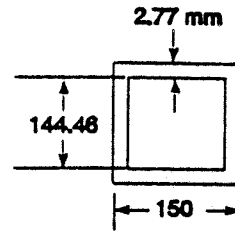
$$R = A/WP = 0.1607 \text{ m}^2/3.042 \text{ m} = 0.0528 \text{ m}$$

$$v = Q/A = 0.10 \text{ m}^3/\text{s}/0.1607 \text{ m}^2 = 0.622 \text{ m/s}$$

$$N_R = \frac{v(4R)\rho}{\mu} = \frac{(0.622)(4)(0.0528)(1260)}{0.30} = 552$$

└ (App. D)

$$\begin{aligned}
 9.32 \quad A &= (0.14446)^2 = 0.02087 \text{ m}^2 \\
 WP &= 4(0.14446) = 0.5778 \text{ m} \\
 R &= \frac{A}{WP} = \frac{0.02087 \text{ m}^2}{0.5778 \text{ m}} = 0.0361 \text{ m} \\
 N_R &= \frac{\nu(4R)}{\nu} = \frac{(35.9)(4)(0.0361)}{3.22 \times 10^{-7}} = 1.61 \times 10^7 \\
 \nu &= \frac{Q}{A} = \frac{0.75 \text{ m}^3/\text{s}}{0.02087 \text{ m}^2} = 35.9 \text{ m/s}
 \end{aligned}$$

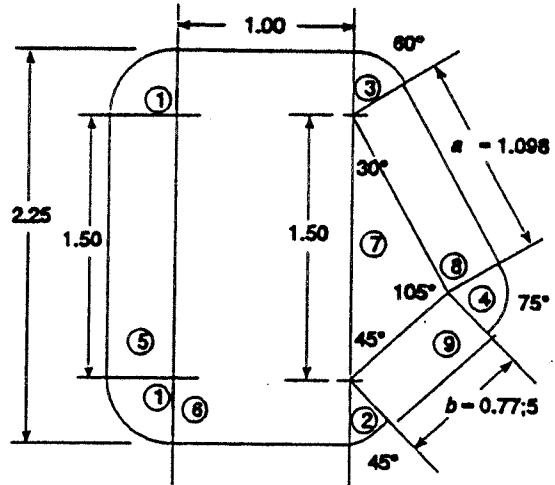


$$\begin{aligned}
 9.33 \quad A &= (0.75)(0.75) + \frac{\pi(1.50)^2}{8} = 1.446 \text{ in}^2 (1 \text{ ft}^2/144 \text{ in}^2) = 0.01004 \text{ ft}^2 \\
 WP &= 0.75 + 2.25 + \pi(1.50)/2 = 5.356 \text{ in} (1 \text{ ft}/12 \text{ in}) = 0.4463 \text{ ft} \\
 R &= A/WP = 0.01004 \text{ ft}^2/0.4463 \text{ ft} = 0.02250 \text{ ft} \\
 \nu &= \frac{Q}{A} = \frac{78.0 \text{ gal}/\text{min}}{0.01004 \text{ ft}^2} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal}/\text{min}} = 17.30 \text{ ft/s} \\
 N_R &= \frac{\nu(4R)}{\nu} = \frac{(17.30)(4)(0.02250)}{1.40 \times 10^{-5}} = 1.112 \times 10^5
 \end{aligned}$$

$$\begin{aligned}
 9.34 \quad A &= \frac{2(\pi)(0.50)^2}{8} + 2(0.50)(0.50) + \left[ \frac{\pi(0.75)^2}{4} - \frac{\pi(0.25)^2}{4} \right] \\
 A &= 1.089 \text{ in}^2 (1 \text{ ft}^2/144 \text{ in}^2) = 0.00756 \text{ ft}^2 \\
 WP &= \pi(0.50) + 4(0.50) + \frac{(\pi)(.25)(2)}{4} + \frac{(\pi)(0.75)(2)}{4} \\
 WP &= 5.142 \text{ in} (1 \text{ ft}/12 \text{ in}) = 0.428 \text{ ft} \\
 R &= A/WP = 0.00756 \text{ ft}^2/0.428 \text{ ft} = 0.0177 \text{ ft} \\
 \nu &= \frac{N_R \nu}{4R} = \frac{(1.5 \times 10^5)(1.40 \times 10^{-5})}{4(0.0177)} = 29.66 \text{ ft/s (High)} \\
 Q &= A\nu = (0.00756 \text{ ft}^2)(29.66 \text{ ft/s}) = 0.224 \text{ ft}^3/\text{s}
 \end{aligned}$$

$$9.35 \quad \left. \begin{aligned} a &= 1.50 \frac{\sin 45^\circ}{\sin 105^\circ} = 1.098 \text{ in} \\ b &= 1.50 \frac{\sin 30^\circ}{\sin 105^\circ} = 0.7765 \text{ in} \end{aligned} \right\} \text{By Law of Sines}$$

PART	$A$	$WP$
1	0.2209 in <sup>2</sup>	1.178 in
2	0.0552	0.2945
3	0.0736	0.3927
4	0.0920	0.4909
5	0.5625	1.500
6	2.250	2.000
7	0.4118	0
8	0.4118	1.0981 = $a$
9	0.2912	0.7765 = $b$
$A =$	4.3690 in <sup>2</sup>	7.7307 = $WP$



$$R = A/WP = 0.5651 \text{ in}(1 \text{ ft}/12 \text{ in}) = \mathbf{0.04710 \text{ ft}}$$

$$\nu = \frac{N_R \mu}{4R\rho} = \frac{(2.6 \times 10^4)(6.60 \times 10^{-6})}{(4)(0.0471)(1.53)} = 0.595 \text{ ft/s}$$

$$Q = A\nu = \frac{(4.369 \text{ in}^2)(0.595 \text{ ft/s})}{(144 \text{ in}^2/\text{ft}^2)} = \mathbf{0.0181 \text{ ft}^3/\text{s}}$$

$$9.36 \quad A = (2)(8) = 16 \text{ mm}^2(1 \text{ m}^2/10^6 \text{ mm}^2) = 1.60 \times 10^{-5} \text{ m}^2$$

$$WP = 2(8) + 2(2) = 20 \text{ mm} = 0.020 \text{ m}$$

$$R = \frac{A}{WP} = \frac{1.60 \times 10^{-5} \text{ m}^2}{0.020 \text{ m}} = 8.00 \times 10^{-4} \text{ m}$$

$$Q = A\nu = (1.60 \times 10^{-5} \text{ m}^2)(25.0 \text{ m/s}) = 4.00 \times 10^{-4} \text{ m}^3/\text{s} \text{ each}$$

$$Q_{\text{tot}} = (4.00 \times 10^{-4} \text{ m}^3/\text{s})6 = \mathbf{2.40 \times 10^{-3} \text{ m}^3/\text{s}}$$

$$N_R = \frac{\nu(4R)(\rho)}{\mu} = \frac{(25)(4)(8.00 \times 10^{-4})(1.20)}{1.50 \times 10^{-5}} = \mathbf{6.40 \times 10^3}$$

$$9.37 \quad \text{From Prob. 9.24, } R = 0.0898 \text{ ft; } N_R = 3.808 \times 10^5; \nu = 8.79 \text{ ft/s; Water at } 90^\circ\text{F}$$

$$\frac{4R}{\varepsilon} = \frac{4(0.0898)}{8.5 \times 10^{-5}} = 4226; \text{ then } f = 0.0165$$

$$h_L = f \frac{L}{4R} \cdot \frac{\nu^2}{2g} = \frac{(0.0165)(30)(8.79)^2}{(4)(0.0898)(2)(32.2)} = 1.65 \text{ ft}$$

$$\Delta p = \gamma_w h_L = (62.1 \text{ lb}/\text{ft}^3)(1.65 \text{ ft})(1 \text{ ft}^2/144 \text{ in}^2) = \mathbf{0.713 \text{ psi}}$$

9.38 Some data from Prob. 9.25 and Fig. 9.10.

**Tube:** Water at 95°C;  $\gamma = 9.44 \text{ kN/m}^3$ ;  $N_R = 1.23 \times 10^5$

$$\frac{D}{\varepsilon} = \frac{(0.01021)}{4.6 \times 10^{-5}} = 222; \text{ then } f = 0.030$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = \frac{(0.030)(5.25)(3.66)^2}{(0.01021)(2)(9.81)} = 10.53 \text{ m}$$

$$\Delta p = \gamma_w h_L = (9.44 \text{ kN/m}^3)(10.53 \text{ m}) = \mathbf{99.4 \text{ kPa}}$$

**Shell:** Ethylene glycol at 25°C;  $\gamma = 10.79 \text{ kN/m}^3$ :

$$v = 10.56 \text{ m/s}; R = 1.76 \times 10^{-3}; N_R = 5049 = 5.049 \times 10^3$$

$$4R/\varepsilon = (4)(1.76 \times 10^{-3} \text{ m})/(4.6 \times 10^{-5} \text{ m}) = 153; \text{ Then } f = 0.044$$

$$h_L = f \frac{L}{4R} \frac{v^2}{2g} = 0.044 \frac{525}{4(0.00176)} \frac{10.56^2}{2(9.81)} = 186.5 \text{ m}$$

$$\Delta p = \gamma h_L = (10.79 \text{ kN/m}^3)(186.5 \text{ m}) = 2018 \text{ kN/m}^2 = 2018 \text{ kPa [Very high]}$$

9.39 Some data from Prob. 9.26 and Fig. 9.11.

**Each Pipe:** Water at 20°C;  $\gamma = 9.79 \text{ kN/m}^3$ ;  $N_R = 6.08 \times 10^4$

$$\frac{D}{\varepsilon} = \frac{(0.1541)}{4.6 \times 10^{-5}} = 3350; \text{ then } f = 0.021$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = \frac{(0.021)(3.80)(0.402)^2}{(0.1541)(2)(9.81)} = 0.00427 \text{ m}$$

$$\Delta p = \gamma_w h_L = (9.79 \text{ kN/m}^3)(0.00427 \text{ m}) = 0.00418 \text{ kPa} = \mathbf{41.8 \text{ Pa}}$$

**Duct:** Benzene at 70°C;  $\gamma_B = (0.862)(9.81 \text{ kN/m}^3) = 8.46 \text{ kN/m}^3$

$$N_R = 6.08 \times 10^4; R = 0.0157 \text{ m}; \frac{4R}{\varepsilon} = \frac{(4)(0.0157)}{4.6 \times 10^{-5}} = 1365$$

$$f = 0.023; h_L = f \frac{L}{4R} \frac{v^2}{2g} = \frac{(0.023)(3.80)(0.392)^2}{(4)(0.0157)(2)(9.81)} = 0.0109 \text{ m}$$

$$\Delta p = \gamma_B h_L = (8.46 \text{ kN/m}^3)(0.0109 \text{ m}) = 0.0920 \text{ kPa} = \mathbf{92.0 \text{ Pa}}$$

9.40 Some data from Prob. 9.27 and Fig. 9.12.

**Each Pipe:** Water at 200°F;  $\gamma_w = 60.1 \text{ lb/ft}^3$ ;  $N_R = 1.00 \times 10^6$

$$\frac{D}{\varepsilon} = \frac{0.1342}{1.5 \times 10^{-4}} = 895; \text{ then } f = 0.021$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = \frac{(0.021)(50)(25)^2}{(0.1342)(2)(32.2)} = 75.9 \text{ ft}$$

$$\Delta p = \gamma_w h_L = (60.1 \text{ lb/ft}^3)(75.9 \text{ ft})(1 \text{ ft}^2/144 \text{ in}^2) = \mathbf{31.7 \text{ psi}}$$

**Shell:** Water at 60°F;  $\gamma = 62.4 \text{ lb/ft}^3$ ;  $N_R = 2.35 \times 10^5$ ;  $R = 0.0284 \text{ ft}$

$$\frac{4R}{\varepsilon} = \frac{(4)(0.0284)}{1.5 \times 10^{-4}} = 758; \text{ then } f = 0.0225$$

$$h_L = f \frac{L}{4R} \frac{v^2}{2g} = \frac{(0.0225)(50)(25)^2}{(4)(0.0284)(2)(32.2)} = 96.1 \text{ ft}$$

$$\Delta p = \gamma_w h_L = (62.4 \text{ lb/ft}^3)(96.1 \text{ ft})(1 \text{ ft}^2/144 \text{ in}^2) = \mathbf{41.6 \text{ psi}}$$

- 9.41 Data from Prob. 9.28 and Fig. 9.15. Copper tubes.  
 Water at 10°C;  $\gamma_w = 9.81 \text{ kN/m}^3$ ;  $N_R = 1.58 \times 10^5$ ;  $R = 5.670 \times 10^{-3} \text{ m}$   

$$\frac{4 R}{\varepsilon} = \frac{(4)(5.670 \times 10^{-3})}{1.5 \times 10^{-6}} = 15120: f = 0.017$$

$$h_L = f \frac{L}{4 R} \cdot \frac{v^2}{2g} = \frac{(0.017)(3.60)(9.05)^2}{(4)(5.670 \times 10^{-3})(2)(9.81)} = 11.26 \text{ m}$$

$$\Delta p = \gamma_w h_L = (9.81 \text{ kN/m}^3)(11.26 \text{ m}) = \mathbf{111 \text{ kPa}}$$
- 9.42 Data from Prob. 9.29 and Fig. 9.16.  $N_R = 1500$  Laminar  

$$f = \frac{64}{N_R} = \frac{64}{1500} = 0.0427: R = 9.77 \times 10^{-3} \text{ ft}: L = \frac{57 \text{ in}}{12 \text{ in/ft}} = 4.75 \text{ ft}$$

$$h_L = f \frac{L}{4 R} \cdot \frac{v^2}{2g} = \frac{(0.0427)(4.75)(6.09)^2}{(4)(9.77 \times 10^{-3})(2)(32.2)} = 2.99 \text{ ft}$$
 Ethylene glycol at 77°F -  $\gamma = 68.47 \text{ lb/ft}^3$   

$$\Delta p = \gamma h_L = (68.47 \text{ lb/ft}^3)(2.99 \text{ ft})(1 \text{ ft}^2/144 \text{ in}^2) = \mathbf{1.42 \text{ psi}}$$
- 9.43 Data from Prob. 9.31 and Fig. 9.18.  $N_R = 552$  Laminar  

$$f = \frac{64}{N_R} = \frac{64}{552} = 0.116: R = 0.0528 \text{ m}$$

$$h_L = f \frac{L}{4 R} \cdot \frac{v^2}{2g} = \frac{(0.116)(22.6)(0.622)^2}{(4)(0.0528)(2)(9.81)} = 0.244 \text{ m}$$

$$\Delta p = \gamma_G h_L = (1.26)(9.81 \text{ kN/m}^3)(0.244 \text{ m}) = \mathbf{3.02 \text{ kPa}}$$
- 9.44 Data from Prob. 9.32:  $R = 0.0361 \text{ m}$ ;  $N_R = 1.61 \times 10^7$   

$$\frac{4 R}{\varepsilon} = \frac{(4)(0.0361)}{1.5 \times 10^{-6}} = 96267: f = 0.008 \text{ approx.}$$

$$h_L = f \frac{L}{4 R} \cdot \frac{v^2}{2g} = \frac{(0.008)(22.6)(35.9)^2}{(4)(0.0361)(2)(9.81)} = 82.2 \text{ m}$$

$$\Delta p = \gamma h_L = (9.47 \text{ kN/m}^3)(82.2 \text{ m}) = \mathbf{779 \text{ kPa}}$$
 └ Water at 90°C
- 9.45 Data from Prob. 9.33 and Fig. 9.19.  $N_R = 1.112 \times 10^5$   

$$R = 0.0225 \text{ ft}: \frac{4 R}{\varepsilon} = \frac{(4)(0.0225)}{2.5 \times 10^{-5}} = 3600: f = 0.019$$

$$L = (105 \text{ in})(1 \text{ ft}/12 \text{ in}) = 8.75 \text{ ft}$$

$$h_L = f \frac{L}{4 R} \cdot \frac{v^2}{2g} = \frac{(0.019)(8.75)(17.30)^2}{(4)(0.0225)(2)(32.2)} = 8.58 \text{ ft}$$

$$\Delta p = \gamma h_L = (62.4 \text{ lb/ft}^3)(8.58 \text{ ft})(1 \text{ ft}^2/144 \text{ in}^2) = \mathbf{3.72 \text{ psi}}$$

9.46 Data from Prob. 9.34 and Fig. 9.20.  $N_R = 1.5 \times 10^5$ ;  $R = 0.0177$  ft;  $v = 29.66$  ft/s

$$\frac{4 R}{\varepsilon} = \frac{(4)(0.0177)}{1.5 \times 10^{-4}} = 472; f = 0.025 \quad [\text{Steel}]$$

$$L = (45 \text{ in})(1 \text{ ft}/12 \text{ in}) = 3.75 \text{ ft}$$

$$h_L = f \frac{L}{4 R} \cdot \frac{v^2}{2g} = \frac{(0.025)(3.75)(29.66)^2}{(4)(0.0177)(2)(32.2)} = 18.1 \text{ ft}$$

$$\Delta p = \gamma h_L = (62.4 \text{ lb}/\text{ft}^3)(18.1 \text{ ft})(1 \text{ ft}^2/144 \text{ in}^2) = \mathbf{7.84 \text{ psi}}$$

9.47  $A = (2.25)(1.50) - 7(\pi(0.375)^2/4) = 2.602 \text{ in}^2(1 \text{ ft}^2/144 \text{ in}^2) = 0.01807 \text{ ft}^2$

$$WP = 2(2.25) + 2(1.50) + 7(\pi)(0.375) = 15.75 \text{ in}(1 \text{ ft}/12 \text{ in}) = 1.312 \text{ ft}$$

$$R = \frac{A}{WP} = \frac{0.01807 \text{ ft}^2}{1.312 \text{ ft}} = 0.0138 \text{ ft}$$

$$\left. \begin{aligned} N_R &= \frac{v 4 R \rho}{\mu}; v = \frac{N_R \mu}{4 R \rho} = \frac{(8000)(3.38 \times 10^{-4})}{4(0.0138)(2.13)} = 23.05 \text{ ft/s} \\ L &= 128 \text{ in}(1 \text{ ft}/12 \text{ in}) = 10.67 \text{ ft}; \frac{4 R}{\varepsilon} = \frac{4(0.0138)}{5 \times 10^{-6}} = 11000 \end{aligned} \right\} f = 0.0325$$

$$h_L = f \frac{L}{4 R} \cdot \frac{v^2}{2g} = (0.0325) \frac{10.67}{4(0.0138)} \frac{(23.05)^2}{2(32.2)} = \mathbf{51.9 \text{ ft}}$$

$$Q = Av = (0.01807 \text{ ft}^2)(23.05 \text{ ft/s}) = 0.417 \text{ ft}^3/\text{s} \times \frac{449 \text{ gal}/\text{min}}{1 \text{ ft}^3/\text{s}} = \mathbf{187 \text{ gal}/\text{min}}$$

9.48  $A = (0.100 \text{ m})^2 - 4(0.02)(0.03) \text{ m}^2 = 0.0076 \text{ m}^2$  }  $R = \frac{A}{WP} = 0.0119 \text{ m}$

$$WP = 4(0.10) + 8(0.03) = 0.64 \text{ m}$$

$$v = \frac{Q}{A} = \frac{3000 \text{ L}/\text{min}}{0.0076 \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L}/\text{min}} = 6.58 \text{ m/s}$$

$$N_R = \frac{v(4 R) \rho}{\mu} = \frac{(6.58)(4)(0.0119)(789)}{5.60 \times 10^{-4}} = 4.40 \times 10^5; f = 0.0135$$

$$h_L = f \frac{L}{4 R} \cdot \frac{v^2}{2g} = \frac{(0.0135)(2.25)(6.58)^2}{4(0.0119)(2)(9.81)} = \mathbf{1.41 \text{ m}}$$

9.49  $A = (28)(14) - 3[(8)(2) + \pi(2)^2/4] = 334.6 \text{ in}^2(1 \text{ ft}^2/144 \text{ in}^2) = 2.32 \text{ ft}^2$

$$WP = 2(28) + 2(14) + 3[2(8) + \pi(2)] = 150.8 \text{ in}(1 \text{ ft}/12 \text{ in}) = 12.57 \text{ ft}$$

$$R = A/WP = 0.1848 \text{ ft}$$

$$N_R = \frac{v(4 R) \rho}{\mu} = \frac{(20)(4)(0.1848)(2.06 \times 10^{-3})}{4.14 \times 10^{-7}} = 7.36 \times 10^4$$

9.50 **Each Tube:** Ethyl Alcohol at 0°F; assume  $\rho = 1.53$  slugs/ft<sup>3</sup>

$$\mu = 5 \times 10^{-5} \text{ lb-s}/\text{ft}^2 \text{ (App. D)}; N_R = \frac{v D \rho}{\mu}$$

$$v = \frac{N_R \mu}{D \rho} = \frac{(3.5 \times 10^4)(5.0 \times 10^{-5})}{(0.044)(1.53)} = 26.02 \text{ ft/s}$$

$$D = 13.4 \text{ mm}(1.0 \text{ in}/25.4 \text{ mm}) = 0.5276 \text{ in} \times 1 \text{ ft}/12 \text{ in} = 0.044 \text{ ft}$$

$$Q = Av = \frac{\pi(0.044 \text{ ft})^2}{4} \times 26.02 \text{ ft} = 0.0395 \text{ ft}^3/\text{s}$$

$$\text{Total Flow for 3 Tubes: } Q_T = 3(0.0395) = \mathbf{0.118 \text{ ft}^3/\text{s}}$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = \frac{(0.0232)(10.5)(26.02)^2}{(0.044)(2)(32.2)} = \mathbf{58.2 \text{ ft}}$$

$$\frac{D}{\varepsilon} = \frac{0.044}{5 \times 10^{-6}} = 8793; f = 0.0232$$

$$\Delta p = \gamma h_L = (49.01 \text{ lb/ft}^3)(58.2 \text{ ft})(1 \text{ ft}^2/144 \text{ in}^2) = \mathbf{19.8 \text{ psi}}$$

**Shell:** Methyl Alcohol at 77°F (App. B)

$$A = (2.00)(1.00) + \pi(1.00)^2/4 - 3\pi(0.625)^2/4 = 1.865 \text{ in}^2(1 \text{ ft}^2/144 \text{ in}^2)$$

$$A = 0.01295 \text{ ft}^2$$

$$WP = 2(2.0) + \pi(1.0) + 3\pi(0.625) = 13.03 \text{ in}(1 \text{ ft}/12 \text{ in}) = 1.086 \text{ ft}$$

$$R = A/WP = 0.0119 \text{ ft}$$

$$v = \frac{N_R \mu}{4 R \rho} = \frac{(3.5 \times 10^4)(1.17 \times 10^{-5})}{4(0.0119)(1.53)} = 5.61 \text{ ft/s}$$

$$Q = Av = (0.01295 \text{ ft}^2)(5.61 \text{ ft/s}) = \mathbf{0.0727 \text{ ft}^3/\text{s}}$$

$$\frac{4 R}{\varepsilon} = \frac{4(0.0119)}{5 \times 10^{-6}} = 9540; f = 0.0232$$

$$h_L = f \frac{L}{4 R} \frac{v^2}{2g} = \frac{(0.0232)(10.5)(5.61)^2}{4(0.0119)(2)(32.2)} = 2.50 \text{ ft}$$

$$\Delta p = \gamma h_L = (49.1 \text{ lb/ft}^3) \times 2.50 \text{ ft} \times (1 \text{ ft}^2/144 \text{ in}^2) = \mathbf{0.851 \text{ psi}}$$

9 51 Given: Water at 40°F;  $N_R = 3.5 \times 10^4$ ; Figure 9.27; Section is semicircular.

Find: Volume flow rate of water.

$$N_R = v(4R)/\nu; \text{ Then, } v = N_R \nu/(4R) = \text{Average velocity of flow}$$

$$\nu = 1.67 \times 10^{-5} \text{ ft}^2/\text{s} = \text{Kinematic viscosity}$$

$$A = (1.431 \times 10^{-2} \text{ ft}^2)/2 = 7.155 \times 10^{-3} \text{ ft}^2$$

$$ID = 0.1350 \text{ ft}; WP = ID + \pi(ID)/2 = ID(1 + \pi/2) = 0.347 \text{ ft}$$

$$R = A/WP = (7.155 \times 10^{-3} \text{ ft}^2)/(0.347 \text{ ft}) = 0.0206 \text{ ft}$$

$$\text{Then, } v = N_R \nu/(4R) = (3.5 \times 10^4)(1.67 \times 10^{-5})/(4)(0.0206) = 7.09 \text{ ft/s}$$

$$Q = Av = (7.155 \times 10^{-3} \text{ ft}^2)(7.09 \text{ ft/s}) = \mathbf{0.0507 \text{ ft}^3/\text{s} = Q}$$

Energy Loss for 92 in (7.667 ft) of drawn steel:  $h_L = f(L/4R)(v/2g)$

$$4R/\varepsilon = 4(0.0206 \text{ ft})/(5.0 \times 10^{-6} \text{ ft}) = 16480 \quad \text{Then } f = 0.023$$

$$h_L = (0.023) [7.667/(4)(0.0206)][(7.09)^2/(2)(32.2)] = \mathbf{1.67 \text{ ft}}$$

9.52 **Given:** Figure 9.28. Three semicircular sections. Velocity =  $v = 15 \text{ ft/s}$  in each.

Ethylene glycol at 77°F;  $\rho = 2.13 \text{ slugs/ft}^3$ ;  $\mu = 3.38 \times 10^{-4} \text{ lb s/ft}^2$  (App. B)

Find: Reynolds number in each passage.  $N_R = v(4R)\rho/\mu$

**Top channel:** 2-in Type K.copper tube (Half).  $ID = 0.1632 \text{ ft}$ ;  $A_{\text{tot}} = 2.093 \times 10^{-2} \text{ ft}^2$

$$A = A_{\text{tot}}/2 = (2.093 \times 10^{-2} \text{ ft}^2)/2 = 1.0465 \times 10^{-2} \text{ ft}^2$$

$$WP = ID + \pi(ID)/2 = ID(1 + \pi/2) = 0.4196 \text{ ft}$$

$$R = A/WP = (1.0465 \times 10^{-2} \text{ ft}^2)/(0.4196 \text{ ft}) = 0.0249 \text{ ft}$$

$$N_R = v(4R)\rho/\mu = (15)(4)(0.0249)(2.13)/(3.38 \times 10^{-4}) = 9.43 \times 10^3 = \mathbf{9430 = N_R \quad \text{Turbulent}}$$

**Both Side Channels:** 1½-in Type K copper tube (Half).  $ID = 0.1234$  ft;  $A_{tot} = 1.196 \times 10^{-2}$  ft<sup>2</sup>  
 $A = A_{tot}/2 = (1.196 \times 10^{-2} \text{ ft}^2)/2 = 5.98 \times 10^{-3}$  ft<sup>2</sup>  
 $WP = ID + \pi(ID)/2 = ID(1 + \pi/2) = 0.3172$  ft  
 $R = A/WP = (5.98 \times 10^{-3} \text{ ft}^2)/(0.3172 \text{ ft}) = 0.01885$  ft  
 $N_R = v(4R)\rho/\mu = (15)(4)(0.01885)(2.13)/(3.38 \times 10^{-4}) = 7.127 \times 10^3 = 7127 = N_R$  **Turbulent**

Energy Loss for 54 in (4.50 ft) of drawn copper:  $h_L = f(L/4R)(v^2/2g)$   
*Top:*  $4R/\varepsilon = 4(0.0249 \text{ ft})/(5.0 \times 10^{-6} \text{ ft}) = 19\,920$  Then  $f = 0.0315$   
 $h_L = (0.0315)[4.50/(4)(0.0249)][(15.0)^2/(2)(32.2)] = 4.97$  ft  
*Each side:*  $R/\varepsilon = 4(0.01885 \text{ ft})/(5.0 \times 10^{-6} \text{ ft}) = 15\,080$  Then  $f = 0.0340$   
 $h_L = (0.0340)[4.50/(4)(0.01885)][(15.0)^2/(2)(32.2)] = 7.09$  ft (each of two sides)  
**Total loss for all three channels:**  $h_{LT} = 4.97 + 2(7.09) = 19.15$  ft

- 9.53 **Given:** Figure 9.29. Rectangular channel with three fins.  $Q = 225$  L/min  
 Brine (20% NaCl),  $sg = 1.10$  at  $0^\circ\text{C}$ ;  $\rho = 1.10(1000 \text{ kg/m}^3) = 1100 \text{ kg/m}^3$   
 $\mu = 2.5 \times 10^{-3}$  N s/m<sup>2</sup> (App.D)  
 Find: Reynolds number for the flow.  $N_R = v(4R)\rho/\mu$   
 $A = (20)(50) - 3(5)(10) = (850 \text{ mm}^2 [(1 \text{ m}^2)/(10^3 \text{ mm})^2]) = 8.5 \times 10^{-4}$  m<sup>2</sup>  
 $WP = 2(20) + 2(50) + 6(10) = 200$  mm  
 $R = A/WP = (850 \text{ mm}^2)/(200 \text{ mm}) = (4.25 \text{ mm})(1 \text{ m}^2/1000 \text{ mm}) = 0.00425$  m  
 $v = Q/A = (0.00375 \text{ m}^3/\text{s})/(8.5 \times 10^{-4} \text{ m}^2) = 4.41$  m/s  
 $N_R = v(4R)\rho/\mu = (4.41)(4)(0.00425)(1100)/(2.5 \times 10^{-3}) = 3.30 \times 10^4 = N_R$  **Turbulent**  
 Energy Loss for 1.80 m of commercial steel:  $h_L = f(L/4R)(v^2/2g)$   
 $4R/\varepsilon = 4(0.00425 \text{ m})/(4.6 \times 10^{-5}) = 370$  Then  $f = 0.030$   
 $h_L = (0.030)[1.80/(4)(0.00425)][(4.41)^2/(2)(9.81)] = 3.149$  m

# CHAPTER TEN

## MINOR LOSSES

10.1  $D_2/D_1 = 100/50 = 2.00$ ;  $K = 0.52$  (Table 10.1)

$$h_L = K v_1^2 / 2g = 0.52(3.0 \text{ m/s})^2 / (2)(9.81 \text{ m/s}^2) = \mathbf{0.239 \text{ m}}$$

10.2  $v_1 = \frac{Q}{A_1} = \frac{3.0 \times 10^{-3} \text{ m}^3/\text{s}}{4.636 \times 10^{-4} \text{ m}^2} = 6.47 \text{ m/s}$ ;  $\frac{D_2}{D_1} = \frac{85.4 \text{ mm}}{24.3 \text{ mm}} = 3.51$

$$K = 0.73 \text{ (Table 10.1)}; h_L = K \frac{v_1^2}{2g} = \frac{0.73(6.47)^2}{2(9.81)} \text{ m} = \mathbf{1.56 \text{ m}}$$

10.3  $v_1 = \frac{Q}{A_1} = \frac{0.10 \text{ ft}^3/\text{s}}{0.00499 \text{ ft}^2} = 20.0 \text{ ft/s}$ ;  $\frac{D_2}{D_1} = \frac{0.2803 \text{ ft}}{0.07975 \text{ ft}} = 3.51$ ;  $K = 0.73$  (Table 10.1)

$$h_L = K \frac{v_1^2}{2g} = \frac{(0.73)(20.0 \text{ ft/s})^2}{2(32.2 \text{ ft/s}^2)} = \mathbf{4.55 \text{ ft}}$$

10.4  $\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$ ;  $\frac{D_2}{D_1} = \frac{6.0}{2.0} = 3.0 \rightarrow K = 0.78$  (Table 10.1)

$$p_1 - p_2 = \gamma \left[ \frac{v_2^2 - v_1^2}{2g} + h_L \right]; \text{ assume } z_1 = z_2$$

$$h_L = K v_1^2 / 2g = (0.78)(4.0 \text{ ft/s})^2 / 2(32.2 \text{ ft/s}^2) = 0.194 \text{ ft}$$

$$v_2 = v_1 \left( \frac{D_1}{D_2} \right)^2 = 4.0 \text{ ft/s} \left( \frac{2.0}{6.0} \right)^2 = 0.444 \text{ ft/s}$$

$$p_1 - p_2 = \frac{62.4 \text{ lb}}{\text{ft}^3} \left[ \frac{0.444^2 - 4.0^2}{2(32.2)} + 0.194 \right] \text{ ft} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} = \mathbf{-0.0224 \text{ psi}}$$

10.5  $\frac{D_2}{D_1} = 3.0$ ;  $K = 0.16$  (Table 10.2) for  $\theta = 15^\circ$

$$h_L = K v_1^2 / 2g = 0.16(4.0)^2 / 2(32.2) = 0.0398 \text{ ft}$$

$$p_1 - p_2 = 62.4 \left[ \frac{0.44^2 - 4.00^2}{2(32.2)} + 0.0398 \right] \text{ ft} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} = \mathbf{-0.0891 \text{ psi}}$$

10.6  $\frac{D_2}{D_1} = \frac{75}{25} = 3.0$ ;  $K = 0.31$  (Table 10.2) for  $\theta = 20^\circ$

$$h_L = K v_1^2 / 2g = 0.31(3.00 \text{ m/s})^2 / 2(9.81 \text{ m/s}^2) = 0.142 \text{ m}$$

10.7  $K = 0.71$ ;  $h_L = 0.71(3.00)^2 / 2(9.81) = \mathbf{0.326 \text{ m}}$

$$10.8 \quad v_1 = \frac{Q}{A_1} = \frac{85 \text{ gal/min}}{0.02333 \text{ ft}^2} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 8.11 \text{ ft/s}; \quad \frac{D_2}{D_1} = \frac{0.5054}{0.1723} = 2.93$$

$$h_L = K v_1^2 / 2g = K(8.11)^2 / 2(32.2) = K(1.022 \text{ ft})$$

$\theta$	2°	10°	15°	20°	30°	40°	60°
$K$	0.03	0.08	0.16	0.31	0.48	0.59	0.71
$h_L$	0.031	0.082	0.164	0.317	0.491	0.603	0.726 ft

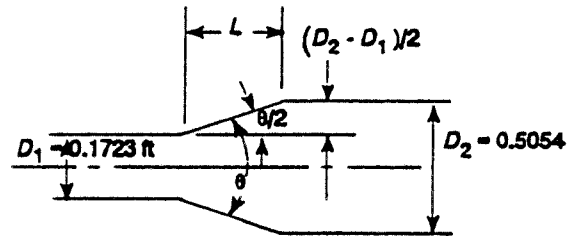
10.9 Graph shown after Problem 10.11.

10.10 and 10.11

$$\sin\left(\frac{\theta}{2}\right) = \frac{(D_2 - D_1)/2}{L}$$

$$L = \frac{(D_2 - D_1)/2}{\sin(\theta/2)}$$

$$L = \frac{(0.5054 - 0.1723)/2}{\sin(\theta/2)} = \frac{0.1666 \text{ ft}}{\sin(\theta/2)}$$



$\theta$	$\theta/2$	$\sin(\theta/2)$	$L(\text{ft})$	Prob. 10.10 $h_{L_f}$ (ft)	Prob. 10.8 $h_{L_{exp}}$ (ft)	Prob. 10.11 $h_{L_{exp}}$ (ft)
2°	1°	0.01745	9.54	0.0414	0.031	0.0724
10°	5°	0.08716	1.910	0.0083	0.082	0.0903
15°	7.5°	0.1305	1.276	0.0055	0.164	0.1695
20°	10°	0.1736	0.959	0.0042	0.317	0.3212
30°	15°	0.2588	0.643	0.0028	0.491	0.4938
40°	20°	0.342	0.487	0.0021	0.603	0.6051
60°	30°	0.500	0.333	0.0014	0.726	0.7274

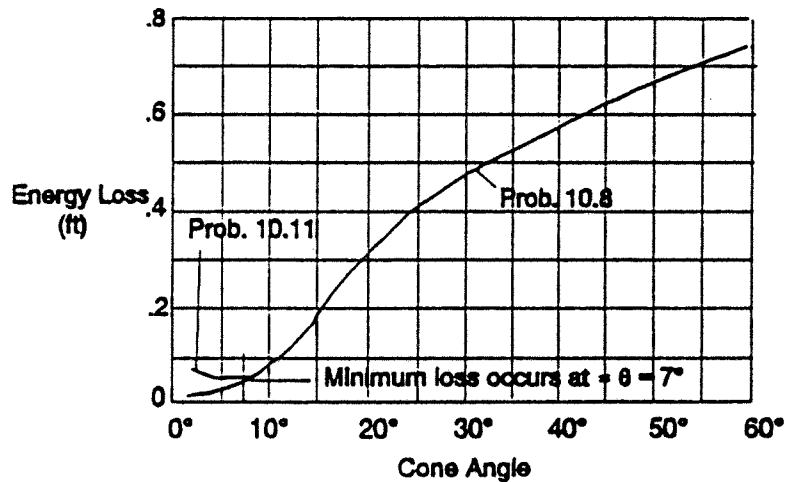
$$h_{L_f} = f \frac{L v^2}{D 2g} = \frac{(0.0215)(L)(2.099)^2}{(0.3389)(2)(32.2)} = 0.00434(L)$$

$$D = (D_2 + D_1)/2 = (0.5054 + 0.1723)/2 = 0.3389 \text{ ft}$$

$$A = \pi D^2 / 4 = \pi(0.3389)^2 / 4 = 0.0902 \text{ ft}^2$$

$$v = \frac{Q}{A} = \frac{85 \text{ gal/min}}{0.0902 \text{ ft}^2} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 2.099 \text{ ft/s}$$

$$N_R = \frac{vD}{\nu} = \frac{(2.099)(0.3389)}{1.21 \times 10^{-5}} = 5.88 \times 10^4; \quad \frac{D}{\epsilon} = \frac{0.3389}{1.5 \times 10^{-4}} = 2259; \quad f = 0.0215$$



10.12 **Ideal diffuser - No energy loss**

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g} \because h_L = 0, z_1 = z_2$$

$$p_2 = p_1 + \gamma \left[ \frac{v_1^2 - v_2^2}{2g} \right] = 500 \text{ kPa} + \frac{9.79 \text{ kN}}{\text{m}^3} \left[ \frac{4.98^2 - 0.584^2}{2(9.81)} \text{ m} \right] = 512.2 \text{ kPa}$$

12.2 kPa Recovery

$$v_1 = \frac{Q}{A_1} = \frac{150 \text{ L/min}}{5.017 \times 10^{-4}} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 4.98 \text{ m/s}$$

$$v_2 = \frac{Q}{A_2} = \frac{150}{(4.282 \times 10^{-3})(60000)} = 0.584 \text{ m/s}$$

$$10.13 \quad p_2 = p_1 + \gamma \left[ \frac{v_1^2 - v_2^2}{2g} - h_L \right] = 500 + 9.79 \left[ \frac{4.98^2 - 0.584^2}{2(9.81)} - 0.873 \right] = 503.7 \text{ kPa} - 3.7 \text{ kPa recov.} = 500 \text{ kPa}$$

30% of ideal

$$h_L = K \frac{v_1^2}{2g} = 0.69 \frac{(4.98)^2}{2(9.81)} = 0.873 \text{ m}$$

$$D_2/D_1 = 73.8 \text{ mm}/25.3 \text{ mm} = 2.92; K = 0.69$$

10.14 **Same analysis as 10.13**

a.  $\theta = 60^\circ; K = 0.71; h_L = 0.899 \text{ m}; p_2 = 503.6 \text{ kPa}; 29\% \text{ of ideal}$

b.  $\theta = 30^\circ; K = 0.48; h_L = 0.607 \text{ m}; p_2 = 506.4 \text{ kPa}; 53\% \text{ of ideal}$

c.  $\theta = 10^\circ; K = 0.08; h_L = 0.101 \text{ m}; p_2 = 511.2 \text{ kPa}; 92\% \text{ of ideal}$

10.15 **Exit loss:**  $h_L = 1.0 v^2/2g = 1.0(2.146)^2/2(9.81) = 0.235 \text{ m}$

$$v = \frac{Q}{A} = \frac{0.04 \text{ m}^3/\text{s}}{1.864 \times 10^{-2} \text{ m}^2} = 2.146 \text{ m/s}$$

10.16 **Exit loss:**  $h_L = 1.0 v^2/2g = 1.0(7.48)^2/2(32.2) = \mathbf{0.868 \text{ ft}}$

$$v = \frac{Q}{A} = \frac{1.50 \text{ ft}^3/\text{s}}{0.2006 \text{ ft}^2} = 7.48 \text{ ft/s}$$

10.17 **Sudden contraction:**  $h_L = K v_2^2/2g$

$$v_2 = v_1 \left( \frac{A_1}{A_2} \right) = v_1 \left( \frac{D_1}{D_2} \right)^2 = 4.00 \text{ ft/s} \left( \frac{4.0}{2.0} \right)^2 = 16.00 \text{ ft/s}$$

For  $D_2/D_1 = 2.0$ ,  $K = 0.34$  (Table 10.3)

$$h_L = (0.34)(16.0 \text{ ft/s})^2/2(32.2 \text{ ft/s}^2) = \mathbf{1.35 \text{ ft}}$$

10.18 
$$p_2 = p_1 + \gamma \left[ \frac{v_1^2 - v_2^2}{2g} - h_L \right]$$

$$= 80 \text{ psig} + (0.87) \left[ \frac{62.4 \text{ lb}}{\text{ft}^3} \right] \left[ \frac{4.00^2 - 16.00^2}{2(32.2)} - 1.35 \right] \text{ft} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2}$$

$p_2 = 80 \text{ psig} - 1.91 \text{ psi} = \mathbf{78.09 \text{ psig}}$   
See Probs. 10.12, 10.13 for analysis.

10.19 **False:**  $K$  decreases, but  $h_L = K(v_2^2/2g)$

The velocity head increases faster than  $K$  decreases.

Examples:  $v_2 = 1.2 \text{ m/s}$ ;  $K = 0.44$ ;  $h_L = 0.0323 \text{ m}$

$v_2 = 6.0 \text{ m/s}$ ;  $K = 0.39$ ;  $h_L = 0.716 \text{ m}$

$v_2 = 12.0 \text{ m/s}$ ;  $K = 0.33$ ;  $h_L = 2.42 \text{ m}$

10.20 **Sudden contraction:**  $h_L = K(v_2^2/2g)$

$$\frac{D_1}{D_2} = \frac{122.3 \text{ mm}}{49.3 \text{ mm}} = 2.48$$

$$v_2 = \frac{Q}{A_2} = \frac{500 \text{ L/min}}{1.905 \times 10^{-3} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 4.37 \text{ m/s}; K = 0.38 \text{ (Table 10.3)}$$

$$h_L = (0.38)(4.37)^2/2(9.81) = \mathbf{0.371 \text{ m}}$$

10.21 **Gradual contraction:** From Prob. 10.20:  $v_2 = 4.37 \text{ m/s}$ ;  $\frac{D_1}{D_2} = 2.48$

$$K = 0.23; h_L = (0.23)(4.37)^2/2(9.81) = \mathbf{0.224 \text{ m}}$$
 (Fig. 10.10)  $\theta = 105^\circ$

10.22 **Sudden contraction:**  $D_1/D_2 = 0.3188 \text{ ft}/0.125 \text{ ft} = 2.55$

$$v_2 = \frac{Q}{A_2} = \frac{250 \text{ gal/min}}{0.01227 \text{ ft}^2} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 45.38 \text{ ft/s}; K = 0.31 \text{ (Table 10.3)}$$

$$h_L = K v_2^2/2g = (0.31)(45.38)^2/2(32.2) = \mathbf{9.91 \text{ ft}}$$

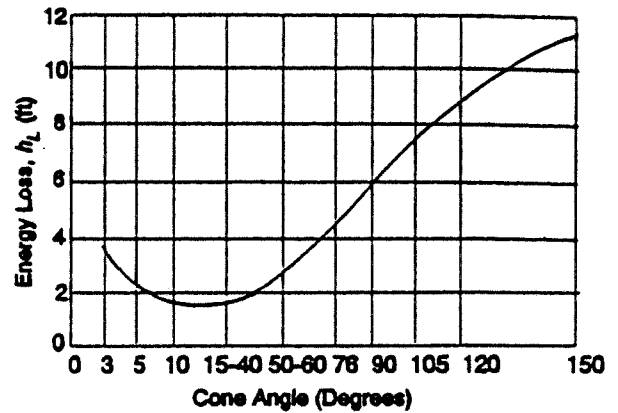
10.23 **Gradual contraction:** Data from Prob. 10.22:  $K = 0.135$  (Fig. 10.10)  $\theta = 76^\circ$

$$h_L = (0.135)(45.38)^2/2(32.2) = 4.32 \text{ ft}$$

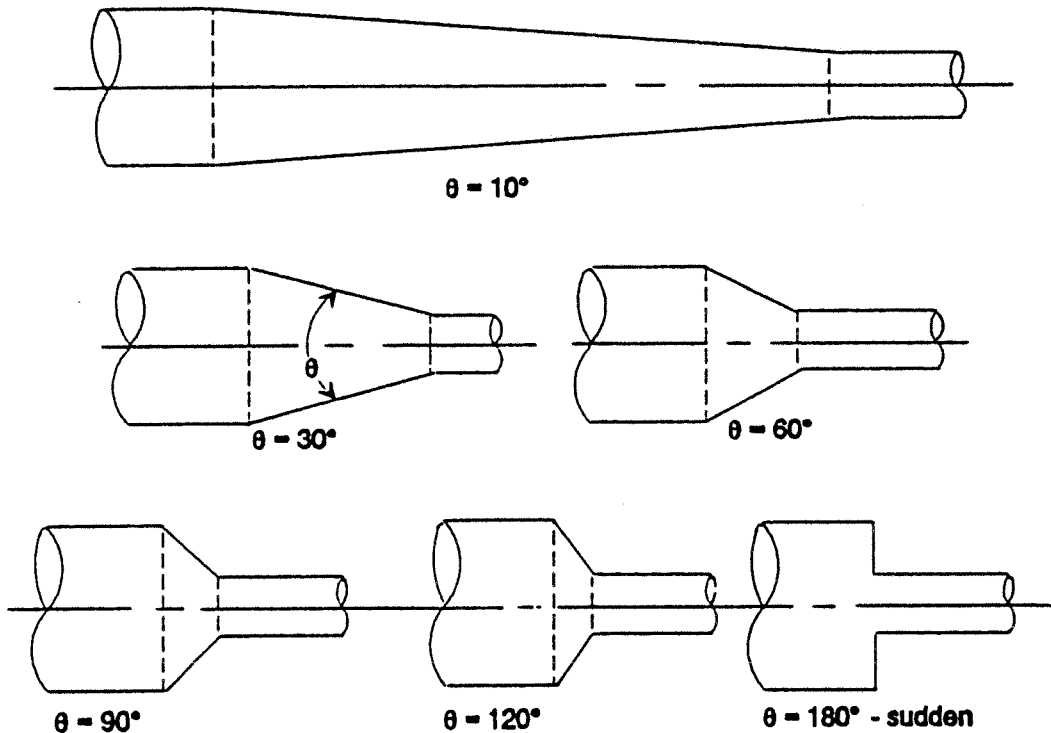
10.24 **Gradual contraction:** Data from Prob. 10.22:  $D_1/D_2 = 2.55$

$$h_L = K v_2^2/2g = K(45.38)^2/2(32.2) = K(31.98 \text{ ft})$$

$\theta$	$K$	$h_L$ (ft)
150°	0.36	11.51
120°	0.28	8.95
105°	0.23	7.35
90°	0.19	6.08
76°	0.135	4.32
50–60°	0.075	2.40
15–40°	0.045	1.44
10°	0.048	1.53
5°	0.084	2.69
3°	0.109	3.49



10.25 Sketches of selected contractions:



10.27 Gradual contraction,  $\theta = 120^\circ$

$D_1 = 6.14$  in,  $D_2 = 3.32$  in Ductile iron pipe

$D_1/D_2 = 1.85$ ;  $K = 0.255$

$$10.28 \quad v_2 = \frac{Q}{A_2} = \frac{50 \text{ gal/min}}{1.907 \times 10^{-2} \text{ ft}^2} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 5.84 \text{ ft/s}$$

$$h_L = K \left( \frac{v_2^2}{2g} \right) = 0.50 \left[ \frac{(5.84 \text{ ft/s})^2}{2(32.2 \text{ ft/s}^2)} \right] = 0.265 \text{ ft}$$

$$10.29 \quad \text{Entrance loss: } h_L = K \frac{v_2}{2g} = K \frac{(3.0 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)} = K(0.459 \text{ m})$$

a.  $K = 1.0$ ;  $h_L = 0.459 \text{ m}$

b.  $K = 0.50$ ;  $h_L = 0.229 \text{ m}$

c.  $K = 0.25$ ;  $h_L = 0.115 \text{ m}$

d.  $K = 0.04$ ;  $h_L = 0.018 \text{ m}$

10.30 10 in Sch. 40 pipe:  $D = 0.2545$  m

**Globe valve:**  $L_e/D = 340$

$$L_e = (L_e/D) \times D = 340(0.2545 \text{ m}) = 86.53 \text{ m}$$

10.31 **Gate valve, fully open:**  $L_e/D = 8$

$$L_e = (L_e/D) \times D = 8(0.2545 \text{ m}) = 2.04 \text{ m}$$

10.32 **Ball-type check valve:**

$$\text{Let } K = f_T(L_e/D) = f_T(150) = 0.019(150) = 2.85$$

For 2-in Schedule 40 pipe,  $f_T = 0.019$  (Table 10.5)

$$10.33 \quad \Delta p = \gamma h_L = \gamma \left[ f_T \frac{L_e}{D} \frac{v^2}{2g} \right] = (0.90) \left( \frac{62.4 \text{ lb}}{\text{ft}^3} \right) \left[ (0.016)(150) \frac{(10.4)^2}{2(32.2)} \right] \frac{(\text{ft})(1 \text{ ft}^2)}{144 \text{ in}^2} = 1.58 \text{ psi}$$

$$\text{Angle valve } v = \frac{Q}{A} = \frac{650 \text{ gal/min}}{0.1390 \text{ ft}^2} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 10.4 \text{ ft/s}$$

$$f_T = 0.016 \text{ (Table 10.5)}$$

$$10.34 \quad v = \frac{Q}{A} = \frac{750 \text{ L/min}}{3.09 \times 10^{-3} \text{ m}^2} \times \frac{1 \text{ m}^3/2}{60000 \text{ L/min}} = 4.045 \text{ m/s}; \quad \frac{v^2}{2g} = \frac{(4.045)^2}{2(9.81)} = 0.834 \text{ m}$$

**Elbow**  $f_T = 0.018$  (Table 10.5)

$$\Delta p = \gamma h_L = \gamma \left[ f_T \frac{L_e}{D} \frac{v^2}{2g} \right] = \frac{9.81 \text{ kN}}{\text{m}^3} [0.018(30)(0.834 \text{ m})] = 4.42 \text{ kPa}$$

10.35 **Street elbow:**  $L_e/D = 50$  (See Prob. 10.34)

$$\Delta p = \gamma h_L = (9.81)[(0.018)(50)(0.834)] = 7.36 \text{ kPa}$$

10.36 **Long radius elbow:**  $L_e/D = 20$  (See Prob. 10.34, 10.35)

$$\Delta p = \gamma h_L = 9.81 [(0.018)(20)(0.834)] = 2.95 \text{ kPa} \text{ Lowest}$$

$\Delta p$  is proportional to  $L_e/D$ .

10.37 Pt. 1 at inlet; Pt. 2 at outlet

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_{L_{\text{pipe}}} - h_{L_{\text{bend}}} = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g} : v_1 = v_2; \text{ assume } z_1 = z_2$$

$$p_1 - p_2 = \gamma (h_{L_{\text{pipe}}} + h_{L_{\text{bend}}})$$

**Close return bend:**  $L_e/D = 50$ ,  $f_T = 0.027$  (Table 10.5)

$$v = \frac{Q}{A} = \frac{12.5 \text{ gal/min}}{0.00211 \text{ ft}^2} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 13.19 \text{ ft/s}$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(13.19)(0.0518)(2.13)}{3.38 \times 10^{-4}} = 4.31 \times 10^3$$

$$D/\varepsilon = 0.0518/1.5 \times 10^{-4} = 345; f = 0.041$$

$$h_{L_{\text{bend}}} = f_T \frac{L_e}{D} \frac{v^2}{2g} = (0.027)(50) \frac{(13.19)^2}{2(32.2)} \text{ ft} = 3.65 \text{ ft}$$

$$h_{L_{\text{tube}}} = f \frac{L}{D} \frac{v^2}{2g} = (0.041) \left[ \frac{8.00}{0.0518} \right] \frac{(13.19)^2}{2(32.2)} = 17.12 \text{ ft}$$

$$p_1 - p_2 = (68.47)[17.12 + 3.65]/144 = \mathbf{9.87 \text{ psi}}$$

10.38 3/4-in Steel tube, 0.065 in wall thickness

$$D = 0.620 \text{ in} = 0.05167 \text{ ft}; A = 2.097 \times 10^{-3} \text{ ft}^2$$

$$v = \frac{Q}{A} = \frac{(12.5/449) \text{ ft}^3/\text{s}}{2.097 \times 10^{-3} \text{ ft}^2} = 13.28 \text{ ft/s}$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(13.28)(0.05167)(2.13)}{3.38 \times 10^{-4}} = 4.32 \times 10^3$$

$$D/\varepsilon = \frac{0.05167}{(1.5 \times 10^{-4})} = 344; f = 0.041$$

Use  $f_T = 0.027$  because  $D/\varepsilon$  is the same as for the 1/2-in steel pipe in Problem 10.37.

$$90^\circ \text{ Bend: } r = R_o - D_o/2 = 3.50 \text{ in} - 2.00/2 = 2.50 \text{ in}$$

$$r/D = 2.50 \text{ in}/0.620 \text{ in} = 4.03$$

Use  $L_e/D = 14$  from Fig. 10.23

$$h_{L_{\text{bend}}} = 2f_T \frac{L_e}{D} \frac{v^2}{2g} = (2)(0.027)(14) \frac{(13.28)^2}{2(32.2)} = 2.07 \text{ ft (2 Bends)}$$

$$h_{L_{\text{tube}}} = f \frac{L}{D} \frac{v^2}{2g} = (0.041) \left[ \frac{8.50}{0.05167} \right] \frac{(13.28)^2}{2(32.2)} = 18.46 \text{ ft}$$

See Problem 10.37:

$$p_1 - p_2 = \gamma [h_{L_{\text{tube}}} + h_{L_{\text{bend}}}] = (68.47) [18.46 + 2.07]/144$$

$$p_1 - p_2 = 9.76 \text{ psi (Virtually equal to Prob. 10.37)}$$

10.39  $v = \frac{Q}{A} = \frac{0.40 \text{ ft}^3/\text{s}}{0.05132 \text{ ft}^2} = 7.79 \text{ ft/s}$ : **Tee-flow through run:**  $\frac{L_e}{D} = 20$   
 $f_T = 0.018$  (Table 10.5)  
 $h_L = f_T \frac{L_e}{D} \frac{v^2}{2g} = (0.018)(20) \frac{(7.79)^2}{2(32.2)} = \mathbf{0.340 \text{ ft}}$

10.40 **Tee-flow through branch:**  $L_e/D = 60$   
 $v = \frac{Q}{A} = \frac{0.08 \text{ m}^3/\text{s}}{0.01365 \text{ m}^2} = 4.76 \text{ m/s}$   
 $f_T = 0.018$  (Table 10.5)  
 $h_L = f_T \frac{L_e}{D} \frac{v^2}{2g} = (0.018)(60) \frac{(4.76)^2}{2(9.81)} = \mathbf{1.25 \text{ m}}$

10.41 **Pipe bend:**  $R_o = 300 \text{ mm}$ ;  $r = R_o - D_o/2 = 300 - \frac{28.6}{2} = 285.7 \text{ mm}$   
 $r/D = 0.2857 \text{ m}/0.0253 \text{ m} = 11.3 \rightarrow L_e/D = 32$  from Fig. 10.23.  
 $v = \frac{Q}{A} = \frac{250 \text{ L/min}}{5.017 \times 10^{-4} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 8.31 \text{ m/s}$   
 $N_R = \frac{vD}{\nu} = \frac{(8.31)(0.0253)}{3.60 \times 10^{-7}} = 5.84 \times 10^5$ ;  $\frac{D}{\epsilon} = \frac{0.0253}{1.5 \times 10^{-6}} = 16867$ ;  
 $f_T = 0.0115$  in zone of complete turbulence  
 $h_L = f_T \frac{L_e}{D} \frac{v^2}{2g} = (0.0115)(32) \frac{(8.31)^2}{2(9.81)} = \mathbf{1.29 \text{ m}}$

10.42 **Pipe bend:** See Prob. 10.41 for some data.  
 For minimum energy loss,  $r/D = 3$ ,  $L_e/D = 11.8$  (Fig. 10.23)  
 $r = \left(\frac{r}{D}\right)D = (3)(25.3 \text{ mm}) = \mathbf{76 \text{ mm}}$   
 $h_L = f_T \frac{L_e}{D} \frac{v^2}{2g} = (0.0115)(11.8) \frac{(8.31)^2}{2(9.81)} = \mathbf{0.477 \text{ m}}$

10.43 **Proposal 1 - Pipe bend:**  $\frac{r}{D} = \frac{750 \text{ mm}}{49.8 \text{ mm}} = 15.1; \frac{L_e}{D} = 40.5$  (Fig. 10.23)

$$v = \frac{Q}{A} = \frac{750 \text{ L/min}}{1.945 \times 10^{-3} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 6.43 \text{ m/s}$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(6.43)(0.0498)(802)}{1.92 \times 10^{-3}} = 1.34 \times 10^5; \frac{D}{\varepsilon} = \frac{0.0498}{1.5 \times 10^{-6}} = 33200;$$

$f = 0.017; f_T = 0.010$  in zone of complete turbulence

$$h_L = f_T \frac{L_e}{D} \frac{v^2}{2g} = (0.010)(40.5) \frac{(6.43)^2}{2(9.81)} = \mathbf{0.85 \text{ m}}$$

**Proposal 2 - Bend + tube:**  $\frac{r}{D} = \frac{150 \text{ mm}}{49.8 \text{ mm}} = 3.01; \frac{L_e}{D} = 11.8$

$$\left. \begin{aligned} h_{L_{\text{bend}}} &= f_T \frac{L_e}{D} \frac{v^2}{2g} = (0.010)(11.8) \frac{(6.43)^2}{2(9.81)} = 0.248 \text{ m} \\ h_{L_{\text{tube}}} &= f \frac{L}{D} \frac{v^2}{2g} = (0.017) \frac{1.20}{0.0498} \frac{(6.43)^2}{2(9.81)} = 0.862 \text{ m} \end{aligned} \right\} h_{L_{\text{tot}}} = 1.11 \text{ m}$$

10.44  $v = \frac{Q}{A} = \frac{750 \text{ L/min}}{1.905 \times 10^{-3} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 6.56 \text{ m/s}; \frac{v^2}{2g} = \frac{(6.56)^2}{2(9.81)} = 2.194 \text{ m}$

$$N_R = \frac{vD\rho}{\mu} = \frac{(6.56)(0.0493)(802)}{1.92 \times 10^{-3}} = 1.35 \times 10^5$$

$D/\varepsilon = 0.0493/4.6 \times 10^{-5} = 1072; f = 0.0215; f_T = 0.019$

$$\left. \begin{aligned} h_{L_{\text{elbow}}} &= f_T \frac{L_e}{D} \frac{v^2}{2g} = (0.019)(30)(2.194 \text{ m}) = 1.25 \text{ m} \\ h_{L_{\text{pipe}}} &= f \frac{L}{D} \frac{v^2}{2g} = (0.0215) \left( \frac{1.40}{0.0493} \right) (2.194) = 1.340 \text{ m} \end{aligned} \right\} h_{L_{\text{total}}} = 2.59 \text{ m}$$

$$\frac{2.59 \text{ m}}{0.85 \text{ m}} = 3.05 \text{ times proposal 1.}$$

$$\frac{2.59 \text{ m}}{1.11 \text{ m}} = 2.33 \text{ times proposal 2.}$$

10.45 **Bend in tube:**  $\frac{r}{D} = \frac{150 \text{ mm}}{15.75 \text{ mm}} = 9.52; \frac{L_e}{D} = 29$  (Fig. 10.23)

$$v = \frac{Q}{A} = \frac{40 \text{ L/min}}{1.948 \times 10^{-4} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 3.42 \text{ m/s}$$

$$\frac{D}{\varepsilon} = \frac{0.01575}{4.6 \times 10^{-5}} = 342; f_T = 0.025 \text{ in zone of complete turbulence}$$

$$h_L = f_T \frac{L_e}{D} \frac{v^2}{2g} = (0.025)(29) \frac{(3.42)^2}{2(9.81)} = \mathbf{0.432 \text{ m}}$$

$$10.46 \quad \frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{v_2^2}{2g} \quad \left| \quad A_1 = \frac{\pi D_1^2}{4} = \frac{\pi(0.050 \text{ m})^2}{4} = 0.001963 \text{ m}^2 \right.$$

$$h_L = \frac{p_1 - p_2}{\gamma_w} + z_1 - z_2 + \frac{v_1^2 - v_2^2}{2g} \quad \left| \quad A_2 = \frac{\pi D_2^2}{4} = \frac{\pi(0.10 \text{ m})^2}{4} = 0.007854 \text{ m}^2 \right.$$

$$z_1 - z_2 = -1.20 \text{ m}$$

$$v_1 = \frac{Q}{A_1} = \frac{6.0 \times 10^{-3} \text{ m}^3/\text{s}}{0.001963 \text{ m}^2} = 3.056 \text{ m/s}; \quad \frac{v_1^2}{2g} = \frac{(3.056)^2}{2(9.81)} = 0.476 \text{ m}$$

$$v_2 = \frac{Q}{A_2} = \frac{6.0 \times 10^{-3}}{0.007854} = 0.764 \text{ m/s}; \quad \frac{v_2^2}{2g} = \frac{(0.764)^2}{2(9.81)} = 0.0297 \text{ m}$$

$$\text{Manometer: } p_1 + \gamma_w(0.25 \text{ m}) - \gamma_m(0.35 \text{ m}) - \gamma_w(1.10 \text{ m}) = p_2$$

$$p_1 - p_2 = \gamma_m(0.35 \text{ m}) + \gamma_w(1.10 - 0.25) \text{ m}$$

$$\frac{p_1 - p_2}{\gamma_w} = \frac{\gamma_m(0.35 \text{ m})}{\gamma_w} + \frac{\gamma_w(0.85 \text{ m})}{\gamma_w} = \frac{132.8(0.35 \text{ m})}{9.69} + 0.85 \text{ m}$$

$$\frac{p_1 - p_2}{\gamma_w} = 4.80 \text{ m} + 0.85 \text{ m} = 5.65 \text{ m}$$

$$\text{Then } h_L = 5.65 - 1.20 + 0.476 - 0.0297 = 4.90 \text{ m}$$

$$\text{Let } h_L = K \frac{v_1^2}{2g}$$

$$\text{Then } K = \frac{h_L}{v_1^2/2g} = \frac{4.90 \text{ m}}{0.476 \text{ m}} = 10.3$$

10.47 90° Bend. Steel tube; 1/2 in OD x 0.065 in wall thickness.

$$r = 2.00 \text{ in. } D = 0.370 \text{ in} = 0.03083 \text{ ft.}$$

$$D/\varepsilon = 0.03083/1.5 \times 10^{-4} = 206. \text{ Then } f_T = 0.0295 \text{ in fully turbulent zone. } A = 7.467 \times 10^{-4} \text{ ft}^2.$$

$$Q = 3.5 \text{ gal/min} = 0.00780 \text{ ft}^3/\text{s. } v = Q/A = (0.00780 \text{ ft}^3/\text{s})/(0.00780 \text{ ft}^2) = 10.44 \text{ ft/s.}$$

$$(v^2/2g) = (10.44 \text{ ft/s})^2/[2(32.2 \text{ ft/s}^2)] = 1.692 \text{ ft. } r/D = 2.00 \text{ in}/0.370 \text{ in} = 5.41.$$

$$L_e/D = 17 \text{ (Fig. 10.27). } K = f_T/(L_e/D) = 0.0295(17) = 0.5015.$$

$$h_L = K(v^2/2g) = 0.5015(1.692 \text{ ft}) = \mathbf{0.849 \text{ ft} = h_L}$$

10.48 90° Bend. Steel tube; 1 1/4 in OD x 0.083 in wall thickness.

$$r = 3.25 \text{ in. } D = 1.084 \text{ in} = 0.09033 \text{ ft.}$$

$$D/\varepsilon = 0.09033/1.5 \times 10^{-4} = 602. \text{ Then } f_T = 0.023 \text{ in fully turbulent zone. } A = 6.409 \times 10^{-3} \text{ ft}^2.$$

$$Q = 27.5 \text{ gal/min} = 0.0612 \text{ ft}^3/\text{s. } v = Q/A = (0.0612 \text{ ft}^3/\text{s})/(0.006409 \text{ ft}^2) = 9.556 \text{ ft/s}$$

$$(v^2/2g) = (9.556 \text{ ft/s})^2/[2(32.2 \text{ ft/s}^2)] = 1.418 \text{ ft. } r/D = 3.25 \text{ in}/1.084 \text{ in} = 3.00.$$

$$L_e/D = 12.5 \text{ (Fig. 10.27), } K = f_T/(L_e/D) = 0.023(12.5) = 0.288.$$

$$h_L = K(v^2/2g) = 0.288(1.418 \text{ ft}) = \mathbf{0.408 \text{ ft} = h_L}$$

10.49 Data from Problem 10.47. Coil with 6.0 revolutions.  $K = 0.5015$  for one 90° bend.

$$n = 6.0 \text{ rev}(4 \text{ 90}^\circ \text{ bends})/\text{rev} = 24 \text{ 90}^\circ \text{ bends. } v^2/2g = 1.692 \text{ ft. } r/D = 5.41. f_T = 0.0295.$$

$$K_B = (n - 1) [0.25 \pi f_T (r/D) + 0.5K] + K \text{ [Equation 10-10]}$$

$$K_B = (24 - 1)[0.25 \pi (0.0295)(5.41) + 0.5(0.5015)] + 0.5015 = \mathbf{9.15 = K_B}$$

$$h_L = K_B(v^2/2g) = (9.15)(1.692 \text{ ft}) = \mathbf{15.5 \text{ ft} = h_L}$$

- 10.50 Data from Problem 10.48. Coil with 8.5 revolutions.  $K = 0.288$  for one  $90^\circ$  bend.  
 $n = 8.5 \text{ rev}(4 \text{ } 90^\circ \text{ bends})/\text{rev} = 34 \text{ } 90^\circ \text{ bends}$ .  $v^2/2g = 1.418 \text{ ft}$ .  $r/D = 3.00$ .  $f_T = 0.023$ .  
 $K_B = (n - 1)(0.25 \pi f_T (r/D) + 0.5K) + K$  [Equation 10-10]  
 $K_B = (34 - 1)[0.25\pi(0.023)(3.00) + 0.5(0.288)] + 0.288 = \mathbf{6.83} = K_B$   
 $h_L = K_B(v^2/2g) = (6.83)(1.418) = \mathbf{9.68 \text{ ft}} = h_L$
- 10.51 Data from Problem 10.47. 145 degree bend.  $K = 0.5015$  for one  $90^\circ$  bend.  
 $n = 145^\circ/90^\circ = 1.61 \text{ } 90^\circ \text{ bends}$ .  $v^2/2g = 1.692 \text{ ft}$ .  $r/D = 5.41$ .  $f_T = 0.0295$ .  
 $K_B = (n - 1)[0.25 \pi f_T (r/D) + 0.5K] + K$  [Equation 10-10]  
 $K_B = (1.61 - 1)[0.25 \pi (0.0295)(5.41) + 0.5(0.5015)] + 0.5015 = \mathbf{0.731} = K_B$   
 $h_L = K_B(v^2/2g) = (0.731)(1.692 \text{ ft}) = \mathbf{1.25 \text{ ft}} = h_L$
- 10.52 Data from Problem 10.48. 60 degree bend.  $K = 0.288$  for one  $90^\circ$  bend.  
 $n = 60^\circ/90^\circ = 0.667 \text{ } 90^\circ \text{ bends}$ .  $v^2/2g = 1.418 \text{ ft}$ .  $r/D = 3.00$ .  $f_T = 0.023$ .  
 $K_B = (n - 1)[(0.25 \pi f_T (r/D) + 0.5K) + K$  [Equation 10-10]  
 $K_B = (0.667 - 1)[0.25\pi(0.023)(3.00) + 0.5(0.288)] + 0.288 = \mathbf{0.222} = K_B$   
 $h_L = K_B(v^2/2g) = (0.222)(1.418) = \mathbf{0.315 \text{ ft}} = h_L$
- 10.53 Directional control valve. Figure 10.29. For  $Q = 5 \text{ gal/min}$ ,  $\Delta p = 60 \text{ psi}$ .
- 10.54 Directional control valve. Figure 10.29. For  $Q = 7.5 \text{ gal/min}$ ,  $\Delta p = 104 \text{ psi}$ .  
 For  $Q = 10 \text{ gal/min}$ ,  $\Delta p = 175 \text{ psi}$ .
- 10.55 Find  $K$  if  $\Delta p = \gamma h_L = \gamma K(v^2/2g)$ . Then,  $K = (\Delta p)/[\gamma(v^2/2g)]$  Dimensionless.  
 From Prob. 10.53: For  $Q = 5 \text{ gal/min}$ ,  $\Delta p = 60 \text{ psi} = 8640 \text{ lb/ft}^2$ .  
 $5/8 \text{ OD tube with } t = 0.065 \text{ in}$ .  $A = 1.336 \times 10^{-3} \text{ ft}^2$ .  $\gamma = 0.90(62.4 \text{ lb/ft}^3) = 56.16 \text{ lb/ft}^3$ .  
 $v = Q/A = [(5 \text{ gpm})/(1 \text{ ft}^3/\text{s}/449 \text{ gpm})]/(1.336 \times 10^{-3} \text{ ft}^2) = 8.34 \text{ ft/s}$   
 $(v^2/2g) = (8.34 \text{ ft/s})^2/[2(32.2 \text{ ft/s}^2)] = 1.079 \text{ ft}$   
 $K = (\Delta p)/[\gamma(v^2/2g)] = (8640 \text{ lb/ft}^2)/[(56.16 \text{ lb/ft}^3)(1.079 \text{ ft})] = \mathbf{143} = K$
- 10.56 Procedure like Prob. 10.55: For  $Q = 7.5 \text{ gal/min}$ ,  $\Delta p = 104 \text{ psi}$ .  $v = 12.5 \text{ ft/s}$ .  $K = \mathbf{110}$   
 For  $Q = 10 \text{ gal/min}$ ,  $\Delta p = 175 \text{ psi}$ .  $v = 16.67 \text{ fUs}$ .  $K = \mathbf{104}$ .
- 10.57 Use Eq. 10-10. Solving for  $C_v = Q/\sqrt{\Delta p/\text{sg}}$ .  
 From Problem 10.53,  $Q = 5.0 \text{ gal/min}$ ,  $\Delta p = 60.0 \text{ psi}$ , and  $\text{sg} = 0.90$ . Then,  
 $C_v = Q/\sqrt{\Delta p/\text{sg}} = 5.0/\sqrt{60/0.90} = 0.612 = C_v$
- 10.58 See Problem 10.57 for procedure and data from Problem 10.54.  
 For  $Q = 7.5 \text{ gal/min}$ :  $C_v = Q/\sqrt{\Delta p/\text{sg}} = 7.5/\sqrt{104/0.90} = 0.698 = C_v$   
 For  $Q = 10.0 \text{ gal/min}$ :  $C_v = Q/\sqrt{\Delta p/\text{sg}} = 10.0/\sqrt{175/0.90} = 0.717 = C_v$

For Problems 10.59 to 10.70, values of  $C$ , are found from Table 10.6.

10.59  $\Delta p = \text{sg}(Q/C_v)^2 = 0.981(150/170)^2 = 0.764 \text{ psi}$   
 $\text{sg} = 61.2 \text{ lb/ft}^3/62.4 \text{ lb/ft}^3 = 0.981$

$$10.60 \quad \Delta p = sg(Q/C_v)^2 = 0.989(600/640)^2 = 0.869 \text{ psi}$$
$$sg = 61.7 \text{ lb/ft}^3 / 62.4 \text{ lb/ft}^3 = 0.989$$

$$10.61 \quad \Delta p = sg(Q/C_v)^2 = 0.997(15/25)^2 = 0.359 \text{ psi}$$
$$sg = 62.2 \text{ lb/ft}^3 / 62.4 \text{ lb/ft}^3 = 0.997$$

For Problems 10.62 to 10.70, values of  $sg$  are found from Appendix B.

$$10.62 \quad \Delta p = sg(Q/C_v)^2 = 1.590(60/90)^2 = 0.707 \text{ psi}$$

$$10.63 \quad \Delta p = sg(Q/C_v)^2 = 0.68(300/330)^2 = 0.562 \text{ psi}$$

$$10.64 \quad \Delta p = sg(Q/C_v)^2 = 0.495(5000/4230)^2 = 0.692 \text{ psi}$$

$$10.65 \quad \Delta p = sg(Q/C_v)^2 = 1.590(60/34)^2 = 4.952 \text{ psi}$$

$$10.66 \quad \Delta p = sg(Q/C_v)^2 = 0.68(300/160)^2 = 2.391 \text{ psi}$$

$$10.67 \quad \Delta p = sg(Q/C_v)^2 = 0.495(1500/700)^2 = 2.273 \text{ psi}$$

$$10.68 \quad \Delta p = sg(Q/C_v)^2 = 1.030(18/25)^2 = 0.534 \text{ psi}$$

$$10.69 \quad \Delta p = sg(Q/C_v)^2 = 0.823(300/330)^2 = 0.680 \text{ psi}$$

$$10.70 \quad \Delta p = sg(Q/C_v)^2 = 1.258(3500/2300)^2 = 2.913 \text{ psi}$$

# CHAPTER ELEVEN

## SERIES PIPE LINE SYSTEMS

### Class I systems

11.1 **Class I;** Pt. A at tank surface:  $\frac{P_A}{\gamma} + z_A + \frac{v_A^2}{2g} - h_L = \frac{P_B}{\gamma} + z_B + \frac{v_B^2}{2g}$ ;  $p_A = 0$ ,  $v_A = 0$

$$p_B = \gamma_w \left[ z_A - z_B + \frac{v_B^2}{2g} - h_L \right] = \gamma_w \left[ 12 \text{ m} - h_{v_1} - 1.0h_{v_1} - 3f_T(30)h_{v_1} - f \frac{L}{D} h_{v_1} \right]$$

Entr.    3 Elbows    Friction

$$h_{v_1} = \text{Velocity head in pipe} = \frac{v_B^2}{2g} = \frac{1}{2g} \left( \frac{Q}{A} \right)^2 = \frac{(1.99 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)} = 0.202 \text{ m}$$

$$N_R = vD/\nu = (1.99)(0.098)/(1.30 \times 10^{-6}) = 1.50 \times 10^5$$

$$D/\epsilon = 0.098/1.5 \times 10^{-6} = 65300 \rightarrow f = 0.0165;$$

$f_T \approx 0.010$  in zone of complete turbulence

$$p_B = \frac{9.81 \text{ kN}}{\text{m}^3} \left[ 12 \text{ m} - 0.202 - 0.202 - (3)(0.010)(30)(0.202) - (0.0165) \frac{80.5}{0.098} (0.202) \right]$$

$$p_B = 85.1 \text{ kN/m}^2 = \mathbf{85.1 \text{ kPa}}$$

11.2 **Class I;**  $\frac{P_A}{\gamma} + z_A + \frac{v_A^2}{2g} - h_L = \frac{P_B}{\gamma} + z_B + \frac{v_B^2}{2g}$ ;  $v_A = v_B = 0$ ;  $p_B = 0$

$$p_A = \gamma[z_B - z_A + h_L] = \gamma[4.5 \text{ m} + h_L]; f_T = 0.019$$

$$h_L = 1.0h_v + 100f_T h_v + 150f_T h_v + 30f_T h_v + 1.0h_v + f \frac{38}{0.0525} h_v = h_v[7.32 + 724f]$$

Ent.    Chk. valve    Ang. V.    Elbow    Exit    Friction

$$h_v = \frac{v^2}{2g} \text{ (in pipe): } v = \frac{Q}{A} = \frac{435 \text{ L/min}}{2.168 \times 10^{-3} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 3.344 \text{ m/s}$$

$$h_v = (3.344)^2/(2)(9.81) = 0.570 \text{ m}$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(3.344)(0.0525)(820)}{1.70 \times 10^{-3}} = 8.47 \times 10^4; \frac{D}{\epsilon} = \frac{0.0525}{4.6 \times 10^{-5}} = 1141; f = 0.0222$$

$$p_A = \gamma[4.5 \text{ m} + h_L] = (0.82)(9.81 \text{ kN/m}^3)[4.5 \text{ m} + 0.570 \text{ m}(7.32 + 724(0.0222))] = \mathbf{143.5 \text{ kPa}}$$

11.3 **Class I;**  $\frac{P_A}{\gamma} + z_A + \frac{v_A^2}{2g} - h_L = \frac{P_B}{\gamma} + z_B + \frac{v_B^2}{2g}$ ;  $p_A = p_B + \gamma[(z_B - z_A) + h_L]$

$$v = \frac{Q}{A} = \frac{60 \text{ gal/min}}{0.02333 \text{ ft}^2} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 5.73 \text{ ft/s}; \quad h_v = \frac{v^2}{2g} = \frac{(5.73)^2}{2(32.2)} = 0.509 \text{ ft}$$

$$h_L = 6.5h_v + 2(30)f_T h_v + f \frac{50}{0.1723} h_v = (6.5 + 60f_T + 290f)h_v; \quad f_T = 0.019$$

$$N_R = \frac{vD\rho}{\eta} = \frac{(5.73)(0.1723)(0.90)(1.94)}{6.0 \times 10^{-5}} = 2.87 \times 10^4; \quad \frac{D}{\varepsilon} = \frac{0.1723}{1.5 \times 10^{-4}} = 1150$$

$$f = 0.0260; \quad \text{Then } h_L = [6.5 + 60(0.019) + 290(0.0260)](0.509 \text{ ft}) = 7.73 \text{ ft}$$

$$p_A = 200 \text{ psig} + \frac{(0.90)(62.4 \text{ lb})}{\text{ft}^3} [25 \text{ ft} + 7.73 \text{ ft}] \frac{1 \text{ ft}^2}{144 \text{ in}^2} = \mathbf{212.8 \text{ psig}}$$

11.4 **Class I**

$$\frac{P_A}{\gamma} + z_A + \frac{v_A^2}{2g} - h_L = \frac{P_B}{\gamma} + z_B + \frac{v_B^2}{2g}$$

$$p_A = p_B + \gamma \left[ (z_B - z_A) + \frac{v_B^2 - v_A^2}{2g} + h_L \right]$$

$$\frac{v_A^2}{2g} = \frac{(20.9)^2}{2(32.2)} \text{ ft} = 6.79 \text{ ft}; \quad \frac{v_B^2}{2g} = 1.32 \text{ ft}$$

$$Q = 750 \text{ gal/min} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 1.67 \text{ ft}^3/\text{s}$$

$$v_A = \frac{Q}{A_A} = \frac{1.67 \text{ ft}^3/\text{s}}{0.07986 \text{ ft}^2} = 20.9 \text{ ft/s}$$

$$v_B = \frac{Q}{A_B} = \frac{1.67 \text{ ft}^3/\text{s}}{0.181 \text{ ft}^2} = 9.23 \text{ ft/s}$$

$$f_T = 0.017$$

$$h_L = 2(30)f_T \frac{v_A^2}{2g} + f \frac{40 \text{ ft}}{0.3188 \text{ ft}} \frac{v_A^2}{2g} + 0.28 \frac{v_A^2}{2g} = (1.30 + 125f) \frac{v_A^2}{2g}$$

Elbows                  Friction                  Enlarge

$$\text{Where } D_2/D_1 = 0.4801/0.3188 = 1.51 \rightarrow K = 0.28 \text{ (Table 10.1)}$$

$$\text{At } 100^\circ\text{F}, \quad v_o = 7.21 \times 10^{-4} \text{ ft}^2/\text{s}; \quad N_{R_A} = \frac{v_A D_A}{\nu} = \frac{(20.9)(0.3188)}{7.21 \times 10^{-4}} = 9.25 \times 10^3$$

$$D/\varepsilon = 0.3188/1.5 \times 10^{-4} = 2125 \rightarrow f = 0.032$$

$$h_L = [1.30 + 125(0.032)](6.79 \text{ ft}) = 36.0 \text{ ft}$$

$$p_A = 500 \text{ psig} + \frac{(0.895)(62.4 \text{ lb})}{\text{ft}^3} [4.0 + (1.32 - 6.79) + 36.0] \frac{\text{ft}(1 \text{ ft}^2)}{144 \text{ in}^2} = \mathbf{513.4 \text{ psig}}$$

$$\text{Similarly: At } 210^\circ\text{F}, \quad \nu = 7.85 \times 10^{-5}; \quad N_R = 8.49 \times 10^4 \rightarrow f = 0.0205$$

$$h_L = 26.2 \text{ ft}; \quad p_A = \mathbf{509.6 \text{ psig}}$$

11.5 **Class I;**  $\frac{p_A}{\gamma} + z_A + \frac{v_A^2}{2g} - h_L = \frac{p_B}{\gamma} + z_B + \frac{v_B^2}{2g}$ ,

**Then**  $p_A = p_B + \gamma_o \left[ (z_A - z_B) + \frac{v_B^2 - v_A^2}{2g} + h_L \right]$

$$v_A = \frac{Q}{A_A} = \frac{0.015 \text{ m}^3/\text{s}}{1.682 \times 10^{-2} \text{ m}^2} = 0.892 \text{ m/s}; \frac{v_A^2}{2g} = \frac{0.892^2}{2(9.81)} \text{ m} = 0.0405 \text{ m}$$

$$v_B = \frac{Q}{A_B} = \frac{0.015}{1.905 \times 10^{-3}} = 7.87 \text{ m/s}; \frac{v_B^2}{2g} = \frac{(7.87)^2}{2(9.81)} \text{ m} = 3.16 \text{ m}$$

$$N_{R_A} = \frac{v_A D_A}{\nu} = \frac{(0.892)(0.1463)}{2.12 \times 10^{-5}} = 6.15 \times 10^3; D/\epsilon = \frac{0.1463}{4.6 \times 10^{-5}} = 3180; f_A = 0.035$$

$$N_{R_B} = \frac{v_B D_B}{\nu} = \frac{(7.87)(0.0493)}{2.12 \times 10^{-5}} = 1.83 \times 10^4; D/\epsilon = \frac{0.0493}{4.6 \times 10^{-5}} = 1072; f_B = 0.028$$

$$f_{TB} = 0.019$$

$$h_L = f_A \frac{180}{0.1463} (0.0405) + 0.37(3.16) + 2(20)(f_{TB})(3.16) + f_B \frac{8}{0.0493} \quad (3.16)$$

Friction 6-in                  Contr.                  Elbows                  Friction 2-in

Where  $D_1/D_2 = 0.1463/0.0493 = 2.97$ ;  $K = 0.37$ , Table 10.3

$$h_L = 19.68 \text{ m}$$

$$p_A = 12.5 \text{ MPa} + \frac{8.80 \text{ kN}}{\text{m}^2} [4.5 + 3.16 - 0.0405 + 19.68] \text{ m} = 12.5 \text{ MPa} + 240 \text{ kPa}$$

$$p_A = 12.74 \text{ MPa}$$

11.6 **Class I**

Pts. 1 and 2 at reservoir surfaces:  $p_1 = p_2 = 0$ ;  $v_1 = v_2 = 0$

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}; z_1 - z_2 = h_L = \text{sum of 8 losses}$$

Water at 10°C;  $\nu = 1.30 \times 10^{-6} \text{ m}^2/\text{s}$

**3-in pipe:**  $v_3 = \frac{Q}{A_3} = 5.37 \text{ m/s}; \frac{v_3^2}{2g} = 1.47 \text{ m}; N_{R_3} = \frac{v_3 D_3}{\nu} = 3.48 \times 10^5$

$$D_3/\epsilon = 0.0843/1.2 \times 10^{-4} = 703; f_3 = 0.022; F_{T3} = 0.0215$$

**6-in pipe:**  $v_6 = \frac{Q}{A_6} = 1.57 \text{ m/s}; \frac{v_6^2}{2g} = 0.126 \text{ m}; N_{R_6} = \frac{v_6 D_6}{\nu} = 1.88 \times 10^5$

$$D_6/\epsilon = 0.1560/1.2 \times 10^{-4} = 1300; f_6 = 0.0205; f_{T6} = 0.0185$$

$$h_L = 1.0 \frac{v_3^2}{2g} + f_3 \frac{100}{0.0843} \frac{v_3^2}{2g} + 2(30)f_{T3} \frac{v_3^2}{2g} + 160f_{T3} \frac{v_3^2}{2g} + 0.43 \frac{v_3^2}{2g} + f_6 \frac{300}{0.1560} \frac{v_6^2}{2g}$$

Entr.    Friction 3-in    Elbows 3-in    Gate valve    Enl.    Friction 6-in

$$+ 2(30)f_{T6} \frac{v_6^2}{2g} + 1.0 \frac{v_6^2}{2g}$$

Elbows 6-in    Exit

$$z_1 - z_2 = \sum h_L = 1.47 + 38.4 + 1.90 + 5.06 + 0.63 + 4.97 + 0.140 + 0.126$$

$$z_1 - z_2 = 52.7 \text{ m}$$

11.7 **Class I**

$$\frac{p_A}{\gamma} + z_A + \frac{v_A^2}{2g} - h_L = \frac{p_B}{\gamma} + z_B + \frac{v_B^2}{2g}; p_A - p_B + \gamma[(z_B - z_A) + h_L]; v_A = v_B$$

$$v_A = v_B = \frac{Q}{A} = \frac{1.70 \text{ L/min}}{8.189 \times 10^{-5} \text{ m}^2} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 0.346 \text{ m/s}; \frac{v^2}{2g} = 6.10 \times 10^{-3} \text{ m}$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(0.346)(0.01021)(1250)}{3.0 \times 10^{-4}} = 1.47 \times 10^4; \frac{D}{\varepsilon} = 6807; f = 0.0282; f_T = 0.013$$

$$h_L = f \frac{30}{0.01021} \frac{v^2}{2g} + 150 f_T \frac{v^2}{2g} + 340 f_T \frac{v^2}{2g} + 8(50) f_T \frac{v^2}{2g} = 0.577 \text{ m}$$

Friction    Ball chk.    Globe v.    8 Ret. bends

$$p_A - p_B = (1.25)(9.81 \text{ kN/m}^3)[1.2 \text{ m} + 0.577 \text{ m}] = \mathbf{21.79 \text{ kPa}}$$

*(See Computer solution on next page)*

APPLIED FLUID MECHANICS		I Pressure SI: CLASS I SERIES SYSTEMS	
<b>Objective: Pressure: Point 2</b>		Reference points for the energy equation:	
Problem 11.7-Mott-Modified Fig. 11.17		Pt. 1: In pipe at Point A Pt. 2: In pipe at Point B	
<b>System Data: SI Metric Units</b>			
Volume flow rate: $Q = 2.83E-05 \text{ m}^3/\text{s}$		Elevation at point 1 = 0 m	
Pressure at point 1 = 100 kPa		Elevation at point 2 = 1.2 m	
*Pressure at point 2 = 78.4 kPa		If Ref. pt. is in pipe: Set $v_1$ " = B20" OR Set $v_2$ " = E20"	
Velocity at point 1 = 0.346 m/s -->		Vel head at point 1 = 0.006104 m	
Velocity at point 2 = 0.346 m/s -->		Vel head at point 2 = 0.006104 m	
<b>Fluid Properties:</b>			
Specific weight = 12.2625 kN/m <sup>3</sup>		May need to compute: $v = \eta/\rho$	
		Kinematic viscosity = 2.40E-07 m <sup>2</sup> /s	
<b>Pipe 1: 1/2-in x 0.049 steel tube</b>		<b>Pipe 2: None</b>	
Diameter: $D = 0.01021 \text{ m}$		Diameter: $D = 0.09797 \text{ m}$	
Wall roughness: $\epsilon = 1.50E-06 \text{ m}$		Wall roughness: $\epsilon = 1.50E-06 \text{ m}$ See Table 8.2	
Length: $L = 30 \text{ m}$		Length: $L = 0 \text{ m}$	
Area: $A = 8.19E-05 \text{ m}^2$		Area: $A = 7.54E-03 \text{ m}^2$ [ $A = \pi D^2/4$ ]	
$D/\epsilon = 6807$		$D/\epsilon = 65313$ Relative roughness	
$L/D = 2938$		$L/D = 0$	
Flow Velocity = 0.346 m/s		Flow Velocity = 0.0038 m/s [ $v = Q/A$ ]	
Velocity head = 0.006104 m		Velocity head = 0.0000 m	
Reynolds No. = 1.47E+04		Reynolds No. = 1.53E+03 [ $N_R = vD/\nu$ ]	
Friction factor: $f = 0.0282$		Friction factor: $f = 0.0563$ Using Eq. 8-7	
<b>Energy losses-Pipe 1:</b>			
	K	Qty.	
Pipe: $K_1 = f(L/D) =$	82.96	1	Energy loss $h_{L1} = 0.5064 \text{ m}$ Friction
Check Valve: $K_2 =$	1.95	1	Energy loss $h_{L2} = 0.0119 \text{ m}$ ( $f_T = 0.013$ )
Globe Valve: $K_3 =$	4.420	1	Energy loss $h_{L3} = 0.0270 \text{ m}$ ( $f_T = 0.013$ )
Return Bends: $K_4 =$	0.65	8	Energy loss $h_{L4} = 0.0317 \text{ m}$ ( $f_T = 0.013$ )
Element 5: $K_5 =$	0.00	1	Energy loss $h_{L5} = 0.00 \text{ m}$
Element 6: $K_6 =$	0.00	1	Energy loss $h_{L6} = 0.00 \text{ m}$
Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} = 0.00 \text{ m}$
Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} = 0.00 \text{ m}$
<b>Energy losses-Pipe 2:</b>			
	K	Qty.	
Pipe: $K_1 = f(L/D) =$	0.00	1	Energy loss $h_{L1} = 0.00 \text{ m}$ Friction
Element 2: $K_2 =$	0.00	1	Energy loss $h_{L2} = 0.00 \text{ m}$
Element 3: $K_3 =$	0.00	1	Energy loss $h_{L3} = 0.00 \text{ m}$
Element 4: $K_4 =$	0.00	1	Energy loss $h_{L4} = 0.00 \text{ m}$
Element 5: $K_5 =$	0.00	1	Energy loss $h_{L5} = 0.00 \text{ m}$
Element 6: $K_6 =$	0.00	1	Energy loss $h_{L6} = 0.00 \text{ m}$
Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} = 0.00 \text{ m}$
Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} = 0.00 \text{ m}$
			Total energy loss $h_{Ltot} = 0.5770 \text{ m}$
<b>Results:</b>			
			Change in pressure A to B: -21.79 kPa

\*NOTE: Pressure at point 1 set arbitrarily to 100 kPa.

Pressure at point 2 is computed for illustration of effect of pressure drop.

**Class II systems**

11.8 **Class II**  $h_L = 30.0 \text{ ft} = f \frac{L v^2}{D 2g}$  **Method IIC Iteration**

Then  $v = \sqrt{\frac{2gh_L D}{fL}} = \sqrt{\frac{2(32.2)(30)(0.3188)}{f(25)}} = \sqrt{\frac{24.64}{f}}$

$N_R = \frac{vD}{\nu} = \frac{v(0.3188)}{7.37 \times 10^{-6}} = 4.33 \times 10^4 (v)$ ;  $\frac{D}{\epsilon} = \frac{0.3188}{1.5 \times 10^{-4}} = 2120$

Try  $f = 0.02$ ; then  $v = \sqrt{24.64/f} = 35.1 \text{ ft/s}$

$N_R = 4.33 \times 10^4 (35.1) = 1.52 \times 10^6$ ; **New  $f = 0.0165$**

$v = \sqrt{24.64/0.0165} = 38.6 \text{ ft/s}$ ;  $N_R = 1.67 \times 10^6$ ;  **$f = 0.0165$  OK**

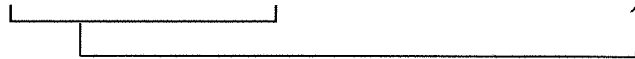
$Q = Av = (0.07986 \text{ ft}^2)(38.6 \text{ ft/s}) = 3.08 \text{ ft}^3/\text{s}$

**Class II** [Repeated using computational approach - Sec. 11.5]

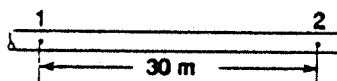
$h_L = 30.0 \text{ ft}$ ;  $D/\epsilon = 2120$ ; Use Eq. 11-3.

$$Q = -2.22D^2 \sqrt{\frac{gDh_L}{L}} \log \left[ \frac{1}{3.7D/\epsilon} + \frac{1.784v}{D\sqrt{gDh_L/L}} \right]$$

$$Q = -2.22(0.3188)^2 \sqrt{\frac{(32.2)(0.3188)(30)}{25}} \log \left[ \frac{1}{3.7(2120)} + \frac{(1.784)(7.37 \times 10^{-6})}{(0.3188)\sqrt{12.32}} \right]$$



$Q = 3.05 \text{ ft}^3/\text{s}$

11.9 **Class II**   $\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$ ;  $z_1 = z_2$   
 $v_1 = v_2$

**Method IIC Iteration**

$h_L = \frac{p_1 - p_2}{\gamma} = \frac{68 \text{ kN/m}^2}{((0.90)(9.81 \text{ kN/m}^3))} = 7.70 \text{ m} = f \frac{L v^2}{D 2g}$ ;  $v = \sqrt{\frac{2gh_L D}{fL}}$

$v = \sqrt{\frac{2(9.81)(7.70)(0.04658)}{f(30)}} = \sqrt{\frac{0.235}{f}}$ ;  $\frac{D}{\epsilon} = \frac{0.04658}{1.5 \times 10^{-6}} = 31053$

Try  $f = 0.03$ ;  $v = \sqrt{0.235/0.03} = 2.80 \text{ m/s}$

$N_R = \frac{vD\rho}{\eta} = \frac{v(0.04658)(900)}{3.0 \times 10^{-3}} = 1.40 \times 10^4 (v) = 3.92 \times 10^4$

New  $f = 0.022$ ;  **$v = 3.27 \text{ m/s}$** ;  $N_R = 4.58 \times 10^4$ ;  $f = 0.0210$

**$v = 3.345 \text{ m/s}$ ;  $N_R = 4.69 \times 10^4$ ;  $f = 0.0210$  No change**

*Spreadsheet solutions to Problems 11.8, 11.9, and 11.10 are on next page.*

APPLIED FLUID MECHANICS	II-A & II-B US: CLASS II SERIES SYSTEMS	
<b>Objective: Volume flow rate</b> Problem 11.8	<b>Method II-A: No minor losses</b> Uses Equation 11-3 to find maximum allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data: US Customary Units</b>		
Pressure at point 1 = 112.917 psig	Elevation at point 1 =	0 ft
Pressure at point 2 = 100 psig	Elevation at point 2 =	0 ft
Energy loss: $h_L = 30.00$ ft		
<b>Fluid Properties:</b> Water at 100F May need to compute: $v = \eta/\rho$		
Specific weight = 62.00 lb/ft <sup>3</sup>	Kinematic viscosity = 7.37E-06 ft <sup>2</sup> /s	
<b>Pipe data: 4-in Sch 40 steel pipe</b>		
Diameter: $D = 0.3188$ ft	<b>Results: Maximum values</b> Volume flow rate: $Q = 3.0546$ ft <sup>3</sup> /s Using Eq. 11-3 Velocity: $v = 38.27$ ft/s	
Wall roughness: $\epsilon = 1.50E-04$ ft		
Length: $L = 25$ ft		
Area: $A = 0.07982$ ft <sup>2</sup>		
$D/\epsilon = 2125.33$		

APPLIED FLUID MECHANICS	II-A & II-B US: CLASS II SERIES SYSTEMS	
<b>Objective: Volume flow rate</b> Problem 11.9	<b>Method II-A: No minor losses</b> Uses Equation 11-3 to find maximum allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data: SI Metric Units</b>		
Pressure at point 1 = 168 kPa	Elevation at point 1 =	0 m
Pressure at point 2 = 100 kPa	Elevation at point 2 =	0 m
Energy loss: $h_L = 7.70$ m		
<b>Fluid Properties:</b> May need to compute: $v = \eta/\rho$		
Specific weight = 8.83 kN/m <sup>3</sup>	Kinematic viscosity = 3.33E-06 m <sup>2</sup> /s	
<b>Pipe data: 2-in steel tube, <math>t = 0.083</math></b>		
Diameter: $D = 0.04658$ ft	<b>Results: Maximum values</b> Volume flow rate: $Q = 0.0056$ m <sup>3</sup> /s Using Eq. 11-3 Velocity: $v = 3.31$ m/s	
Wall roughness: $\epsilon = 1.50E-06$ ft		
Length: $L = 30$ ft		
Area: $A = 0.001704$ m <sup>2</sup>		
$D/\epsilon = 31053.33$		

APPLIED FLUID MECHANICS	II-A & II-B US: CLASS II SERIES SYSTEMS	
<b>Objective: Volume flow rate</b> Problem 11.10	<b>Method II-A: No minor losses</b> Uses Equation 11-3 to find maximum allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data: US Customary Units</b>		
Pressure at point 1 = 250 psig	Elevation at point 1 =	55 ft
Pressure at point 2 = 180 psig	Elevation at point 2 =	0 ft
Energy loss: $h_L = 202.22$ ft		
<b>Fluid Properties:</b> Ethyl glycol at 77F May need to compute: $v = \eta/\rho$		
Specific weight = 68.47 lb/ft <sup>3</sup>	Kinematic viscosity = 1.59E-06 ft <sup>2</sup> /s	
<b>Pipe data: 6-in coated ductile iron pipe</b>		
Diameter: $D = 0.512$ ft	<b>Results: Maximum values</b> Volume flow rate: $Q = 1.4500$ ft <sup>3</sup> /s Using Eq. 11-3 Velocity: $v = 7.04$ ft/s	
Wall roughness: $\epsilon = 4.00E-04$ ft		
Length: $L = 5000$ ft		
Area: $A = 0.20589$ ft <sup>2</sup>		
$D/\epsilon = 1280$		

APPLIED FLUID MECHANICS		II-A & II-B SI: CLASS II SERIES SYSTEMS	
<b>Objective: Volume flow rate</b> Problem 11.11		<b>Method II-A: No minor losses</b> Uses Equation 11-3 to find maximum allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data:</b>		<b>SI Metric Units</b>	
Pressure at point 1 =	550 kPa	Elevation at point 1 =	7.5 m
Pressure at point 2 =	585 kPa	Elevation at point 2 =	0 m
Energy loss: $h_L =$		3.93 m	
<b>Fluid Properties:</b>		Water at 15C May need to compute: $v = \eta/\rho$	
Specific weight =	9.81 kN/m <sup>3</sup>	Kinematic viscosity =	1.15E-06 m <sup>2</sup> /s
<b>Pipe data: 1-1/4x0.083 drawn steel pipe</b>			
Diameter: $D =$		0.02753 m	
Wall roughness: $\epsilon =$		1.50E-06 m	
Length: $L =$		7.5 m	
Area: $A =$		0.000595 m <sup>2</sup>	
$D/\epsilon =$		18353.33	
		<b>Results: Maximum values</b>	
		Volume flow rate: $Q =$	0.0023 m <sup>3</sup> /s Using Eq. 11-3
		Velocity: $v =$	3.91 m/s

CLASS II SERIES SYSTEMS		Volume flow rate: $Q = 0.001793 \text{ m}^3/\text{s}$	
<b>Method II-B: Use results of Method IIA;</b> Include minor losses; then pressure at Point 2 is computed		Given: Pressure $p_1 =$ 550 kPa <b>Pressure <math>p_2 =</math> 585.01 kPa</b> <b>NOTE: Should be &gt; 585 kPa</b>	
<b>Additional Pipe Data:</b>		<b>Adjust estimate for <math>Q</math> until <math>p_2</math> is equal or greater than desired.</b>	
$L/D =$	272	Velocity at point 1 =	3.01 m/s  --> If velocity is in pipe:
Flow Velocity =	3.01 m/s	Velocity at point 2 =	3.01 m/s  --> Enter "=B24"
Velocity head =	0.462 m	Vel. head at point 1 =	0.462 m
Reynolds No. =	7.21E+04	Vel. head at point 2 =	0.462 m
Friction factor: $f =$	0.0194		
<b>Energy losses in Pipe:</b>	<b>K Qty.</b>		
Pipe: $K_1 = f(L/D) =$	5.29 1	Energy loss $h_{L1} =$	2.45 m Friction
Ball check value: $K_2 =$	1.605 2	Energy loss $h_{L2} =$	1.48 m $f_T = 0.0107$
Element 3: $K_3 =$	0.00 1	Energy loss $h_{L3} =$	0.00 m
Element 4: $K_4 =$	0.00 1	Energy loss $h_{L4} =$	0.00 m
Element 5: $K_5 =$	0.00 1	Energy loss $h_{L5} =$	0.00 m
Element 6: $K_6 =$	0.00 1	Energy loss $h_{L6} =$	0.00 m
Element 7: $K_7 =$	0.00 1	Energy loss $h_{L7} =$	0.00 m
Element 8: $K_8 =$	0.00 1	Energy loss $h_{L8} =$	0.00 m
		Total energy loss $h_{Ltot} =$	3.93 m

<b>APPLIED FLUID MECHANICS</b>		<b>II-A &amp; II-B US: CLASS II SERIES SYSTEMS</b>	
<b>Objective: Volume flow rate</b> Problem 11.12		<b>Method II-A: No minor losses</b> Uses Equation 11-3 to find maximum allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data: US Customary Units</b>			
Pressure at point 1 =	120 psig	Elevation at point 1 =	0 ft
Pressure at point 2 =	105 psig	Elevation at point 2 =	20 ft
Energy loss: $h_L = 19.85$ ft			
<b>Fluid Properties:</b> Turpentine at 77F		May need to compute: $v = \eta/\rho$	
Specific weight =	54.20 lb/ft <sup>3</sup>	Kinematic viscosity =	1.70E-05 ft <sup>2</sup> /s
<b>Pipe data: 3-in coated ductile iron pipe</b>		<b>Results: Maximum values</b> Volume flow rate: $Q = 0.9782$ ft <sup>3</sup> /s Using Eq. 11-3 Velocity: $v = 16.23$ ft/s	
Diameter: $D =$	0.277 ft		
Wall roughness: $\epsilon =$	4.00E-04 ft		
Length: $L =$	60 ft		
Area: $A =$	0.06026 ft <sup>2</sup>		
	$D/\epsilon = 692.5$		

<b>CLASS II SERIES SYSTEMS</b>		Volume flow rate: $Q = 0.89850$ ft <sup>3</sup> /s	
<b>Method II-B: Use results of Method IIA;</b> Include minor losses; then pressure at Point 2 is computed		Given: Pressure $p_1 = 120$ psig <b>Pressure <math>p_2 = 105.00</math> psig</b> <b>NOTE: Should be &gt; 105 psig</b>	
<b>Additional Pipe Data:</b>		<b>Adjust estimate for <math>Q</math> until <math>p_2</math> is equal or greater than desired.</b>	
$L/D =$	217	Velocity at point 1 =	14.91 ft/s  --> If velocity is in pipe:
Flow Velocity =	14.91 ft/s	Velocity at point 2 =	14.91 ft/s  --> Enter "=B24"
Velocity head =	3.452 ft	Vel. head at point 1 =	3.45 ft
Reynolds No. =	2.43E+05	Vel. head at point 2 =	3.45 ft
Friction factor: $f =$	0.0226		
<b>Energy losses in Pipe:</b>			
Pipe: $K_1 = f(L/D) =$	4.89 1	Energy loss $h_{L1} =$	16.90 ft Friction
Long rad elbow: $K_2 =$	0.43 2	Energy loss $h_{L2} =$	2.97 ft $f_T = 0.0215$
Element 3: $K_3 =$	0.00 1	Energy loss $h_{L3} =$	2.45 ft
Element 4: $K_4 =$	0.00 1	Energy loss $h_{L4} =$	0.00 ft
Element 5: $K_5 =$	0.00 1	Energy loss $h_{L5} =$	0.00 ft
Element 6: $K_6 =$	0.00 1	Energy loss $h_{L6} =$	0.00 ft
Element 7: $K_7 =$	0.00 1	Energy loss $h_{L7} =$	0.00 ft
Element 8: $K_8 =$	0.00 1	Energy loss $h_{L8} =$	0.00 ft
		Total energy loss $h_{Ltot} =$	19.86 ft

APPLIED FLUID MECHANICS		II-A & II-B US: CLASS II SERIES SYSTEMS	
<b>Objective: Volume flow rate</b> Problem 11.13 (a) Figure 11.18		<b>Method II-A: No minor losses</b> Uses Equation 11-3 to find maximum allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data: US Customary Units</b>			
Pressure at point 1 =	20 psig	Elevation at point 1 =	0 ft
Pressure at point 2 =	0 psig	Elevation at point 2 =	18 ft
Energy loss: $h_L = 28.45$ Ft			
<b>Fluid Properties:</b> Turpentine at 77F May need to compute: $v = \eta/\rho$			
Specific weight =	62.00 lb/ft <sup>3</sup>	Kinematic viscosity =	7.37E-06 ft <sup>2</sup> /s
<b>Pipe data: Smooth aluminum tube</b>		<b>Results: Maximum values</b> Volume flow rate: $Q = 0.0194$ ft <sup>3</sup> /s Using Eq. 11-3 Velocity: $v = 14.23$ ft/s	
Diameter: $D =$	0.417 ft		
Wall roughness: $\epsilon =$	1.00E-08 ft		
Length: $L =$	20 ft		
Area: $A =$	0.00137 ft <sup>2</sup>		
	$D/\epsilon = 4170000$		

CLASS II SERIES SYSTEMS		Volume flow rate: $Q = 0.01107$ ft <sup>3</sup> /s	
<b>Method II-B: Use results of Method IIA;</b> Include minor losses; then pressure at Point 2 is computed		Given: Pressure $p_1 =$	20 psig
		Pressure $p_2 =$	0.00 psig
		<b>NOTE: Should be &gt;</b>	0 psig
<b>Additional Pipe Data:</b>		<b>Adjust estimate for <math>Q</math> until <math>p_2</math> is equal or greater than desired.</b>	
$L/D =$	480	Velocity at point 1 =	8.11 ft/s  --> If velocity is in pipe:
Flow Velocity =	8.11 ft/s	Velocity at point 2 =	32.42 ft/s  --> Enter "=B24"
Velocity head =	1.020 ft	Vel. head at point 1 =	1.02 ft
Reynolds No. =	4.59E+04	Vel. head at point 2 =	16.32 ft
Friction factor: $f =$	0.0212		
<b>Energy losses in Pipe:</b>			
Pipe: $K_1 = f(L/D) =$	10.15	1	Energy loss $h_{L1} = 10.36$ ft Friction
Bend: $K_2 =$	0.34	1	Energy loss $h_{L2} = 0.35$ ft $f_T = 0.01$ Assumed
*Nozzle: $K_3 =$	2.40	1	Energy loss $h_{L3} = 2.45$ ft
Element 4: $K_4 =$	0.00	1	Energy loss $h_{L4} = 0.00$ ft
Element 5: $K_5 =$	0.00	1	Energy loss $h_{L5} = 0.00$ ft
Element 6: $K_6 =$	0.00	1	Energy loss $h_{L6} = 0.00$ ft
Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} = 0.00$ ft
Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} = 0.00$ ft
			Total energy loss $h_{Ltot} = 13.15$ ft

\*Nozzle  $K_3$  restated in terms of velocity head in pipe rather than outlet velocity head.

$$*K_3 = 0.15(v_2/v_1)^2 = 0.15(4)^2 = 2.40$$

$$\text{Nozzle Velocity: } v_N = v_p(A_p/A_N) = v_p(D_p/D_N)^2 = 4.0v_p = 4.0(8.11 \text{ ft/s}) = 32.44 \text{ ft/s}$$

<b>APPLIED FLUID MECHANICS</b>		<b>II-A &amp; II-B US: CLASS II SERIES SYSTEMS</b>	
<b>Objective: Volume flow rate</b>		<b>Method II-A: No minor losses</b>	
Problem 11.13 (b) Figure 11.18		Uses Equation 11-3 to find maximum allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data: US Customary Units</b>			
Pressure at point 1 = 80 psig		Elevation at point 1 = 0 ft	
Pressure at point 2 = 0 psig		Elevation at point 2 = 18 ft	
Energy loss: $h_L = 167.81$ ft			
<b>Fluid Properties:</b> Turpentine at 77F May need to compute: $v = \eta/\rho$			
Specific weight = 62.00 lb/ft <sup>3</sup>		Kinematic viscosity = 7.37E-06 ft <sup>2</sup> /s	
<b>Pipe data: Smooth aluminum tube</b>		<b>Results: Maximum values</b>	
Diameter: $D = 0.417$ ft			
Wall roughness: $\epsilon = 1.00E-08$ ft			
Length: $L = 20$ ft			
Area: $A = 0.00137$ ft <sup>2</sup>			
$D/\epsilon = 417000$		Volume flow rate: $Q = 0.0522$ ft <sup>3</sup> /s Using Eq. 11-3	
		Velocity: $v = 38.20$ ft/s	

<b>CLASS II SERIES SYSTEMS</b>		Volume flow rate: $Q = 0.02781$ ft <sup>3</sup> /s	
<b>Method II-B: Use results of Method IIA;</b>		Given: Pressure $p_1 = 80$ psig	
Include minor losses;		Pressure $p_2 = 0.01$ psig	
then pressure at Point 2 is computed		<b>NOTE: Should be &gt; 0 psig</b>	
<b>Additional Pipe Data:</b>		<b>Adjust estimate for Q until <math>p_2</math> is equal or greater than desired.</b>	
$L/D = 480$		Velocity at point 1 = 20.36 ft/s  --> If velocity is in pipe:	
Flow Velocity = 20.36 ft/s		Velocity at point 2 = 81.45 ft/s  --> Enter "=B24"	
Velocity head = 6.439 ft		Vel. head at point 1 = 6.44 ft	
Reynolds No. = 1.15E+05		Vel. head at point 2 = 103.02 ft	
Friction factor: $f = 0.0173$			
<b>Energy losses in Pipe:</b>			
	$K$	Qty.	
Pipe: $K_1 = f(L/D) =$	8.32	1	Energy loss $h_{L1} = 53.57$ ft Friction
Bend: $K_2 =$	0.34	1	Energy loss $h_{L2} = 2.19$ ft $f_T = 0.01$ Assumed
*Nozzle: $K_3 =$	2.40	1	Energy loss $h_{L3} = 15.45$ ft
Element 4: $K_4 =$	0.00	1	Energy loss $h_{L4} = 0.00$ ft
Element 5: $K_5 =$	0.00	1	Energy loss $h_{L5} = 0.00$ ft
Element 6: $K_6 =$	0.00	1	Energy loss $h_{L6} = 0.00$ ft
Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} = 0.00$ ft
Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} = 0.00$ ft
			Total energy loss $h_{Ltot} = 71.21$ ft

\*Nozzle  $K_3$  restated in terms of velocity head in pipe rather than outlet velocity head.

$$*K_3 = 0.15(v_2/v_1)^2 = 0.15(4)^2 = 2.40$$

$$\text{Nozzle Velocity: } v_N = v_p(A_p/A_N) = v_p(D_p/D_N)^2 = 4.0v_p = 4.0(20.36 \text{ ft/s}) = 32.44 \text{ ft/s}$$

APPLIED FLUID MECHANICS		II-A & II-B SI: CLASS II SERIES SYSTEMS	
<b>Objective: Volume flow rate</b>		<b>Method II-A: No minor losses</b>	
Problem 11.14 Figure 11.19		Uses Equation 11-3 to find maximum allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data: SI Metric Units</b>			
Pressure at point 1 =	150 kPa	Elevation at point 1 =	0 m
Pressure at point 2 =	0 kPa	Elevation at point 2 =	5 m
Energy loss: $h_L = 13.59$ m			
<b>Fluid Properties:</b> Kerosene at 25C May need to compute: $v = \eta/\rho$			
Specific weight =	8.07 kN/m <sup>3</sup>	Kinematic viscosity =	1.99E-06 m <sup>2</sup> /s
<b>Pipe data: 2-in Type K Copper tube</b>		<b>Results: Maximum values</b>	
Diameter: $D =$	0.0498 m	Volume flow rate: $Q =$	0.0098 m <sup>3</sup> /s Using Eq. 11-3
Wall roughness: $\epsilon =$	1.50E-06 m	Velocity: $v =$	5.05 m/s
Length: $L =$	30 m		
Area: $A =$	0.001948 m <sup>2</sup>		
$D/\epsilon =$	33200		

CLASS II SERIES SYSTEMS		Volume flow rate: $Q = 0.008485$ m <sup>3</sup> /s	
<b>Method II-B: Use results of Method IIA;</b> Include minor losses; then pressure at Point 2 is computed		Given: Pressure $p_1 =$	150 kPa
		Pressure $p_2 =$	0.01 kPa
		<b>NOTE: Should be &gt;</b>	0 kPa
<b>Additional Pipe Data:</b>		<b>Adjust estimate for Q until <math>p_2</math> is equal or greater than desired.</b>	
$L/D =$	602	Velocity at point 1 =	0.00 ft/s  --> If velocity is in pipe:
Flow Velocity =	4.36 m/s	Velocity at point 2 =	4.36 ft/s  --> Enter "=B24"
Velocity head =	0.967 m	Vel. head at point 1 =	0.000 ft
Reynolds No. =	109E+05	Vel. head at point 2 =	0.967 ft
Friction factor: $f =$	0.0177		
<b>Energy losses in Pipe:</b>			
Pipe: $K_1 = f(L/D) =$	10.69	1	Energy loss $h_{L1} = 10.33$ m Friction
1/2 op. gate valve: $K_2 =$	1.52	1	Energy loss $h_{L2} = 1.47$ m $f_T = 0.0095$
Element 3: $K_3 =$	0.50	1	Energy loss $h_{L3} = 0.48$ m
Element 4: $K_4 =$	0.17	2	Energy loss $h_{L4} = 0.33$ m
Element 5: $K_5 =$	0.00	1	Energy loss $h_{L5} = 0.00$ m
Element 6: $K_6 =$	0.00	1	Energy loss $h_{L6} = 0.00$ m
Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} = 0.00$ m
Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} = 0.00$ m
			Total energy loss $h_{Ltot} = 12.62$ m

11.14 **Class II** Pt. 1 at surface of tank A; Pt. 2 in stream outside pipe.  $v_1 = 0, p_2 = 0$

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g} : \frac{p_1}{\gamma} + (z_1 - z_2) = \frac{v_2^2}{2g} + h_L$$

$$\frac{150 \text{ kN/m}^2}{8.07 \text{ kN/m}^3} - 5 \text{ m} = \boxed{13.59 \text{ m} = \frac{v_2^2}{2g} + h_L} \quad \textcircled{1} \quad \text{Method IIC}$$

$$h_L = 0.50 \frac{v_2^2}{2g} + 160 f_T \frac{v_2^2}{2g} + 2(18) f_T \frac{v_2^2}{2g} + f \frac{30 \text{ mm}}{0.0498 \text{ m}} \frac{v_2^2}{2g} = (2.46 + 602f) \frac{v_2^2}{2g}$$

Entrance    Valve    Bends    Friction

$$\perp r/D = \frac{300 \text{ mm}}{49.8 \text{ mm}} = 6.02 \rightarrow \frac{L_e}{D} = 18 \text{ (Fig. 10.23)}$$

$$D/\epsilon = \frac{0.0498 \text{ m}}{1.5 \times 10^{-6} \text{ m}} = 33200$$

$$f_T = 0.010 \text{ (Approx.)}$$

In Eq. I:

$$13.59 \text{ m} = \frac{v_2^2}{2g} + (2.46 + 602f) \frac{v_2^2}{2g} = (3.46 + 602f) \frac{v_2^2}{2g}$$

$$v = \sqrt{\frac{2g(13.59 \text{ m})}{3.46 + 602f}} = \sqrt{\frac{2(9.81)(13.59)}{3.46 + 602f}} = \sqrt{\frac{266.6}{3.46 + 602f}}$$

Try  $f = 0.02$

$$v = \sqrt{\frac{266.6}{3.46 + 602(0.02)}} = 4.15 \text{ m/s}; N_R = \frac{vD\rho}{\mu} = \frac{(4.15)(0.0498)(823)}{1.64 \times 10^{-3}} = 1.04 \times 10^5$$

New  $f = 0.018$ ;  $v = 4.32 \text{ m/s}$ ;  $N_R = 1.08 \times 10^5$ ; New  $f = 0.018$  **No change**

$$Q = Av = (1.945 \times 10^{-3} \text{ m}^2)(4.32 \text{ m/s}) = 8.40 \times 10^{-3} \text{ m}^3/\text{s}$$

11.15 **Class II with 2 pipes:** Pts. A and B at tank surfaces. **Method IIC**

$$\frac{p_A}{\gamma} + z_A + \frac{v_A^2}{2g} - h_L = \frac{p_B}{\gamma} + z_B + \frac{v_B^2}{2g} : z_A - z_B = h_L = 10 \text{ m}; \quad \begin{matrix} p_A = p_B = 0 \\ v_A = v_B = 0 \end{matrix}$$

$$h_L = 1.0 \frac{v_3^2}{2g} + 2(30) f_{3T} \frac{v_3^2}{2g} + f_3 \frac{55}{0.08432} \frac{v_3^2}{2g} + 0.45 \frac{v_3^2}{2g} \left. \vphantom{h_L} \right\} \text{Based on 3-in pipe; } f_{3T} = 0.022$$

$$\text{Entrance    Elbows    Friction    Enlarge. } \frac{D_2}{D_1} = \frac{0.156}{0.0843} = 1.85$$

$$+ f_6 \frac{30}{0.156} \frac{v_6^2}{2g} + 30 f_{6T} \frac{v_6^2}{2g} + 45 f_{6T} \frac{v_6^2}{2g} + 1.0 \frac{v_6^2}{2g} \left. \vphantom{h_L} \right\} \text{Based on 6-in pipe; } f_{6T} = 0.019$$

Friction    Elbow    Valve    Exit

$$h_L = (2.77 + 652f_3) \frac{v_3^2}{2g} + (2.43 + 192f_6) \frac{v_6^2}{2g}$$

$$\text{But } v_3 = v_6 \frac{A_6}{A_3} = v_6 \left( \frac{D_6}{D_3} \right)^2 = v_6 \left( \frac{0.156}{0.0843} \right)^2 = 3.42 v_6; v_3^2 = 11.73 v_6^2$$

$$h_L = (2.77 + 652f_3) \frac{11.73v_6^2}{2g} + (2.43 + 192f_6) \frac{v_6^2}{2g} = (34.9 + 7646f_3 + 192f_6) \frac{v_6^2}{2g}$$

---

**Solve for  $v_6$**

$$\begin{aligned} v_6 &= \sqrt{\frac{2gh_L}{(34.9 + 7646f_3 + 192f_6)}} = \sqrt{\frac{2(9.81)(10)}{34.9 + 7646f_3 + 192f_6}} \\ &= \sqrt{\frac{196.2}{34.9 + 7646f_3 + 192f_6}} \end{aligned}$$

---

Iterate for both  $f_3$  and  $f_6$ :

$$\frac{D_3}{\varepsilon} = \frac{0.0843 \text{ m}}{1.2 \times 10^{-4} \text{ m}} = 703: N_{R_3} = \frac{v_3 D_3}{\nu} = \frac{v_3 (0.0843)}{6.56 \times 10^{-7}} = 1.29 \times 10^5 (v_3)$$

$$\frac{D_6}{\varepsilon} = \frac{0.1560}{1.2 \times 10^{-4}} = 1300: N_{R_6} = \frac{v_6 D_6}{\nu} = \frac{v_6 (0.156)}{6.56 \times 10^{-7}} = 2.38 \times 10^5 (v_6)$$

---

Try  $f_3 = f_6 = 0.02$

$$v_6 = \sqrt{\frac{196.2}{34.9 + 7646(0.02) + 192(0.02)}} = 1.012 \text{ m/s}$$

$$v_3 = 3.42 v_6 = 3.46 \text{ m/s}$$

$$N_{R_3} = 1.29 \times 10^5 (3.46) = 4.46 \times 10^5 \rightarrow \text{New } f_3 = 0.0195$$

$$N_{R_6} = 2.38 \times 10^5 (1.012) = 2.41 \times 10^5 \rightarrow \text{New } f_6 = 0.020$$

---


$$v_6 = \sqrt{\frac{196.2}{34.9 + 7646(0.0195) + 192(0.02)}} = \mathbf{1.02 \text{ m/s}}$$

$$v_3 = 3.30 v_6 = \mathbf{3.51 \text{ m/s}}$$

$$N_{R_3} = 1.29 \times 10^5 (3.50) = 4.20 \times 10^5 \rightarrow f_3 = 0.0195 \text{ No change}$$

$$N_{R_6} = 2.38 \times 10^5 (1.02) = 2.43 \times 10^5 \rightarrow f_6 = 0.020 \text{ No change}$$

---


$$Q = A_6 v_6 = \frac{\pi(0.156 \text{ m})^2}{4} \times 1.02 \text{ m/s} = \mathbf{1.95 \times 10^{-3} \text{ m}^3/\text{s}}$$

11.16 **Class II with two pipes** Pt. B in stream outside pipe.  $p_B = 0$

**Method IIC**

$$\frac{p_A}{\gamma_o} + z_A + \frac{v_A^2}{2g} - h_L = \frac{p_B}{\gamma_o} + z_B + \frac{v_B^2}{2g}; \frac{p_A}{\gamma_o} + z_A - z_B = \frac{v_B^2 - v_A^2}{2g} + h_L$$

$$\frac{p_A}{\gamma_o} + z_A - z_B = \frac{175 \text{ kN/m}^2}{0.93(9.81 \text{ kN/m}^3)} - 4.5 \text{ m} = \boxed{14.68 \text{ m} = \frac{v_B^2}{2g} - \frac{v_A^2}{2g} + h_L} \quad \textcircled{1}$$

$$h_L = f_2 \frac{30}{0.0498} \frac{v_A^2}{2g} + 0.52 \frac{v_A^2}{2g} + f_4 \frac{100}{0.098} \frac{v_B^2}{2g} + 2(30)f_{T4} \frac{v_B^2}{2g}; f_{T4} = 0.010 \text{ approx.}$$

Friction(2-in) Enlarge. Friction (4-in) Elbows

$$L \frac{D_2}{D_1} = \frac{0.098}{0.0498} = 1.97$$

$$D_A/\varepsilon = 0.0498/1.5 \times 10^{-6} = 33200; N_{R_A} = \frac{v_A D_A \rho}{\mu} = \frac{v_A (0.0498)(930)}{9.50 \times 10^{-3}} = 4.88 \times 10^3 (v_A)$$

$$D_B/\varepsilon = 0.098/1.5 \times 10^{-6} = 65333; N_{R_B} = \frac{v_B D_B \rho}{\mu} = \frac{v_B (0.098)(930)}{9.5 \times 10^{-3}} = 9.59 \times 10^3 (v_B)$$

$$h_L = (0.52 + 602f_2) \frac{v_A^2}{2g} + (0.6 + 1020f_4) \frac{v_B^2}{2g}$$

$$\text{But } v_A = v_B \frac{A_B}{A_A} = v_B \left( \frac{D_B}{D_A} \right)^2 = v_B (1.97)^2 = 3.87 v_B; v_A^2 = 15.0 v_B^2$$

$$\text{Then: } h_L = (0.52 + 602f_2) \frac{15.0 v_B^2}{2g} + (0.6 + 1020f_4) \frac{v_B^2}{2g} = \frac{v_B^2}{2g} [8.40 + 9030f_2 + 1020f_4]$$

In Eq.  $\textcircled{1}$

$$14.68 = \frac{v_B^2}{2g} - \frac{15v_B^2}{2g} + \frac{v_B^2}{2g} [8.40 + 9030f_2 + 1020f_4] = \frac{v_B^2}{2g} [-5.60 + 9030f_2 + 1020f_4]$$

$$v_B = \sqrt{\frac{2g(14.68)}{-5.60 + 9030f_2 + 1020f_4}} = \sqrt{\frac{288.1}{-5.60 + 9030f_2 + 1020f_4}} \quad \text{Iterate for both } f_2 \text{ and } f_4.$$

Try  $f_2 = f_4 = 0.02$

$$v_B = \sqrt{\frac{288.1}{-5.60 + 9030(0.02) + 1020(0.02)}} = 1.21 \text{ m/s}; v_A = 3.87 v_B = 4.69 \text{ m/s}$$

$$N_{R_A} = 4.88 \times 10^3 (4.69) = 2.29 \times 10^4; N_{R_B} = 9.59 \times 10^3 (1.21) = 1.16 \times 10^4$$

New  $f_2 = 0.0255, f_4 = 0.0305$

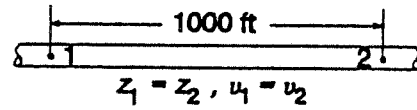
$$v_B = \sqrt{\frac{288.1}{-5.60 + 9030(0.0255) + 1020(0.0305)}} = 1.06 \text{ m/s}; v_A = 3.87 v_B = 4.10 \text{ m/s}$$

$$N_{R_A} = 2.01 \times 10^4 \rightarrow f_2 = 0.0255 \text{ No change}; N_{R_B} = 1.02 \times 10^4 \rightarrow f_4 = 0.0305 \text{ No change}$$

$$Q = A_B v_B = (7.538 \times 10^{-3} \text{ m}^2)(1.06 \text{ m/s}) = 7.99 \times 10^{-3} \text{ m}^3/\text{s}$$

**Class III systems**

11.17 **Class III**



$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$$

$$\frac{p_1 - p_2}{\gamma} = h_L = \frac{10.0 \text{ lb} \cdot \text{ft}^3 \cdot 144 \text{ in}^2}{\text{in}^2 (61.0 \text{ lb}) \text{ft}^2} = 23.61 \text{ ft} = f \frac{L v^2}{D 2g} = \frac{f L Q^2 16}{D 2g \pi^2 D^4}$$

$$D = \left[ \frac{8LQ^2}{\pi^2 g h_L} f \right]^{0.2} = \left[ \frac{8(1000)(0.5)^2}{\pi^2 (32.2)(23.61)} f \right]^{0.2} = (0.267 f)^2$$

$$N_R = \frac{vD}{\nu} = \frac{4QD}{\pi D^2 \nu} = \frac{4(0.5)}{\pi (4.38 \times 10^{-6}) D} = \frac{1.453 \times 10^5}{D}$$

Try  $f = 0.02$

$$D = [0.267(0.02)]^{0.2} = 0.351 \text{ ft};$$

$$N_R = \frac{1.453 \times 10^5}{0.351} = 4.14 \times 10^5; \frac{D}{\epsilon} = \frac{0.351}{1.5 \times 10^{-4}} = 2330$$

New  $f = 0.0175$

$$D = 0.342 \text{ ft}; N_R = 4.25 \times 10^5; D/\epsilon = 2279 \rightarrow f = 0.0175 \text{ No change}$$

⌊ Minimum Specify: **5-in Sch. 80 pipe**,  $D = 0.4011 \text{ ft}$

11.18 **Class III** Same method as Prob. 11.17.

$$D = \left[ \frac{8LQ^2}{\pi^2 g h_L} f \right]^{0.2} = \left[ \frac{8(30)(0.06)^2}{\pi^2 (9.81)(15.74)} f \right]^{0.2} = [5.67 \times 10^{-4} f]^{0.2}$$

$$h_L = \frac{p_1 - p_2}{\gamma} = \frac{150 \text{ kN/m}^2}{9.53 \text{ kN/m}^3} = 15.74 \text{ m}$$

$$N_R = \frac{4Q}{\pi \nu D} = \frac{4(0.06)}{\pi (3.60 \times 10^{-7}) D} = \frac{2.12 \times 10^5}{D}$$

Try  $f = 0.02$

$$D = [5.67 \times 10^{-4} (0.02)]^{0.2} = 0.103 \text{ m};$$

$$N_R = \frac{2.12 \times 10^5}{0.103} = 2.07 \times 10^6; \frac{D}{\epsilon} = \frac{0.103}{1.5 \times 10^{-6}} = 68400$$

New  $f = 0.0105$

$$D = 0.0901 \text{ m}; N_R = 2.35 \times 10^6; \frac{D}{\epsilon} = 60100 \rightarrow f = 0.0105 \text{ No change}$$

⌊ Minimum Specify **4-in type K copper tube**;  $D = 97.97 \text{ mm}$

<b>APPLIED FLUID MECHANICS</b>	<b>III-A &amp; III-B SI: CLASS III SERIES SYSTEMS</b>
<b>Objective: Minimum pipe diameter</b> Problem 11.18	<b>Method III-A:</b> Uses Equation 11-13 to compute the minimum size of pipe of a given length that will flow a given volume flow rate of fluid with a limited pressure drop. (No minor losses)
<b>System Data: SI Metric Units</b>	<b>Fluid Properties: Water at 80C</b>
Pressure at point 1 = 150 kPa	Specific weight = 9.53 kN/m <sup>3</sup>
Pressure at point 2 = 0 kPa	Kinematic Viscosity = 3.60E-07 m <sup>2</sup> /s
Elevation at point 1 = 0 m	<b>Intermediate Results in Eq. 11-13:</b>
Elevation at point 2 = 0 m	L/gh <sub>L</sub> = 0.194292
Allowable Energy Loss: h <sub>L</sub> = 15.74 m	Argument in bracket: 2.89E-22
Volume flow rate: Q = 0.06 m <sup>3</sup> /s	<b>Final Minimum Diameter:</b>
Length of pipe: L = 30 m	Minimum diameter: D = 0.0908 m
Pipe wall roughness: ε = 1.50E-06 m	

Specify 4-in type K copper tube: D = 97.97 mm

<b>APPLIED FLUID MECHANICS</b>	<b>III-A &amp; III-B US: CLASS III SERIES SYSTEMS</b>
<b>Objective: Minimum pipe diameter</b> Example Problem 11.19	<b>Method III-A:</b> Uses Equation 11-8 to compute the minimum size of pipe of a given length that will flow a given volume flow rate of fluid with a limited pressure drop. (No minor losses)
<b>System Data: SI Metric Units</b>	<b>Fluid Properties: Water at 60F</b>
Pressure at point 1 = 0 psig	Specific weight = 62.40 lb/ft <sup>3</sup>
Pressure at point 2 = 0 psig	Kinematic Viscosity = 1.21E-05 ft <sup>2</sup> /s
Elevation at point 1 = 130 ft	<b>Intermediate Results in Eq. 11-8:</b>
Elevation at point 2 = 0 ft	L/gh <sub>L</sub> = 2.522695
Allowable Energy Loss: h <sub>L</sub> = 130.00 ft	Argument in bracket: 6.22E-11
Volume flow rate: Q = 30.067 ft <sup>3</sup> /s	<b>Final Minimum Diameter:</b>
Length of pipe: L = 10560 ft	Minimum diameter: D = 1.9556 ft
Pipe wall roughness: ε = 4.00E-04 ft	

<b>APPLIED FLUID MECHANICS</b>	<b>III-A &amp; III-B US: CLASS III SERIES SYSTEMS</b>
<b>Objective: Minimum pipe diameter</b> Problem 11.17	<b>Method III-A:</b> Uses Equation 11-8 to compute the minimum size of pipe of a given length that will flow a given volume flow rate of fluid with a limited pressure drop. (No minor losses)
<b>System Data: SI Metric Units</b>	<b>Fluid Properties: Water at 160F</b>
Pressure at point 1 = 110 psig	Specific weight = 61.00 lb/ft <sup>3</sup>
Pressure at point 2 = 100 psig	Kinematic Viscosity = 4.38E-06 ft <sup>2</sup> /s
Elevation at point 1 = 0 ft	<b>Intermediate Results in Eq. 11-8:</b>
Elevation at point 2 = 0 ft	L/gh <sub>L</sub> = 1.315562
Allowable Energy Loss: h <sub>L</sub> = 23.61 ft	Argument in bracket: 1.11E-07
Volume flow rate: Q = 0.5 ft <sup>3</sup> /s	<b>Final Minimum Diameter:</b>
Length of pipe: L = 1000 ft	Minimum diameter: D = 0.3479 ft
Pipe wall roughness: ε = 1.50E-04 ft	

Specify 5-in Sch. 80 steel pipe; D = 0.4100 ft

APPLIED FLUID MECHANICS	III-A & III-B US: CLASS III SERIES SYSTEMS
<b>Objective: Minimum pipe diameter</b> Problem 11.20 Figure 11.22	<b>Method III-A:</b> Uses Equation 11-8 to compute the minimum size of pipe of a given length that will flow a given volume flow rate of fluid with a limited pressure drop. (No minor losses)
<b>System Data: SI Metric Units</b> Pressure at point 1 = 0 psig Pressure at point 2 = 0 psig Elevation at point 1 = 12 ft Elevation at point 2 = 0 ft Allowable Energy Loss: $h_L = 12.00$ ft Volume flow rate: $Q = 0.8909$ ft <sup>3</sup> /s Length of pipe: $L = 75$ ft Pipe wall roughness: $\epsilon = 1.50E-04$ ft	<b>Fluid Properties: Water at 80F</b> Specific weight = 62.20 lb/ft <sup>3</sup> Kinematic Viscosity = 9.15E-06 ft <sup>2</sup> /s <b>Intermediate Results in Eq. 11-8:</b> $L/gh_L = 0.194099$ Argument in bracket: 2.91E-09 <b>Final Minimum Diameter:</b> Minimum diameter: $D = 0.3007$ ft

CLASS III SERIES SYSTEMS																																														
<b>Method III-B:</b> Use results of Method III-A; Specify actual diameter; Include minor losses; then pressure at Point 2 is computed.	Specified pipe diameter: $D = 0.4206$ ft-min std sz 5-in Sch 40 steel pipe																																													
<b>Additional Pipe Data:</b> Flow area: $A = 0.13894$ ft <sup>2</sup> Relative roughness: $D/\epsilon = 2804$ $L/D = 178$ Flow Velocity = 6.41 ft/s Velocity head = 0.638 ft Reynolds No. = 2.95E+05 Friction factor: $f = 0.0175$	<b>If velocity is in the pipe, enter "=B23" for value</b> Velocity at point 1 = 0.00 ft/s Velocity at point 2 = 6.41 ft/s Vel. head at point 1 = 0.000 ft Vel. head at point 2 = 0.638 ft <b>Results:</b> Given pressure at point 1 = 0 psig Desired pressure at point 2 = 0 psig <b>Actual pressure at point 2 = 2.28 psig</b> <b>(Compare actual with desired pressure at point 2)</b>																																													
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**Practice problems for any class**

11.21 **Class I** Pt. 1 at tank surface, Pt. 2 in stream outside pipe:  $p_1 = p_2 = 0$ ;  $v_1 = 0$

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g} : \boxed{z_1 - z_2 = \frac{v_2^2}{2g} + h_L} \quad \text{①}$$

$$v_2 = \frac{Q}{A_2} = \frac{1500 \text{ L/min}}{6.38 \times 10^{-3} \text{ m}^2} \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 3.92 \text{ m/s}; \frac{v_2^2}{2g} = \frac{(3.92)^2}{2(9.81)} = 0.782 \text{ m}$$

$$f_T = 0.018$$

$$h_L = 0.5 \frac{v_2^2}{2g} + f_T(160) \frac{v_2^2}{2g} + f_T(30) \frac{v_2^2}{2g} = \frac{v_2^2}{2g} [0.5 + 190 f_T] = 0.782 [0.5 + 190(0.018)] = 3.07 \text{ m}$$

In Eq. ①

$$z_1 - z_2 = \frac{v_2^2}{2g} + h_L = 0.782 + 3.07 = 3.85 \text{ m}$$

$$\text{But } h = z_1 - z_2 - 0.5 \text{ m} = 3.85 \text{ m} - 0.5 \text{ m} = \mathbf{3.35 \text{ m}}$$

11.22 **Class I** Pt. 1 at collector tank surface. Pt. 2 at pump inlet.  $p_1 = 0$ ,  $v_1 = 0$

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g} : \boxed{p_2 = \gamma \left[ (z_1 - z_2) - h_L - \frac{v_2^2}{2g} \right]} \quad \text{①}$$

$$Q = 30 \text{ gal/min} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 0.0668 \text{ ft}^3/\text{s} \quad f_T = 0.019 \text{ for 2-in pipe}$$

$$v_2 = \frac{Q}{A_2} = \frac{0.0668 \text{ ft}^3/\text{s}}{0.02333 \text{ ft}^2} = 2.86 \text{ ft/s}; \frac{v_2^2}{2g} = \frac{(2.86)^2}{2(32.2)} = 0.127 \text{ ft}$$

$$h_L = 0.5 \frac{v_2^2}{2g} + 1.85 \frac{v_2^2}{2g} + f \frac{10.0 \text{ ft}}{0.1723 \text{ ft}} \frac{v_2^2}{2g} + f_T(8) \frac{v_2^2}{2g} = \frac{v_2^2}{2g} (2.50 + 58.0 f)$$

Entrance Filter Friction Valve

$$N_R = \frac{vD\rho}{\mu} = \frac{(2.86)(0.1723)(0.92)(1.94)}{3.6 \times 10^{-5}} = 2.45 \times 10^4; \frac{D}{\epsilon} = \frac{0.1723}{1.5 \times 10^{-4}} = 1149$$

$$f = 0.0265$$

$$h_L = (0.127 \text{ ft}) [2.50 + 58.0(0.0265)] = 0.513 \text{ ft}$$

In Eq. ①:

$$p_2 = (0.92) \left( \frac{62.4 \text{ lb}}{\text{ft}^3} \right) [3.0 - 0.513 - 0.127] \frac{\text{ft ft}^2}{144 \text{ in}^2} = \mathbf{0.94 \text{ psig}}$$

11.23 **Class I** Pt. 1 at collector tank surface; Pt. 3 at upper tank surface.  $p_1 = p_3 = 0$ ,  $v_1 = v_3 = 0$

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L + h_A = \frac{p_3}{\gamma} + z_3 + \frac{v_3^2}{2g}; h_A = (z_3 - z_1) + h_L = 19.0 \text{ ft} + h_L$$

$$h_L = h_{L_{\text{suct}}} + h_{L_{\text{disch}}} = 0.513 \text{ ft} + f_{dR}(100) \frac{v_d^2}{2g} + f_d \frac{18 \text{ ft}}{0.115 \text{ ft}} \frac{v_2^2}{2g} + 1.0 \frac{v_d^2}{2g}$$

$$\begin{array}{cccc} \text{From Prob. 11.22} & \text{Ch. valve} & \text{Friction} & \text{Exit} \\ v_d = \frac{Q}{A_d} = \frac{0.0668 \text{ ft}^3/\text{s}}{0.01039 \text{ ft}^2} = 6.43 \text{ ft/s}; & \frac{v_d^3}{2g} = \frac{(6.43)^2}{2(32.2)} = 0.642 \text{ ft} \end{array}$$

$$N_{R_d} = \frac{v_d D \rho}{\mu} = \frac{(6.43)(0.115)(0.92)(1.94)}{3.6 \times 10^{-5}} = 3.67 \times 10^4 :$$

$$\frac{D}{\varepsilon} = \frac{0.115}{1.5 \times 10^{-4}} = 767 \rightarrow f = 0.0265; f_{dR} = 0.022$$

$$h_L = 0.513 \text{ ft} + (0.022)(100)(0.642) + (0.0265)(157)(0.642) + 1.0(0.642) = 5.24 \text{ ft}$$

$$h_A = 19.0 \text{ ft} + h_L = 19.0 + 5.24 = 24.24 \text{ ft}$$

$$\text{Power} = P_A = h_A \gamma Q = (24.24 \text{ ft})(0.92) \left( \frac{62.4 \text{ lb}}{\text{ft}^3} \right) \left( \frac{0.0668 \text{ ft}^3}{\text{s}} \right) \frac{1 \text{ hp}}{550 \text{ ft-lb/s}} = 0.169 \text{ hp}$$

APPLIED FLUID MECHANICS	III-A & III-B US: CLASS III SERIES SYSTEMS
<b>Objective: Minimum pipe diameter</b>	<b>Method III-A:</b> Uses Equation 11-8 to compute the minimum size of pipe of a given length
Problem 11.24	that will flow a given volume flow rate of fluid
Figure 11.24 – Return System from upper tank	with a limited pressure drop. (No minor losses)
<b>System Data: SI Metric Units</b>	<b>Fluid Properties: Coolant – Given properties</b>
Pressure at point 1 = 0 psig	Specific weight = 57.41 lb/ft <sup>3</sup>
Pressure at point 2 = 0 psig	Kinematic Viscosity = 2.02E-05 ft <sup>2</sup> /s
Elevation at point 1 = 9 ft	<b>Intermediate Results in Eq. 11-8:</b>
Elevation at point 2 = 0 ft	L/gh <sub>L</sub> = 0.134576
Allowable Energy Loss: h <sub>L</sub> = 12.00 ft	Argument in bracket: 1.37E-09
Volume flow rate: Q = 0.6682 ft <sup>3</sup> /s	<b>Final Minimum Diameter:</b>
Length of pipe: L = 39 ft	Minimum diameter: D = 0.1059 ft
Pipe wall roughness: ε = 1.50E-04 ft	

<b>CLASS III SERIES SYSTEMS</b>		<i>Specified pipe diameter: D = 0.115 ft-min std sz</i>	
<b>Method III-B:</b> Use results of Method III-A; Specify actual diameter; Include minor losses; then pressure at Point 2 is computed.		5-in Sch 40 steel pipe	
<b>Additional Pipe Data:</b>		<b>If velocity is in the pipe, enter "=B23" for value</b>	
Flow area: A =	0.01039 ft <sup>2</sup>	Velocity at point 1 =	0.00 ft/s
Relative roughness: D/ε =	767	Velocity at point 2 =	6.43 ft/s
L/D =	339	Vel. head at point 1 =	0.000 ft
Flow Velocity =	6.43 ft/s	Vel. head at point 2 =	0.643 ft
Velocity head =	0.643 ft	<b>Results:</b>	
Reynolds No. =	3.67E+04	Given pressure at point 1 =	0 psig
Friction factor: f =	0.0261	Desired pressure at point 2 =	0 psig
		<b>Actual pressure at point 2 =</b>	<b>0.36 psig</b>
		<b>(Compare actual with desired pressure at point 2)</b>	
<b>Energy losses in Pipe:</b>	K	Qty.	
Pipe Friction: $K_1 = f(L/D) =$	8.84	1	Energy loss $h_{L1} =$ 5.68 ft
Entrance: $K_2 =$	1.00	1	Energy loss $h_{L2} =$ 0.64 ft
Elbows: $K_3 =$	0.66	2	Energy loss $h_{L3} =$ 0.85 ft $f_T = 0.022$
Tee-flow thru run: $K_4 =$	0.44	1	Energy loss $h_{L4} =$ 0.28 ft $f_T = 0.022$
Element 5: $K_5 =$	0.00	1	Energy loss $h_{L5} =$ 0.00 ft
Element 6: $K_6 =$	0.00	1	Energy loss $h_{L6} =$ 0.00 ft
Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} =$ 0.00 ft
Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} =$ 0.00 ft
			Total energy loss $h_{Ltot} =$ 7.45 ft

11.25 **Class II** Computational approach, Eq. 11.12.

$$h_L = \frac{p_1 - p_2}{\gamma} = \frac{10.0 \text{ lb}}{\text{in}^2} \cdot \frac{\text{ft}^3}{62.4 \text{ lb}} \cdot \frac{144 \text{ in}^2}{\text{ft}^2} = 23.08 \text{ ft}$$

1-in Schedule 80 steel pipe;  $D = 0.07975 \text{ ft}$ ;  $A = 0.00499 \text{ ft}^2$

$$D/\epsilon = 0.07975/1.5 \times 10^{-4} = 532$$

Water at 60°F;  $\nu = 1.21 \times 10^{-5} \text{ ft}^2/\text{s}$

$$Q = -2.22D^2$$

$$= -2.22(0.07975)^2 \sqrt{\frac{(32.2)(0.07975)(23.08)}{100}} \log \left[ \frac{1}{3.7(532)} + \frac{(1.7841)(1.21 \times 10^{-5})}{(0.07975)\sqrt{0.5927}} \right]$$

$$Q = 0.0333 \text{ ft}^3/\text{s}$$

$$v = \frac{Q}{A} = \frac{0.0333 \text{ ft}^3/\text{s}}{0.00499 \text{ ft}^2} = 6.68 \text{ ft/s}$$

APPLIED FLUID MECHANICS		II-A & II-B US: CLASS II SERIES SYSTEMS	
<b>Objective: Volume flow rate</b>		<b>Method II-A: No minor losses</b>	
Problem 11.25		Uses Equation 11-3 to find maximum allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data:</b>		<b>US Customary Units</b>	
Pressure at point 1 =	110 psig	Elevation at point 1 =	0 ft
Pressure at point 2 =	100 psig	Elevation at point 2 =	0 ft
Energy loss: $h_L =$		23.08 ft	
<b>Fluid Properties:</b>		Water at 60F May need to compute: $\nu = \eta/\rho$	
Specific weight =	62.40 lb/ft <sup>3</sup>	Kinematic viscosity =	1.21E-05 ft <sup>2</sup> /s
<b>Pipe data: 3-in coated ductile iron pipe</b>		<b>Results: Maximum values</b>	
Diameter: $D =$	0.07975 ft	Volume flow rate: $Q =$	0.03332 ft <sup>3</sup> /s Using Eq. 11-3
Wall roughness: $\epsilon =$	1.50E-04 ft	Velocity: $v =$	6.67 ft/s
Length: $L =$	100 ft		
Area: $A =$	0.00500 ft <sup>2</sup>		
$D/\epsilon =$	531.667		

APPLIED FLUID MECHANICS	III-A & III-B US: CLASS III SERIES SYSTEMS
Objective: Minimum pipe diameter Problem 11.26	<b>Method III-A:</b> Uses Equation 11-8 to compute the minimum size of pipe of a given length that will flow a given volume flow rate of fluid with a limited pressure drop. (No minor losses)
<b>System Data: SI Metric Units</b>	<b>Fluid Properties: Gasoline at 77F</b>
Pressure at point 1 = 108 psig	Specific weight = 42.40 lb/ft <sup>3</sup>
Pressure at point 2 = 100 psig	Kinematic Viscosity = 4.55E-06 ft <sup>2</sup> /s
Elevation at point 1 = 0 ft	<b>Intermediate Results in Eq. 11-8:</b>
Elevation at point 2 = 0 ft	L/gh <sub>L</sub> = 0.137164
Allowable Energy Loss: h <sub>L</sub> = 27.17 ft	Argument in bracket: 9.52E-16
Volume flow rate: Q = 0.22272 ft <sup>3</sup> /s	<b>Final Minimum Diameter:</b>
Length of pipe: L = 120 ft	Minimum diameter: D = 0.1655 ft
Pipe wall roughness: ε = 1.50E-04 ft	

CLASS III SERIES SYSTEMS	Specified pipe diameter: D = 0.1723ft-min std sz 2-inch Sch 40 steel pipe
<b>Method III-B:</b> Use results of Method III-A; Specify actual diameter; Include minor losses; then pressure at Point 2 is computed.	<b>If velocity is in the pipe, enter "=B23" for value</b>
<b>Additional Pipe Data:</b>	Velocity at point 1 = 9.55 ft/s
Flow area: A = 0.02332 ft <sup>2</sup>	Velocity at point 2 = 9.55 ft/s
Relative roughness: D/ε = 1149	Vel. head at point 1 = 1.417 ft
L/D = 696	Vel. head at point 2 = 1.417 ft
Flow Velocity = 9.55 ft/s	<b>Results:</b>
Velocity head = 1.417 ft	Given pressure at point 1 = 108 psig
Reynolds No. = 3.62E+05	Desired pressure at point 2 = 100 psig
Friction factor: f = 0.0200	<b>Actual pressure at point 2 = 102.18 psig</b>
	<b>(Compare actual with desired pressure at point 2)</b>
<b>Energy losses in Pipe:</b>	
Pipe Friction: K <sub>1</sub> = f(L/D) = 13.94 1	Energy loss h <sub>L1</sub> = 19.75 ft
Element 2: K <sub>2</sub> = 0.00 1	Energy loss h <sub>L2</sub> = 0.00 ft
Element 3: K <sub>3</sub> = 0.00 2	Energy loss h <sub>L3</sub> = 0.00 ft
Element 4: K <sub>4</sub> = 0.00 1	Energy loss h <sub>L4</sub> = 0.00 ft
Element 5: K <sub>5</sub> = 0.00 1	Energy loss h <sub>L5</sub> = 0.00 ft
Element 6: K <sub>6</sub> = 0.00 1	Energy loss h <sub>L6</sub> = 0.00 ft
Element 7: K <sub>7</sub> = 0.00 1	Energy loss h <sub>L7</sub> = 0.00 ft
Element 8: K <sub>8</sub> = 0.00 1	Energy loss h <sub>L8</sub> = 0.00 ft
	<b>Total energy loss h<sub>Ltot</sub> = 19.75 ft</b>

11.27 **Class I**  $Q = 475 \text{ L/min}$  ( $1 \text{ m}^3/\text{s}/60000 \text{ L/min}$ )  $= 7.917 \times 10^{-3} \text{ m}^3/\text{s}$

Pt. 1 at reservoir surface; Pt. 2 at pump inlet.  $p_1 = 0, v_1 = 0$

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}; \quad p_2 = \gamma \left[ (z_1 - z_2) - \frac{v_2^2}{2g} - h_L \right] \quad \textcircled{1}$$

$$v_2 = \frac{Q}{A} = \frac{7.917 \times 10^{-3} \text{ m}^3/\text{s}}{3.090 \times 10^{-3} \text{ m}^2} = 2.56 \text{ m/s}; \quad \frac{v_2^2}{2g} = \frac{(2.56)^2}{2(9.81)} = 0.335 \text{ m}$$

$$h_L = \frac{v_2^2}{2g} + (0.0195) \frac{12.90 \text{ m}}{0.0627 \text{ m}} \frac{v_2^2}{2g} + (0.018)(2)(30) \frac{v_2^2}{2g} + (0.018)(340) \frac{v_2^2}{2g} = 4.09 \text{ m}$$

$$N_R = \frac{vD}{\nu} = \frac{(2.56)(0.0627)}{3.60 \times 10^{-7}} = 4.46 \times 10^5; \quad \frac{D}{\epsilon} = \frac{0.0627}{4.6 \times 10^{-5}} = 1363 \rightarrow f = 0.0195$$

$$f_T = 0.018$$

$$L = 11.5 \text{ m} + 1.40 \text{ m} = 12.90 \text{ m}$$

$$z_1 - z_2 = 0.75 \text{ m} - 1.40 \text{ m} = 0.65 \text{ m}$$

In Eq.  $\textcircled{1}$

$$p_2 = \frac{9.53 \text{ kN}}{\text{m}^3} [-0.65 \text{ m} - 0.335 \text{ m} - 4.09 \text{ m}] = -48.4 \text{ kPa}$$

11.28 Design problem with variable solutions: Pressure at pump inlet can be increased by: lowering the pump, raising the reservoir, reducing the flow velocity in the pipe by using a larger pipe, reducing the  $h_L$  in the valve by using a less restrictive valve (gate, butterfly), eliminating elbows or using long-radius elbows, using a well-rounded entrance, and shortening the suction line.

11.29 **Class I** Pt. B in stream outside nozzle.  $p_B = 0$

$$\frac{p_A}{\gamma} + z_A + \frac{v_A^2}{2g} - h_L + h_A = \frac{p_B}{\gamma} + z_B + \frac{v_B^2}{2g}$$

$$h_A = (z_B - z_A) + \frac{v_B^2 - v_A^2}{2g} - \frac{p_A}{\gamma} + h_L$$

$$v_A = \frac{Q}{A_A} = \frac{0.50 \text{ ft}^3/\text{s}}{0.05132 \text{ ft}^2} = 9.743 \text{ ft/s}$$

$$\frac{v_A^2}{2g} = \frac{(9.743)^2}{2(32.2)} \text{ ft} = 1.474 \text{ ft}$$

$$v_B = \frac{Q}{A_B} = \frac{0.50}{\frac{\pi(1.3/12)^2}{4}} = 54.2 \text{ ft/s}$$

$$\frac{v_B^2}{2g} = 45.7 \text{ ft}$$

$$\rho = \frac{\gamma}{g} = \frac{64.0 \text{ lb/ft}^3}{32.2 \text{ ft/s}^2} = 1.988 \frac{\text{slugs}}{\text{ft}^3}$$

In 2 1/2-in discharge line:

$$v_d = \frac{Q}{A_d} = \frac{0.50}{0.03326} = 15.03 \text{ ft/s}$$

$$\frac{v_d^2}{2g} = \frac{(15.03)^2}{2(32.2)} = 3.509 \text{ ft}$$

$$N_{R_d} = \frac{v_d D \rho}{\mu} = \frac{(15.03)(0.2058)(1.988)}{4.0 \times 10^{-5}} = 1.54 \times 10^5$$

$$D/\varepsilon = 0.2058/1.5 \times 10^{-4} = 1372 \rightarrow f = 0.0205; f_T = 0.018$$

$$h_L = \underbrace{(0.0205) \frac{82 \text{ ft}}{0.2058 \text{ ft}}}_{\text{Friction}} \underbrace{(3.509)}_{\text{Elbow}} + 0.018(30)(3.509) + 32.6(3.51 \text{ ft}) = 144.8 \text{ ft}$$

$$\text{Then } h_A = 80 \text{ ft} + 45.7 \text{ ft} - 1.474 \text{ ft} - \frac{(-3.50 \text{ lb})\text{ft}^3}{\text{in}^2} \frac{144 \text{ in}^2}{64.0 \text{ lb ft}^2} + 144.8 \text{ ft} = 276.9 \text{ ft}$$

$$\text{Power} = P_A = h_A \gamma Q = (276.9 \text{ ft})(64.0 \text{ lb/ft}^3)(0.50 \text{ ft}^3/\text{s})/550 \text{ ft-lb/s} = \mathbf{16.1 \text{ hp}}$$

$$\text{Input power} = P_I = P_A/e_M = (16.1 \text{ hp})/0.76 = \mathbf{21.2 \text{ hp} = P_I}$$

11.30 **Class I** See Problem 11.29. 3-in Sch. 40 discharge line.  $f_T = 0.018$

$$v_d = v_A = 9.743 \text{ ft/s}; \frac{v_d^3}{2g} = 1.474 \text{ ft}$$

$$N_{R_d} = \frac{v_d D \rho}{\mu} = \frac{(9.743)(0.2557)(1.988)}{4.0 \times 10^{-5}} = 1.24 \times 10^5 :$$

$$\frac{D}{\varepsilon} = \frac{0.2557}{1.5 \times 10^{-4}} = 1705; f = 0.0205$$

$$h_L = (0.0205) \frac{82}{0.2557} (1.474) + 0.018(30)(1.474) + 32.6(1.474) = 58.5 \text{ ft}$$

$$h_A = 80 + 45.7 - 1.474 + 7.875 + 58.5 = 190.6 \text{ ft}$$

$$P_A = h_A \gamma Q = (256.8)(64.0)(0.50)/550 = \mathbf{11.1 \text{ hp}}$$

$$\text{Input power} = P_I = P_A/e_M = (11.1 \text{ hp})/0.76 = \mathbf{14.6 \text{ hp} = P_I}$$

11.31 **Class I** Pt. B outside pipe.  $p_B = 0$ ,  $v_B = v_A$ .

$$\frac{p_A}{\gamma} + z_A + \frac{v_A^2}{2g} - h_L = \frac{p_B}{\gamma} + z_B + \frac{v_B^2}{2g}; p_A = \gamma [(z_B - z_A) + h_L]$$

$$h_L = f_I(340) \frac{v^2}{2g} + f \frac{27.5 \text{ m}}{0.0409 \text{ m}} \frac{v^2}{2g} + f_T(30) \frac{v^2}{2g} = [f(672) + f_T(370)] \frac{v^2}{2g}$$

Valve Friction Elbow

$$v = \frac{Q}{A} = \frac{200 \text{ L/min}}{1.31 \times 10^{-3} \text{ m}^2} \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 2.54 \text{ m/s}; \frac{v^2}{2g} = \frac{(2.54)^2}{2(9.81)} = 0.328 \text{ m}$$

$$N_{R_v} = \frac{vD}{\nu} = \frac{(2.54)(0.0409)}{1.30 \times 10^{-6}} = 7.98 \times 10^4; \frac{D}{\varepsilon} = \frac{0.0409}{4.6 \times 10^{-5}} = 889; f = 0.0235$$

$$f_T = 0.021$$

$$\text{Then } h_L = [(0.0235)(672) + (0.021)(370)](0.328 \text{ m}) = 7.73 \text{ m}$$

$$p_A = \frac{9.81 \text{ kN}}{\text{m}^3} [25 \text{ m} + 7.73 \text{ m}] = \mathbf{321.1 \text{ kPa}}$$

See spreadsheet on page 167 for solution to Problem 11.31 using the spreadsheet **I Pressure SI**.

Problems 11.32 and 11.33 are solved using the spreadsheet on the following two pages. These problems are of the Class II type and are solved using the procedure described in Section 11.5. Method II-B is used because the system contains significant minor losses. In fact, one objective of these two problems is to compare the performance of two design approaches for the same system, using a different, more efficient valve in Problem 11.33 as compared with Problem 11.32.

Recall that Method II-A is set up and solved first in the spreadsheet. This ignores the minor losses and gives an upper limit for the volume flow rate that can be delivered through the system with a given pressure drop or head loss. Then, Method II-B is used iteratively to hone in on the maximum volume flow rate that can be carried with the minor losses considered. The designer enters a series of estimates for the value of  $Q$  and observes the resulting pressure at the outlet from the piping system. Obviously this pressure for this problem should be exactly zero because the pipe discharges into the free atmosphere. Each trial requires only a few seconds to complete and the designer should continue making estimates until the pressure at the outlet is at or close to zero.

Problem 11.32 shows that  $Q = 0.00283 \text{ m}^3/\text{s}$  (170 L/min) can be delivered through the given system with a fully open globe valve installed and with a pressure of 300 kPa at point A at the water main.

In Problem 11.33, the globe valve is replaced with a fully open gate valve having much less energy loss. The result is that  $Q = 0.003394 \text{ m}^3/\text{s}$  (204 L/min) can be delivered with the same pressure at point A. This is approximately a 20% increase in flow. Also, it is only about 3% less than the flow that could be delivered through the pipe with no minor losses at all, as shown in the results of Method II-A at the top of the spreadsheet.

APPLIED FLUID MECHANICS		<i>I Pressure SI:</i> CLASS I SERIES SYSTEMS	
<b>Objective: Pressure: Point 2</b>		Reference points for the energy equation:	
Problem 11.31		Pt. 1: In pipe at Point A	
Fig. 11.27		Pt. 2: In pipe at Point B	
<b>System Data:</b>		<b>SI Metric Units</b>	
Volume flow rate: $Q = 3.33E-03 \text{ m}^3/\text{s}$		Elevation at point 1 = 0 m	
Pressure at point 1 = 320.58 kPa		Elevation at point 2 = 25 m	
Pressure at point 2 = 0.00 kPa		If Ref. pt. is in pipe: Set $v_1$ " = B20" OR Set $v_2$ " = E20"	
Velocity at point 1 = 2.537 m/s -->		Vel head at point 1 = 0.328084 m	
Velocity at point 2 = 2.537 m/s -->		Vel head at point 2 = 0.328084 m	
<b>Fluid Properties:</b> Water at 10C		May need to compute: $v = \eta/\rho$	
Specific weight = 9.81 kN/m <sup>3</sup>		Kinematic viscosity = 1.30E-06 m <sup>2</sup> /s	
<b>Pipe 1: 1 1/2-in Sch 40 steel pipe</b>		<b>Pipe 2: None</b>	
Diameter: $D = 0.0409 \text{ M}$		Diameter: $D = 0.09797 \text{ m}$	
Wall roughness: $\epsilon = 4.60E-05 \text{ m}$		Wall roughness: $\epsilon = 1.50E-06 \text{ m}$ See Table 8.2	
Length: $L = 27.5 \text{ m}$		Length: $L = 0 \text{ m}$	
Area: $A = 1.31E-03 \text{ m}^2$		Area: $A = 7.54E-03 \text{ m}^2$ [ $A = \pi D^2/4$ ]	
$D/\epsilon = 889$		$D/\epsilon = 65313$ Relative roughness	
$L/D = 672$		$L/D = 0$	
Flow Velocity = 2.537 m/s		Flow Velocity = 0.4422 m/s [ $v = Q/A$ ]	
Velocity head = 0.328084 m		Velocity head = 0.0100 m	
Reynolds No. = 7.98E+04		Reynolds No. = 3.33E+04 [ $N_R = vD/\nu$ ]	
Friction factor: $f = 0.0233$		Friction factor: $f = 0.0228$ Using Eq. 8-7	
<b>Energy losses-Pipe 1:</b>		<b>Energy losses-Pipe 2:</b>	
$K$	Qty.	$K$	Qty.
Pipe: $K_1 = f(L/D) = 15.64$	1	Energy loss $h_{L1} = 5.13 \text{ m}$	Friction
Elbow: $K_2 = 0.63$	1	Energy loss $h_{L2} = 0.21 \text{ m}$	( $f_T = 0.021$ )
Globe Valve: $K_3 = 7.14$	1	Energy loss $h_{L3} = 2.34 \text{ m}$	( $f_T = 0.021$ )
Element 4: $K_4 = 0.00$	1	Energy loss $h_{L4} = 0.00 \text{ m}$	
Element 5: $K_5 = 0.00$	1	Energy loss $h_{L5} = 0.00 \text{ m}$	
Element 6: $K_6 = 0.00$	1	Energy loss $h_{L6} = 0.00 \text{ m}$	
Element 7: $K_7 = 0.00$	1	Energy loss $h_{L7} = 0.00 \text{ m}$	
Element 8: $K_8 = 0.00$	1	Energy loss $h_{L8} = 0.00 \text{ m}$	
<b>Energy losses-Pipe 2:</b>		<b>Energy losses-Pipe 2:</b>	
$K$	Qty.	$K$	Qty.
Pipe: $K_1 = f(L/D) = 0.00$	1	Energy loss $h_{L1} = 0.00 \text{ m}$	Friction
Element 2: $K_2 = 0.00$	1	Energy loss $h_{L2} = 0.00 \text{ m}$	
Element 3: $K_3 = 0.00$	1	Energy loss $h_{L3} = 0.00 \text{ m}$	
Element 4: $K_4 = 0.00$	1	Energy loss $h_{L4} = 0.00 \text{ m}$	
Element 5: $K_5 = 0.00$	1	Energy loss $h_{L5} = 0.00 \text{ m}$	
Element 6: $K_6 = 0.00$	1	Energy loss $h_{L6} = 0.00 \text{ m}$	
Element 7: $K_7 = 0.00$	1	Energy loss $h_{L7} = 0.00 \text{ m}$	
Element 8: $K_8 = 0.00$	1	Energy loss $h_{L8} = 0.00 \text{ m}$	
<b>Results:</b>		Total energy loss $h_{L\text{tot}} = 7.68 \text{ m}$	
		Total change in pressure = -320.58 kPa	
		Pressure at target point: 320.58 kPa	

<b>APPLIED FLUID MECHANICS</b>		<b>CLASS II SERIES SYSTEMS</b>	
<b>Objective: Volume flow rate</b>		<b>Method II-A: No minor losses</b>	
Problem 11.32 Figure 11.27		Uses Equation 11-3 to estimate the allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data:</b>		<b>SI Metric Units</b>	
Pressure at point 1 =	300 kPa	Elevation at point 1 =	0 m
Pressure at point 2 =	0 kPa	Elevation at point 2 =	25 m
Energy loss: $h_L =$		5.58 m	
<b>Fluid Properties:</b>		May need to compute: $v = \eta/\rho$	
Specific weight =	9.81 kN/m <sup>3</sup>	Kinematic viscosity =	1.30E-06 m <sup>2</sup> /s
<b>Pipe data:</b>		<b>Results: Maximum values</b>	
Diameter: $D =$	0.0409 m	Volume flow rate: $Q =$	0.0035 m <sup>3</sup> /s
Wall roughness: $\varepsilon =$	4.60E-05 m	Velocity: $v =$	2.66 m/s
Length: $L =$	27.5 m		
Area: $A =$	0.00131 m <sup>2</sup>		
$D/\varepsilon =$	889.13		

<b>CLASS II SERIES SYSTEMS</b>		Volume flow rate: $Q = 0.00283 \text{ m}^3/\text{s}$	
<b>Method II-B: Use results of Method IIA; Include minor losses; then pressure at Point 2 is computed</b>		Given: Pressure $p_1 =$ 300 kPa Pressure $p_2 =$ 0.00 kPa <b>NOTE: Should be &gt; 0 kPa</b>	
<b>Additional Pipe Data:</b>		<b>Adjust estimate for Q until <math>p_2</math> is greater than desired pressure.</b>	
$L/D =$	672	Velocity at point 1 =	2.15 m/s  --> If velocity is in pipe
Flow Velocity =	2.15 m/s	Velocity at point 2 =	2.15 m/s  --> Enter "=B24"
Velocity head =	0.236 m	Vel. head at point 1 =	0.236 m
Reynolds No. =	6.76E+04	Vel. head at point 2 =	0.236 m
Friction factor: $f =$	0.0237		
<b>Energy losses in Pipe 1:</b>			
Pipe: $K_1 = f(L/D) =$	15.91	1	Energy loss $h_{L1} =$ 3.75 m Friction
1 std. elbows: $K_2 =$	0.63	1	Energy loss $h_{L2} =$ 0.15 m
Globe valve: $K_3 =$	7.14	1	Energy loss $h_{L3} =$ 1.68 m
Element 4: $K_4 =$	0.00	1	Energy loss $h_{L4} =$ 0.00 m
Element 5: $K_5 =$	0.00	1	Energy loss $h_{L5} =$ 0.00 m
Element 6: $K_6 =$	0.00	1	Energy loss $h_{L6} =$ 0.00 m
Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} =$ 0.00 m
Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} =$ 0.00 m
		Total energy loss $h_{Ltot} =$ 5.58 m	

<b>APPLIED FLUID MECHANICS</b>		<b>CLASS II SERIES SYSTEMS</b>	
<b>Objective: Volume flow rate</b>		<b>Method II-A: No minor losses</b>	
Problem 11.33		Uses Equation 11-3 to estimate the allowable volume flow rate	
Figure 11.27		to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data:</b>		<b>SI Metric Units</b>	
Pressure at point 1 =	300 kPa	Elevation at point 1 =	0 m
Pressure at point 2 =	0 kPa	Elevation at point 2 =	25 m
Energy loss: $h_L =$		5.58 m	
<b>Fluid Properties:</b>		May need to compute: $v = \eta/\rho$	
Specific weight =	9.81 kN/m <sup>3</sup>	Kinematic viscosity =	1.30E-06 m <sup>2</sup> /s
<b>Pipe data:</b>		<b>Results: Maximum values</b>	
Diameter: $D =$	0.0409 m	Volume flow rate: $Q =$	0.0035 m <sup>3</sup> /s
Wall roughness: $\varepsilon =$	4.60E-05 m	Velocity: $v =$	2.66 m/s
Length: $L =$	27.5 m		
Area: $A =$	0.00131 m <sup>2</sup>		
$D/\varepsilon =$	889.13		

<b>CLASS II SERIES SYSTEMS</b>		Volume flow rate: $Q = 0.003394 \text{ m}^3/\text{s} = 203.6 \text{ L/min}$	
<b>Method II-B:</b> Use results of Method IIA; Include minor losses; then pressure at Point 2 is computed		Given: Pressure $p_1 =$ 300 kPa Pressure $p_2 =$ 0.01 kPa <b>NOTE: Should be &gt; 0 kPa</b>	
<b>Additional Pipe Data:</b>		<b>Adjust estimate for <math>Q</math> until <math>p_2</math> is greater than desired pressure.</b>	
$L/D =$	672	Velocity at point 1 =	2.58 m/s  --> If velocity is in pipe.
Flow Velocity =	2.58 m/s	Velocity at point 2 =	2.58 m/s  --> Enter "B24"
Velocity head =	0.340 m	Vel. head at point 1 =	0.340 m
Reynolds No. =	8.13E+04	Vel. head at point 2 =	0.340 m
Friction factor: $f =$	0.0232		
<b>Energy losses in Pipe 1:</b>			
Pipe: $K_1 = f(L/D) =$	15.61	1	Energy loss $h_{L1} =$ 5.31 m Friction
1 std. elbows: $K_2 =$	0.63	1	Energy loss $h_{L2} =$ 0.21 m
Gate valve: $K_3 =$	0.17	1	Energy loss $h_{L3} =$ 0.06 m
Element 4: $K_4 =$	0.00	1	Energy loss $h_{L4} =$ 0.00 m
Element 5: $K_5 =$	0.00	1	Energy loss $h_{L5} =$ 0.00 m
Element 6: $K_6 =$	0.00	1	Energy loss $h_{L6} =$ 0.00 m
Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} =$ 0.00 m
Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} =$ 0.00 m
		Total energy loss $h_{Ltot} =$ 5.58 m	

11.34 **Class I** Pt. 1 at surface of tank A; Pt. 2 outside pipe in tank B.  $v_1 = 0$

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g} : \quad p_1 = p_2 + \gamma \left[ (z_2 - z_1) + \frac{v_2^2}{2g} + h_L \right] \quad \textcircled{1}$$

$$v_2 = \frac{Q}{A} = \frac{250 \text{ gal/min}}{0.02333 \text{ ft}^2} \cdot \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 23.87 \text{ ft/s} : \quad \frac{v_2^2}{2g} = \frac{(23.87)^2}{2(32.2)} = 8.844 \text{ ft}$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(23.87)(0.1723)(1.53)}{2.10 \times 10^{-5}} = 3.00 \times 10^5 :$$

$$\frac{D}{\varepsilon} = \frac{0.1723}{1.5 \times 10^{-4}} = 1149 \rightarrow f = 0.0205$$

$$h_L = 0.5 \frac{v_2^2}{2g} + f_T(160) \frac{v_2^2}{2g} + 2f_T(30) \frac{v_2^2}{2g} + f \left( \frac{110 \text{ ft}}{0.1723 \text{ ft}} \right) \frac{v_2^2}{2g} : f_T = 0.019$$

Entr.      Valve      2 Elbows      Friction

$$h_L = \frac{v_2^2}{2g} [4.68 + 638f] = 8.844 \text{ ft} [4.68 + 638(0.0205)] = 157.1 \text{ ft}$$

$$\textcircled{1} \quad p_1 = 40.0 \text{ psig} + \frac{49.01 \text{ lb}}{\text{ft}^3} [20 \text{ ft} + 8.844 \text{ ft} + 157.1 \text{ ft}] \frac{1 \text{ ft}^2}{144 \text{ in}^2} = \mathbf{103.3 \text{ psig}}$$

<b>APPLIED FLUID MECHANICS</b>	<b>II-A &amp; II-B US: CLASS II SERIES SYSTEMS</b>	
<b>Objective: Volume flow rate</b>	<b>Method II-A: No minor losses</b>	
Problem 11.35 Figure 11.28	Uses Equation 11-3 to find maximum allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data: US Customary Units</b>		
Pressure at point 1 = 125 psig	Elevation at point 1 = 18 ft	
Pressure at point 2 = 40 psig	Elevation at point 2 = 38 ft	
Energy loss: $h_L = 229.74$ ft		
<b>Fluid Properties:</b> Ethyl Alcohol -77F May need to compute: $\nu = \eta/\rho$		
Specific weight = 49.01 lb/ft <sup>3</sup>	Kinematic viscosity = 1.37E-05 ft <sup>2</sup> /s	
<b>Pipe data: 2-in Sch 40 steel pipe</b>		
Diameter: $D = 0.1723$ ft		
Wall roughness: $\epsilon = 1.50E-04$ ft		
Length: $L = 110$ ft		
Area: $A = 0.02332$ ft <sup>2</sup>	<b>Results: Maximum values</b>	
$D/\epsilon = 1148.67$	Volume flow rate: $Q = 0.7981$ ft <sup>3</sup> /s	Using Eq. 11-3
	Velocity: $v = 34.23$ ft/s	

<b>CLASS II SERIES SYSTEMS</b>			Volume flow rate: $Q = 65990$ ft <sup>3</sup> /s = 296.3 gal/min
<b>Method II-B: Use results of Method IIA;</b> Include minor losses; then pressure at Point 2 is computed			Given: Pressure $p_1 = 125$ psig <b>Pressure <math>p_2 = 40.1</math> psig</b> <b>NOTE: Should be &gt; 40 psig</b>
<b>Additional Pipe Data:</b>			<b>Adjust estimate for <math>Q</math> until <math>p_2</math> is equal or greater than desired.</b>
$L/D = 638$	Flow Velocity = 28.30 ft/s	Velocity head = 12.438 ft	Velocity at point 1 = 0.00 ft/s  --> If velocity is in pipe: Velocity at point 2 = 28.30 ft/s  --> Enter "=B24"
Reynolds No. = 3.56E+05	Friction factor: $f = 0.0200$		Vel. head at point 1 = 0.00 ft Vel. head at point 2 = 12.44 ft
<b>Energy losses in Pipe:</b>			
Pipe: $K_1 = f(L/D) = 12.79$	Qty. = 1	Energy loss $h_{L1} = 159.05$ ft	Friction
Std. Elbows: $K_2 = 0.57$	Qty. = 1	Energy loss $h_{L2} = 14.18$ ft	$f_T = 0.019$
1/2 op gate valve: $K_3 = 3.04$	Qty. = 1	Energy loss $h_{L3} = 37.81$ ft	$f_T = 0.019$
Entrance: $K_4 = 0.50$	Qty. = 1	Energy loss $h_{L4} = 6.22$ ft	
Element 5: $K_5 = 0.00$	Qty. = 1	Energy loss $h_{L5} = 0.00$ ft	
Element 6: $K_6 = 0.00$	Qty. = 1	Energy loss $h_{L6} = 0.00$ ft	
Element 7: $K_7 = 0.00$	Qty. = 1	Energy loss $h_{L7} = 0.00$ ft	
Element 8: $K_8 = 0.00$	Qty. = 1	Energy loss $h_{L8} = 0.00$ ft	
			Total energy loss $h_{Ltot} = 217.26$ ft

APPLIED FLUID MECHANICS		II-A & II-B US: CLASS II SERIES SYSTEMS	
<b>Objective: Volume flow rate</b>		<b>Method II-A: No minor losses</b>	
Problem 11.36 Figure 11.28		Uses Equation 11-3 to find maximum allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data: US Customary Units</b>			
Pressure at point 1 =	125 psig	Elevation at point 1 =	18 ft
Pressure at point 2 =	40 psig	Elevation at point 2 =	38 ft
Energy loss: $h_L = 229.74$ ft			
<b>Fluid Properties:</b> Ethyl Alcohol -77F May need to compute: $v = \eta/\rho$			
Specific weight = 49.01 lb/ft <sup>3</sup>		Kinematic viscosity = 1.37E-05 ft <sup>2</sup> /s	
<b>Pipe data: 2-in Sch 40 steel pipe</b>			
Diameter: $D = 0.1723$ ft			
Wall roughness: $\epsilon = 1.50E-04$ ft			
Length: $L = 110$ ft			
Area: $A = 0.02332$ ft <sup>2</sup>		<b>Results: Maximum values</b>	
$D/\epsilon = 1148.67$		Volume flow rate: $Q = 0.7981$ ft <sup>3</sup> /s Using Eq. 11-3	
		Velocity: $v = 34.23$ ft/s	

CLASS II SERIES SYSTEMS		Volume flow rate: $Q = 0.71960$ ft <sup>3</sup> /s = 323.1 gal/min	
<b>Method II-B: Use results of Method IIA;</b>		Given: Pressure $p_1 = 125$ Psig	
Include minor losses;		Pressure $p_2 = 40.00$ Psig	
then pressure at Point 2 is computed		<b>NOTE: Should be &gt; 40 Psig</b>	
<b>Additional Pipe Data:</b>		<b>Adjust estimate for Q until <math>p_2</math> is equal or greater than desired.</b>	
$L/D = 638$		Velocity at point 1 = 0.00 ft/s  --> If velocity is in pipe:	
Flow Velocity = 30.86 ft/s		Velocity at point 2 = 30.86 ft/s  --> Enter "=B24"	
Velocity head = 14.790 ft		Vel. head at point 1 = 0.00 ft	
Reynolds No. = 3.88E+05		Vel. head at point 2 = 14.79 Ft	
Friction factor: $f = 0.0200$			
<b>Energy losses in Pipe:</b>			
Pipe: $K_1 = f(L/D) = 12.74$	Qty. 1	Energy loss $h_{L1} = 188.44$ ft Friction	
Std. Elbows: $K_2 = 0.570$	2	Energy loss $h_{L2} = 16.86$ ft $f_T = 0.019$	
Open gate valve: $K_3 = 0.152$	1	Energy loss $h_{L3} = 2.25$ ft $f_T = 0.019$	
Entrance: $K_4 = 0.500$	1	Energy loss $h_{L4} = 7.40$ ft	
Element 5: $K_5 = 0.00$	1	Energy loss $h_{L5} = 0.00$ ft	
Element 6: $K_6 = 0.00$	1	Energy loss $h_{L6} = 0.00$ ft	
Element 7: $K_7 = 0.00$	1	Energy loss $h_{L7} = 0.00$ ft	
Element 8: $K_8 = 0.00$	1	Energy loss $h_{L8} = 0.00$ ft	
		Total energy loss $h_{Ltot} = 214.95$ ft	

<b>APPLIED FLUID MECHANICS</b>		<b>II-A &amp; II-B US: CLASS II SERIES SYSTEMS</b>	
<b>Objective: Volume flow rate</b>		<b>Method II-A: No minor losses</b>	
Problem 11.37		Uses Equation 11-3 to find maximum allowable volume flow rate	
Figure 11.28 - Modified		to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data: US Customary Units</b>			
Pressure at point 1 =	125 psig	Elevation at point 1 =	18 ft
Pressure at point 2 =	40 psig	Elevation at point 2 =	38 ft
Energy loss: $h_L = 229.74$ ft			
<b>Fluid Properties:</b> Ethyl Alcohol -77F May need to compute: $v = \eta/\rho$			
Specific weight = 49.01 lb/ft <sup>3</sup>		Kinematic viscosity = 1.37E-05 ft <sup>2</sup> /s	
<b>Pipe data: 2-in Sch 40 steel pipe</b>			
Diameter: $D = 0.1723$ ft		<b>Results: Maximum values</b>	
Wall roughness: $\epsilon = 1.50E-04$ ft			
Length: $L = 110$ ft			
Area: $A = 0.02332$ ft <sup>2</sup>			
$D/\epsilon = 1148.67$			
Volume flow rate: $Q = 0.7981$ ft <sup>3</sup> /s		Using Eq. 11-3	
Velocity: $v = 34.23$ ft/s			

<b>CLASS II SERIES SYSTEMS</b>		Volume flow rate: $Q = 0.72870$ ft <sup>3</sup> /s = 327.2 gal/min	
<b>Method II-B: Use results of Method IIA;</b>		Given: Pressure $p_1 = 125$ Psig	
Include minor losses;		Pressure $p_2 = 40.01$ Psig	
then pressure at Point 2 is computed		<b>NOTE: Should be &gt; 40 Psig</b>	
<b>Additional Pipe Data:</b>		<b>Adjust estimate for Q until <math>p_2</math> is equal or greater than desired.</b>	
$L/D = 638$		Velocity at point 1 = 0.00 ft/s  --> If velocity is in pipe:	
Flow Velocity = 31.25 ft/s		Velocity at point 2 = 31.25 ft/s  --> Enter "=B24"	
Velocity head = 15.167 ft		Vel. head at point 1 = 0.00 ft	
Reynolds No. = 3.93E+05		Vel. head at point 2 = 15.17 Ft	
Friction factor: $f = 0.0199$			
<b>Energy losses in Pipe:</b>			
	K	Qty.	
Pipe: $K_1 = f(L/D) = 12.73$	12.73	1	Energy loss $h_{L1} = 193.14$ ft Friction
Long R. Elbows: $K_2 = 0.380$	0.380	2	Energy loss $h_{L2} = 11.53$ ft $f_T = 0.019$
Open gate valve: $K_3 = 0.152$	0.152	1	Energy loss $h_{L3} = 2.31$ ft $f_T = 0.019$
Entrance: $K_4 = 0.500$	0.500	1	Energy loss $h_{L4} = 7.58$ ft
Element 5: $K_5 = 0.00$	0.00	1	Energy loss $h_{L5} = 0.00$ ft
Element 6: $K_6 = 0.00$	0.00	1	Energy loss $h_{L6} = 0.00$ ft
Element 7: $K_7 = 0.00$	0.00	1	Energy loss $h_{L7} = 0.00$ ft
Element 8: $K_8 = 0.00$	0.00	1	Energy loss $h_{L8} = 0.00$ ft
			Total energy loss $h_{Ltot} = 214.56$ ft

<b>APPLIED FLUID MECHANICS</b>	<b>II-A &amp; II-B SI: CLASS II SERIES SYSTEMS</b>
<b>Objective: Volume flow rate</b> Problem 11.38 Figure 11.29	<b>Method II-A: No minor losses</b> Uses Equation 11-3 to estimate the allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1
<b>System Data: SI Metric Units</b>	
Pressure at point 1 = 415 kPa	Elevation at point 1 = 0 m
Pressure at point 2 = 200 kPa	Elevation at point 2 = 0 m
Energy loss: $h_L = 21.92$ m	
<b>Fluid Properties:</b> Water at 15C May need to compute: $v = \eta/\rho$	
Specific weight = 9.81 kN/m <sup>3</sup>	Kinematic viscosity = 1.15E-06 m <sup>2</sup> /s
<b>Pipe data: 6-in Schedule 40 steel pipe</b> Diameter: $D = 0.1023$ m Wall roughness: $\epsilon = 4.60E-05$ m Length: $L = 100$ m Area: $A = 0.008219$ m <sup>2</sup> $D/\epsilon = 2224$	<b>Results: Maximum values</b> Volume flow rate: $Q = 0.0412$ m <sup>3</sup> /s Using Eq. 11-3 Velocity: $v = 5.02$ m/s

<b>CLASS II SERIES SYSTEMS</b>	Volume flow rate: $Q = 0.034690$ m <sup>3</sup> /s
<b>Method II-B: Use results of Method IIA;</b> Include minor losses; then pressure at Point 2 is computed	Given: Pressure $p_1 = 415$ kPa Pressure $p_2 = 200.07$ kPa <b>NOTE: Should be &gt; 200 kPa</b>
<b>Additional Pipe Data:</b> $L/D = 978$ Flow Velocity = 4.22 m/s Velocity head = 0.908 m Reynolds No. = 3.75E+05 Friction factor: $f = 0.0178$	<b>Adjust estimate for Q until <math>p_2</math> is greater than desired pressure.</b> Velocity at point 1 = 0.00 m/s  --> If velocity is in pipe: Velocity at point 2 = 4.22 m/s  --> Enter "=B24" Vel. head at point 1 = 0.000 m Vel. head at point 2 = 0.908 m
<b>Energy losses in Pipe:</b>	
Pipe: $K_1 = f(L/D) = 17.35$ Qty. 1	Energy loss $h_{L1} = 15.75$ m Friction
Globe valve: $K_2 = 5.78$ Qty. 1	Energy loss $h_{L2} = 5.25$ m $f_T = 0.017$
Entrance: $K_3 = 0.00$ Qty. 1	Energy loss $h_{L3} = 0.00$ m
Element 4: $K_4 = 0.00$ Qty. 1	Energy loss $h_{L4} = 0.00$ m
Element 5: $K_5 = 0.00$ Qty. 1	Energy loss $h_{L5} = 0.00$ m
Element 6: $K_6 = 0.00$ Qty. 1	Energy loss $h_{L6} = 0.00$ m
Element 7: $K_7 = 0.00$ Qty. 1	Energy loss $h_{L7} = 0.00$ m
Element 8: $K_8 = 0.00$ Qty. 1	Energy loss $h_{L8} = 0.00$ m
	Total energy loss $h_{Ltot} = 21.00$ m

APPLIED FLUID MECHANICS		II-A & II-B SI: CLASS II SERIES SYSTEMS	
<b>Objective: Volume flow rate</b>		<b>Method II-A: No minor losses</b>	
Problem 11.39		Uses Equation 11-3 to estimate the allowable volume flow rate	
Figure 11.29 – Butterfly valve		to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data: SI Metric Units</b>			
Pressure at point 1 =	415 kPa	Elevation at point 1 =	0 m
Pressure at point 2 =	200 kPa	Elevation at point 2 =	0 m
Energy loss: $h_L = 21.92$ m			
<b>Fluid Properties:</b> Water at 15C		May need to compute: $v = \eta/\rho$	
Specific weight =	9.81 kN/m <sup>3</sup>	Kinematic viscosity =	1.15E-06 m <sup>2</sup> /s
<b>Pipe data: 4-in Schedule 40 steel pipe</b>		<b>Results: Maximum values</b>	
Diameter: $D = 0.1023$ m			
Wall roughness: $\epsilon = 4.60E-05$ m			
Length: $L = 100$ m			
Area: $A = 0.008219$ m <sup>2</sup>			
$D/\epsilon = 2223.913$		Volume flow rate: $Q = 0.0412$ m <sup>3</sup> /s	Using Eq. 11-3
		Velocity: $v = 5.02$ m/s	

CLASS II SERIES SYSTEMS		Volume flow rate: $Q = 0.034690$ m <sup>3</sup> /s	
<b>Method II-B: Use results of Method IIA;</b>		Given: Pressure $p_1 = 415$ kPa	
Include minor losses;		Pressure $p_2 = 200.07$ kPa	
then pressure at Point 2 is computed		<b>NOTE: Should be &gt; 200 kPa</b>	
<b>Additional Pipe Data:</b>		<b>Adjust estimate for Q until <math>p_2</math> is greater than desired pressure.</b>	
$L/D =$	978	Velocity at point 1 =	0.00 m/s  --> If velocity is in pipe:
Flow Velocity =	4.22 m/s	Velocity at point 2 =	4.22 m/s  --> Enter "=B24"
Velocity head =	0.908 m	Vel. head at point 1 =	0.000 m
Reynolds No. =	3.75E+05	Vel. head at point 2 =	0.908 m
Friction factor: $f =$	0.0178		
<b>Energy losses in Pipe:</b>			
Pipe: $K_1 = f(L/D) =$	17.35	1	Energy loss $h_{L1} = 15.75$ m Friction
Globe valve: $K_2 =$	5.78	1	Energy loss $h_{L2} = 5.25$ m $f_T = 0.017$
Entrance: $K_3 =$	0.00	1	Energy loss $h_{L3} = 0.00$ m
Element 4: $K_4 =$	0.00	1	Energy loss $h_{L4} = 0.00$ m
Element 5: $K_5 =$	0.00	1	Energy loss $h_{L5} = 0.00$ m
Element 6: $K_6 =$	0.00	1	Energy loss $h_{L6} = 0.00$ m
Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} = 0.00$ m
Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} = 0.00$ m
			Total energy loss $h_{Ltot} = 21.00$ m

<b>APPLIED FLUID MECHANICS</b>		<b>II-A &amp; II-B SI: CLASS II SERIES SYSTEMS</b>	
<b>Objective: Volume flow rate</b> Problem 11.40 Figure 11.29 5-in pipe; Globe valve		<b>Method II-A: No minor losses</b> Uses Equation 11-3 to estimate the allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data:</b>		<b>SI Metric Units</b>	
Pressure at point 1 =	415 kPa	Elevation at point 1 =	0 m
Pressure at point 2 =	200 kPa	Elevation at point 2 =	0 m
Energy loss: $h_L =$		21.92 m	
<b>Fluid Properties:</b> Water at 15C		May need to compute: $v = \eta/\rho$	
Specific weight =	9.81 kN/m <sup>3</sup>	Kinematic viscosity =	1.15E-06 m <sup>2</sup> /s
<b>Pipe data: 5-in Sch 40 steel pipe</b> Diameter: $D =$ 0.1282 m Wall roughness: $\epsilon =$ 4.60E-05 m Length: $L =$ 100 m Area: $A =$ 0.012908 m <sup>2</sup> $D/\epsilon =$ 2786.957		<b>Results: Maximum values</b> Volume flow rate: $Q =$ 0.0746 m <sup>3</sup> /s Using Eq. 11-3 Velocity: $v =$ 5.78 m/s	

<b>CLASS II SERIES SYSTEMS</b>		Volume flow rate: $Q =$ 0.060570 m <sup>3</sup> /s	
<b>Method II-B: Use results of Method IIA;</b> Include minor losses; then pressure at Point 2 is computed		Given: Pressure $p_1 =$ 415 kPa Pressure $p_2 =$ 200.04 kPa <b>NOTE: Should be &gt; 200 kPa</b>	
<b>Additional Pipe Data:</b> $L/D =$ 780 Flow Velocity = 4.69 m/s Velocity head = 1.122 m Reynolds No. = 5.23E+05 Friction factor: $f =$ 0.0168		<b>Adjust estimate for Q until <math>p_2</math> is greater than desired pressure.</b> Velocity at point 1 = 0.00 m/s  --> If velocity is in pipe: Velocity at point 2 = 4.69 m/s  --> Enter "=B24" Vel. head at point 1 = 0.000 m Vel. head at point 2 = 1.122 m	
<b>Energy losses in Pipe:</b>			
Pipe: $K_1 = f(L/D) =$	13.09	1	Energy loss $h_{L1} =$ 14.69 m Friction
Globe valve: $K_2 =$	5.440	1	Energy loss $h_{L2} =$ 6.10 m $f_T = 0.016$
Entrance: $K_3 =$	0.00	1	Energy loss $h_{L3} =$ 0.00 m
Element 4: $K_4 =$	0.00	1	Energy loss $h_{L4} =$ 0.00 m
Element 5: $K_5 =$	0.00	1	Energy loss $h_{L5} =$ 0.00 m
Element 6: $K_6 =$	0.00	1	Energy loss $h_{L6} =$ 0.00 m
Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} =$ 0.00 m
Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} =$ 0.00 m
		Total energy loss $h_{Ltot} =$ 20.79 m	

APPLIED FLUID MECHANICS		II-A & II-B SI: CLASS II SERIES SYSTEMS	
<b>Objective: Volume flow rate</b>		<b>Method II-A: No minor losses</b>	
Problem 11.41		Uses Equation 11-3 to estimate the allowable volume flow rate	
Figure 11.29-5 in pipe Butterfly		to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data:</b>		<b>SI Metric Units</b>	
Pressure at point 1 =	415 kPa	Elevation at point 1 =	0 m
Pressure at point 2 =	200 kPa	Elevation at point 2 =	0 m
Energy loss: $h_L = 21.92$ m			
<b>Fluid Properties:</b>		Water at 15C	
Specific weight =		9.81 kN/m <sup>3</sup>	
		May need to compute: $v = \eta/\rho$	
		Kinematic viscosity = 1.15E-06 m <sup>2</sup> /s	
<b>Pipe data: 6-in Schedule 40 steel pipe</b>			
Diameter: $D = 0.1282$ m			
Wall roughness: $\epsilon = 4.60E-05$ m			
Length: $L = 100$ m			
Area: $A = 0.012908$ m <sup>2</sup>			
$D/\epsilon = 2786.957$			
		<b>Results: Maximum values</b>	
		Volume flow rate: $Q =$	0.0746 m <sup>3</sup> /s Using Eq. 11-3
		Velocity: $v =$	5.78 m/s

CLASS II SERIES SYSTEMS		Volume flow rate: $Q = 0.069810$ m <sup>3</sup> /s	
<b>Method II-B: Use results of Method IIA;</b>		Given: Pressure $p_1 = 415$ kPa	
Include minor losses;		Pressure $p_2 = 200.03$ kPa	
then pressure at Point 2 is computed		<b>NOTE: Should be &gt; 200 kPa</b>	
<b>Additional Pipe Data:</b>		<b>Adjust estimate for Q until <math>p_2</math> is greater than desired pressure.</b>	
$L/D = 780$		Velocity at point 1 = 0.00 m/s  --> If velocity is in pipe:	
Flow Velocity = 5.41 m/s		Velocity at point 2 = 5.41 m/s  --> Enter "=B24"	
Velocity head = 1.491 m		Vel. head at point 1 = 0.000 m	
Reynolds No. = 6.03E+05		Vel. head at point 2 = 1.491 m	
Friction factor: $f = 0.0166$			
<b>Energy losses in Pipe:</b>			
Pipe: $K_1 = f(L/D) =$	12.98	Qty.	1
Pipe: $K_1 = f(L/D) =$	12.98		1
Energy loss $h_{L1} =$	19.35 m		Friction
Butterfly valve: $K_2 =$	0.720		1
Energy loss $h_{L2} =$	1.07 m		$f_T = 0.016$
Entrance: $K_3 =$	0.00		1
Energy loss $h_{L3} =$	0.00 m		
Element 4: $K_4 =$	0.00		1
Energy loss $h_{L4} =$	0.00 m		
Element 5: $K_5 =$	0.00		1
Energy loss $h_{L5} =$	0.00 m		
Element 6: $K_6 =$	0.00		1
Energy loss $h_{L6} =$	0.00 m		
Element 7: $K_7 =$	0.00		1
Energy loss $h_{L7} =$	0.00 m		
Element 8: $K_8 =$	0.00		1
Energy loss $h_{L8} =$	0.00 m		
		Total energy loss $h_{Ltot} = 20.42$ m	

11.42 **Class I** Note: Pump delivers  $1.0 \text{ in}^3/\text{rev}$

$$Q = \frac{1.0 \text{ in}^3}{\text{rev}} \times \frac{2100 \text{ rev}}{\text{min}} \times \frac{\text{ft}^3}{1728 \text{ in}^3} \times \frac{\text{min}}{60 \text{ s}}$$

$$= 0.0203 \text{ ft}^3/\text{s}$$

$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} - h_L + h_A = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$$

$$z_2 - z_1 = h_A - h_L - \frac{v^2}{2g}$$

$$\text{Power} = P_A = h_A \gamma Q \text{ and } e = \frac{P_A}{P_I}$$

$$\text{Then } P_A = e P_I = (0.75)(0.20 \text{ hp}) \frac{550 \text{ ft-lb/s}}{\text{hp}} = 82.5 \text{ ft-lb/s}$$

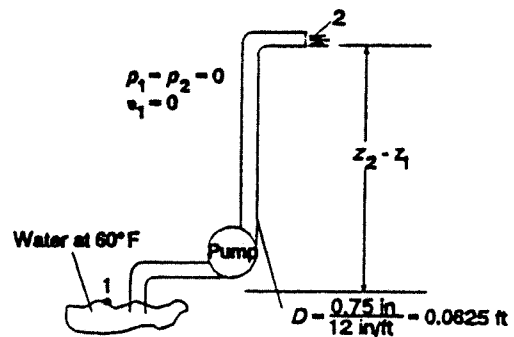
$$h_A = \frac{P_A}{\gamma Q} = \frac{82.5 \text{ ft-lb/s}}{\left(\frac{62.4 \text{ lb}}{\text{ft}^3}\right) \left(\frac{0.0203 \text{ ft}^3}{\text{s}}\right)} = 65.27 \text{ ft}$$

$$v = \frac{Q}{A} = \frac{0.0203 \text{ ft}^3/\text{s}}{\pi(0.0625 \text{ ft})^2/4} = 6.60 \text{ ft/s}; \quad \frac{v^2}{2g} = \frac{(6.60)^2}{2(32.2)} = 0.677 \text{ ft}$$

$$h_L = f \frac{L}{D} \frac{v^2}{2g} = (0.0225) \frac{100}{0.0625} (0.677 \text{ ft}) = 24.36 \text{ ft}$$

$$N_R = \frac{vD}{\nu} = \frac{(6.60)(0.0625)}{1.21 \times 10^{-5}} = 3.41 \times 10^4 \rightarrow f = 0.0225 \text{ (Smooth curve)}$$

$$z_2 - z_1 = 65.27 \text{ ft} - 24.36 \text{ ft} - 0.677 \text{ ft} = \mathbf{40.2 \text{ ft}}$$



APPLIED FLUID MECHANICS	III-A & III-B US: CLASS III SERIES SYSTEMS
<b>Objective: Minimum pipe diameter</b> Problem 11.43 and 11.44 Figure 11.30 Water at 60F	<b>Method III-A:</b> Uses Equation 11-8 to compute the minimum size of pipe of a given length that will flow a given volume flow rate of fluid with a limited pressure drop. (No minor losses)
<b>System Data: SI Metric Units</b> Pressure at point 1 = 80 psig Pressure at point 2 = 60 psig Elevation at point 1 = 0 ft Elevation at point 2 = 25 ft	<b>Fluid Properties: Water at 60F</b> Specific weight = 62.40 lb/ft <sup>3</sup> Kinematic Viscosity = 1.21E-05 ft <sup>2</sup> /s
Allowable Energy Loss: $h_L = 21.15$ ft Volume flow rate: $Q = 0.5$ ft <sup>3</sup> /s Length of pipe: $L = 600$ ft Pipe wall roughness: $\epsilon = 1.50E-04$ ft	<b>Intermediate Results in Eq. 11-8:</b> $L/gh_L = 0.880858$ Argument in bracket: 2.18E-08
	<b>Final Minimum Diameter:</b> Minimum diameter: $D = 0.3259$ ft

CLASS III SERIES SYSTEMS	Specified pipe diameter: $D = 0.3355$ ft-min std size 4-in Sch 40 steel pipe																																				
<b>Method III-B:</b> Use results of Method III-A; Specify actual diameter; Include minor losses; then pressure at Point 2 is computed.	<b>If velocity is in the pipe, enter "=B23" for value</b> Velocity at point 1 = 5.66 ft/s Velocity at point 2 = 5.66 ft/s Vel. head at point 1 = 0.497 ft Vel. head at point 2 = 0.497 ft																																				
<b>Additional Pipe Data:</b> Flow area: $A = 0.08840$ ft <sup>2</sup> Relative roughness: $D/\epsilon = 2237$ $L/D = 1788$ Flow Velocity = 5.66 ft/s Velocity head = 0.497 ft Reynolds No. = 1.57E+05 Friction factor: $f = 0.0191$	<b>Results:</b> Given pressure at point 1 = 80 psig Desired pressure at point 2 = 60 psig <b>Actual pressure at point 2 = 60.80 psig</b> (Compare actual with desired pressure at point 2)																																				
<b>Energy losses in Pipe:</b>																																					
<table border="0"> <thead> <tr> <th></th> <th>K</th> <th>Qty.</th> <th></th> </tr> </thead> <tbody> <tr> <td>Pipe Friction: <math>K_1 = f(L/D) =</math></td> <td>34.19</td> <td>1</td> <td>Energy loss <math>h_{L1} = 16.98</math> ft</td> </tr> <tr> <td>Gate valve: <math>K_2 =</math></td> <td>0.136</td> <td>1</td> <td>Energy loss <math>h_{L2} = 0.07</math> ft <math>f_T = 0.017</math></td> </tr> <tr> <td>Butterfly valve: <math>K_3 =</math></td> <td>0.765</td> <td>1</td> <td>Energy loss <math>h_{L3} = 0.38</math> ft <math>f_T = 0.017</math></td> </tr> <tr> <td>Std. 90 deg elbows: <math>K_4 =</math></td> <td>0.510</td> <td>3</td> <td>Energy loss <math>h_{L4} = 0.76</math> ft <math>f_T = 0.017</math></td> </tr> <tr> <td>Std. 45 deg elbows: <math>K_5 =</math></td> <td>0.272</td> <td>2</td> <td>Energy loss <math>h_{L5} = 0.27</math> ft <math>f_T = 0.017</math></td> </tr> <tr> <td>Swing type chk valve: <math>K_6 =</math></td> <td>1.700</td> <td>1</td> <td>Energy loss <math>h_{L6} = 0.84</math> ft <math>f_T = 0.017</math></td> </tr> <tr> <td>Element 7: <math>K_7 =</math></td> <td>0.00</td> <td>1</td> <td>Energy loss <math>h_{L7} = 0.00</math> ft</td> </tr> <tr> <td>Element 8: <math>K_8 =</math></td> <td>0.00</td> <td>1</td> <td>Energy loss <math>h_{L8} = 0.00</math> ft</td> </tr> </tbody> </table>		K	Qty.		Pipe Friction: $K_1 = f(L/D) =$	34.19	1	Energy loss $h_{L1} = 16.98$ ft	Gate valve: $K_2 =$	0.136	1	Energy loss $h_{L2} = 0.07$ ft $f_T = 0.017$	Butterfly valve: $K_3 =$	0.765	1	Energy loss $h_{L3} = 0.38$ ft $f_T = 0.017$	Std. 90 deg elbows: $K_4 =$	0.510	3	Energy loss $h_{L4} = 0.76$ ft $f_T = 0.017$	Std. 45 deg elbows: $K_5 =$	0.272	2	Energy loss $h_{L5} = 0.27$ ft $f_T = 0.017$	Swing type chk valve: $K_6 =$	1.700	1	Energy loss $h_{L6} = 0.84$ ft $f_T = 0.017$	Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} = 0.00$ ft	Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} = 0.00$ ft	
	K	Qty.																																			
Pipe Friction: $K_1 = f(L/D) =$	34.19	1	Energy loss $h_{L1} = 16.98$ ft																																		
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Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} = 0.00$ ft																																		
	Total energy loss $h_{Ltot} = 19.30$ ft																																				

**NOTES:**

Problem 11.43 answer is the result of the top portion for Method III-A solution.  
 $D_{min} = 0.3259$  ft. Standard 4-in Schedule 40 steel pipe is closest standard size;  $D = 0.3355$  ft.

Problem 11.44 answer is the result of the bottom portion for Method III-B solution.  
 Pipe size is set to 0.3355 ft for the 4-in Schedule 40 steel pipe. With minor losses considered, the pressure at point 2 is 60.80 psig, greater than the desired 60.0 psig. Therefore, it is satisfactory.

<b>APPLIED FLUID MECHANICS</b>	<b>III-A &amp; III-B US: CLASS III SERIES SYSTEMS</b>
<b>Objective: Minimum pipe diameter</b> Problem 11.45 Class III-A and III-B Water at 60F	<b>Method III-A:</b> Uses Equation 11-8 to compute the minimum size of pipe of a given length that will flow a given volume flow rate of fluid with a limited pressure drop. (No minor losses)
<b>System Data: SI Metric Units</b>	<b>Fluid Properties: Water at 60F</b>
Pressure at point 1 = 15 psig	Specific weight = 62.40 lb/ft <sup>3</sup>
Pressure at point 2 = 0 psig	Kinematic Viscosity = 1.21E-05 ft <sup>2</sup> /s
Elevation at point 1 = 150.4 ft	<b>Intermediate Results in Eq. 11-8:</b>
Elevation at point 2 = 172.8 ft	L/gh <sub>L</sub> = 0.140592
Allowable Energy Loss: h <sub>L</sub> = 12.22 ft	Argument in bracket: 6.06E-20
Volume flow rate: Q = 0.08909 ft <sup>3</sup> /s	<b>Final Minimum Diameter:</b>
Length of pipe: L = 55.3 ft	Minimum diameter: D = 0.1124 ft
Pipe wall roughness: ε = 1.00E-06 ft	

<b>CLASS III SERIES SYSTEMS</b>	Specified pipe diameter: D = 0.1342 ft-min std sz 1 1/2 inch Sch 40 steel pipe
<b>Method III-B:</b> Use results of Method III-A; Specify actual diameter; Include minor losses; then pressure at Point 2 is computed.	<b>If velocity is in the pipe, enter "=B23" for value</b>
<b>Additional Pipe Data:</b>	Velocity at point 1 = 6.30 ft/s
Flow area: A = 0.01414 ft <sup>2</sup>	Velocity at point 2 = 6.30 ft/s
Relative roughness: D/ε = 134200	Vel. head at point 1 = 0.616 ft
L/D = 412	Vel. head at point 2 = 0.616 ft
Flow Velocity = 6.30 ft/s	<b>Results:</b>
Velocity head = 0.616 ft	Given pressure at point 1 = 15 psig
Reynolds No. = 6.99E+04	Desired pressure at point 2 = 0 psig
Friction factor: f = 0.0193	<b>Actual pressure at point 2 = 2.13 psig</b>
	<b>(Compare actual with desired pressure at point 2)</b>
<b>Energy losses in Pipe:</b>	
Pipe Friction: K <sub>1</sub> = f(L/D) = 7.96 1	Energy loss h <sub>L1</sub> = 4.90 ft
Ball check valve: K <sub>2</sub> = 1.50 1	Energy loss h <sub>L2</sub> = 0.92 ft (f <sub>T</sub> = 0.01est)
8 std. elbows: K <sub>3</sub> = 0.30 8	Energy loss h <sub>L3</sub> = 1.48 ft (f <sub>T</sub> = 0.01est)
Element: K <sub>4</sub> = 0.00 1	Energy loss h <sub>L4</sub> = 0.00 ft
Element: K <sub>5</sub> = 0.00 1	Energy loss h <sub>L5</sub> = 0.27 ft
Element: K <sub>6</sub> = 0.00 1	Energy loss h <sub>L6</sub> = 0.84 ft
Element 7: K <sub>7</sub> = 0.00 1	Energy loss h <sub>L7</sub> = 0.00 ft
Element 8: K <sub>8</sub> = 0.00 1	Energy loss h <sub>L8</sub> = 0.00 ft
	Total energy loss h <sub>Ltot</sub> = 7.31 ft

APPLIED FLUID MECHANICS		I Power US: CLASS I SERIES SYSTEMS	
<b>Objective: Pump power</b>		Reference points for the energy equation:	
Problem 11.46		Pt. 1: Fluid surface in sump – See Figure 10.25 (Reference) Pt. 2: In free stream of fluid outside end of discharge pipe	
<b>System Data: U.S. Customary Units</b>			
Volume flow rate: $Q = 0.08909 \text{ ft}^3/\text{s}$		Elevation at point 1 = 150.4 ft	
Pressure at point 1 = 0 psig		Elevation at point 2 = 172.8 ft	
Pressure at point 2 = 0 psig		If Ref. pt. is in pipe: Set $v_1$ " = B20" OR Set $v_2$ " = E20"	
Velocity at point 1 = 0.00 ft/s -->		Vel head at point 1 = 0.00 ft	
Velocity at point 2 = 6.30 ft/s -->		Vel head at point 2 = 0.62 ft	
<b>Fluid Properties:</b> Water at 60F		May need to compute: $\nu = \eta/\rho$	
Specific weight = 62.40 lb/ft <sup>3</sup>		Kinematic viscosity = 1.21E-05ft <sup>2</sup> /s	
<b>Pipe 1: 1 1/2-in Sch 40 plastic pipe</b>		<b>Pipe 2: NONE</b>	
Diameter: $D = 0.1342 \text{ ft}$		Diameter: $D = 1 \text{ ft}$	
Wall roughness: $\varepsilon = 1.00\text{E-}06 \text{ ft}$		Wall roughness: $\varepsilon = 1.50\text{E-}04 \text{ ft}$ [See Table 8.2]	
Length: $L = 55.3 \text{ ft}$		Length: $L = 0 \text{ ft}$	
Area: $A = 0.01414 \text{ ft}^2$		Area: $A = 0.78540 \text{ ft}^2$ [ $A = \pi D^2/4$ ]	
$D/\varepsilon = 134200$		$D/\varepsilon = 6667$ Relative roughness	
$L/D = 412$		$L/D = 0$	
Flow Velocity = 6.30 ft/s		Flow Velocity = 0.11 ft/s [ $\nu = Q/A$ ]	
Velocity head = 0.616 ft		Velocity head = 0.000 ft [ $\nu^2/2g$ ]	
Reynolds No. = 6.99E+04		Reynolds No. = 9.37E+03 [ $N_R = \nu D/\nu$ ]	
Friction factor: $f = 0.0193$		Friction factor: $f = 0.0318$ Using Eq. 8-7	
<b>Energy losses-Pipe 1:</b>			
$K$	Qty.		
Pipe: $K_1 = 7.96$	1	Energy loss $h_{L1} =$	4.90 ft
Ball check value: $K_2 = 1.50$	1	Energy loss $h_{L2} =$	0.92 ft [ $f_T = 0.010$ assumed]
Std. elbows: $K_3 = 0.30$	8	Energy loss $h_{L3} =$	1.48 ft [ $f_T = 0.010$ assumed]
Element 4: $K_4 = 0.00$	1	Energy loss $h_{L4} =$	0.00 ft
Element 5: $K_5 = 0.00$	1	Energy loss $h_{L5} =$	0.00 ft
Element 6: $K_6 = 0.00$	1	Energy loss $h_{L6} =$	0.00 ft
Element 7: $K_7 = 0.00$	1	Energy loss $h_{L7} =$	0.00 ft
Element 8: $K_8 = 0.00$	1	Energy loss $h_{L8} =$	0.00 ft
<b>Energy losses-Pipe 2:</b>			
$K$	Qty.		
Pipe: $K_1 = 8.16$	1	Energy loss $h_{L1} =$	0.00 ft
Elbow: $K_2 = 0.54$	1	Energy loss $h_{L2} =$	0.00 ft
Nozzle: $K_3 = 32.60$	1	Energy loss $h_{L3} =$	0.00 ft
Element 4: $K_4 = 0.00$	1	Energy loss $h_{L4} =$	0.00 ft
Element 5: $K_5 = 0.00$	1	Energy loss $h_{L5} =$	0.00 ft
Element 6: $K_6 = 0.00$	1	Energy loss $h_{L6} =$	0.00 ft
Element 7: $K_7 = 0.00$	1	Energy loss $h_{L7} =$	0.00 ft
Element 8: $K_8 = 0.00$	1	Energy loss $h_{L8} =$	0.00 ft
<b>Results:</b>		Total energy loss $h_{L\text{tot}} = 7.31 \text{ ft}$	
		Total head on pump: $h_A = 30.3 \text{ ft}$	
		Power added to fluid: $P_A = 0.31 \text{ hp}$	
		Pump efficiency = 76.00 %	
		Power input to pump: $P_I = 0.403 \text{ hp}$	

APPLIED FLUID MECHANICS	III-A & III-B SI: CLASS III SERIES SYSTEMS
<b>Objective: Minimum pipe diameter</b> Problem 11.47 Figure 11.31 Propyl alcohol at 25C	<b>Method III-A:</b> Uses Equation 11-13 to compute the minimum size of pipe of a given length that will flow a given volume flow rate of fluid with a limited pressure drop. (No minor losses)
<b>System Data: SI Metric Units</b> Pressure at point 1 = 0 kPa Pressure at point 2 = 0 kPa Elevation at point 1 = 17.4 m Elevation at point 2 = 2.4 m Allowable Energy Loss: $h_L = 15.00$ m Volume flow rate: $Q = 0.0025$ m <sup>3</sup> /s Length of pipe: $L = 7$ m Pipe wall roughness: $\varepsilon = 1.50E-06$ m	<b>Fluid Properties:</b> Specific weight = 7.87 kN/m <sup>3</sup> Kinematic Viscosity = 2.39E-06 m <sup>2</sup> /s
	<b>Intermediate Results in Eq. 11-13:</b> $L/gh_L = 0.047571$ Argument in bracket: 1.15E-37
	<b>Final Minimum Diameter:</b> Minimum diameter: $D = 0.0220$ m

CLASS III SERIES SYSTEMS																												
<b>Method III-B:</b> Use results of Method III-A; Specify actual diameter; Include minor losses; then pressure at Point 2 is computed.	Specified pipe diameter: $D = 0.02753$ m Std. 1 1/4-inch steel tube; $t = 0.083$ (Appendix G)																											
<b>Additional Pipe Data:</b> Flow area: $A = 0.000595$ m <sup>2</sup> Relative roughness: $D/\varepsilon = 18353$ $L/D = 254$ Flow Velocity = 4.20 m/s Velocity head = 0.899 m Reynolds No. = 4.84E+04 Friction factor: $f = 0.0211$	<b>If velocity is in the pipe, enter "B23" for value</b> Velocity at point 1 = 0.00 m/s Velocity at point 2 = 0.00 m/s Vel. head at point 1 = 0.000 m Vel. head at point 2 = 0.000 m																											
	<b>Results:</b> Given pressure at point 1 = 0 kPa Desired pressure at point 2 = 0 kPa <b>Actual pressure at point 2 = 5.74 kPa</b> (Actual $p_2$ should be > desired pressure)																											
<b>Energy losses in Pipe:</b> <table border="1"> <thead> <tr> <th></th> <th>K</th> <th>Qty.</th> </tr> </thead> <tbody> <tr> <td>Pipe Friction: <math>K_1 = f(L/D) =</math></td> <td>5.37</td> <td>1</td> </tr> <tr> <td>Filter: <math>K_2 =</math></td> <td>8.50</td> <td>1</td> </tr> <tr> <td>Entrance: <math>K_3 =</math></td> <td>1.00</td> <td>1</td> </tr> <tr> <td>Exit: <math>K_4 =</math></td> <td>1.00</td> <td>1</td> </tr> <tr> <td>Element 5: <math>K_5 =</math></td> <td>0.00</td> <td>1</td> </tr> <tr> <td>Element 6: <math>K_6 =</math></td> <td>0.00</td> <td>1</td> </tr> <tr> <td>Element 7: <math>K_7 =</math></td> <td>0.00</td> <td>1</td> </tr> <tr> <td>Element 8: <math>K_8 =</math></td> <td>0.00</td> <td>1</td> </tr> </tbody> </table>		K	Qty.	Pipe Friction: $K_1 = f(L/D) =$	5.37	1	Filter: $K_2 =$	8.50	1	Entrance: $K_3 =$	1.00	1	Exit: $K_4 =$	1.00	1	Element 5: $K_5 =$	0.00	1	Element 6: $K_6 =$	0.00	1	Element 7: $K_7 =$	0.00	1	Element 8: $K_8 =$	0.00	1	Energy loss $h_{L1} = 4.83$ m Energy loss $h_{L2} = 7.64$ m Energy loss $h_{L3} = 0.90$ m Energy loss $h_{L4} = 0.90$ m Energy loss $h_{L5} = 0.00$ m Energy loss $h_{L6} = 0.00$ m Energy loss $h_{L7} = 0.00$ m Energy loss $h_{L8} = 0.00$ m
	K	Qty.																										
Pipe Friction: $K_1 = f(L/D) =$	5.37	1																										
Filter: $K_2 =$	8.50	1																										
Entrance: $K_3 =$	1.00	1																										
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Element 5: $K_5 =$	0.00	1																										
Element 6: $K_6 =$	0.00	1																										
Element 7: $K_7 =$	0.00	1																										
Element 8: $K_8 =$	0.00	1																										
	Total energy loss $h_{Ltot} = 14.27$ m																											

Actual flow rate will be greater than design value – See next page

Design Volume flow rate:  $Q = 0.0025$  m<sup>3</sup>/s  
 Design Volume flow rate:  $Q = 150$  L/min

<b>APPLIED FLUID MECHANICS</b>		<b>II-A &amp; II-B SI:</b>	<b>CLASS II SERIES SYSTEMS</b>		
<b>Objective: Volume flow rate</b>		<b>Method II-A: No minor losses</b>			
Problem 11.47A-Added part Figure 11.31 Propyl alcohol at 25C		Uses Equation 11-3 to estimate the allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1			
<b>System Data:</b>		<b>SI Metric Units</b>			
Pressure at point 1 =	0 kPa	Elevation at point 1 =	17.4 m		
Pressure at point 2 =	0 kPa	Elevation at point 2 =	2.4 m		
Energy loss: $h_L =$		15.00 m			
<b>Fluid Properties:</b>		May need to compute: $v = \eta/\rho$			
Specific weight =	7.87 kN/m <sup>3</sup>	Kinematic viscosity =	2.39E-06 m <sup>2</sup> /s		
<b>Pipe data: 1 1/4-in steel tube; t = 0.083</b>		<b>Results: Maximum values</b>			
Diameter: $D =$				0.02753 m	
Wall roughness: $\epsilon =$				1.50E-06 m	
Length: $L =$				7 m	
Area: $A =$		0.0005953 m <sup>2</sup>			
$D/\epsilon =$		18353.333			
		Volume flow rate: $Q =$	0.0047 m <sup>3</sup> /s Using Eq. 11-3		
		Velocity: $v =$	7.87 m/s		

<b>CLASS II SERIES SYSTEMS</b>		Volume flow rate: $Q = 0.002566 \text{ m}^3/\text{s}$	
<b>Method II-B: Use results of Method IIA;</b> Include minor losses; then pressure at Point 2 is computed		Given: Pressure $p_1 =$	0 kPa
		Pressure $p_2 =$	0.00 kPa
		<b>NOTE: Should be &gt;</b>	0 kPa
<b>Additional Pipe Data:</b>		<b>Adjust estimate for Q until <math>p_2</math> is greater than desired pressure.</b>	
$L/D =$	254	Velocity at point 1 =	0.00 m/s  --> If velocity is in pipe:
Flow Velocity =	4.31 m/s	Velocity at point 2 =	0.00 m/s  --> Enter "=B24"
Velocity head =	0.947 m	Vel. head at point 1 =	0.000 m
Reynolds No. =	4.96E+04	Vel. head at point 2 =	0.000 m
Friction factor: $f =$	0.0210		
<b>Energy losses in Pipe:</b>	K	Qty.	
Pipe: $K_1 = f(L/D) =$	5.34	1	Energy loss $h_{L1} =$ 5.06 m Friction
Filter: $K_2 =$	8.500	1	Energy loss $h_{L2} =$ 8.05 m
Entrance: $K_3 =$	0.68	1	Energy loss $h_{L3} =$ 0.95 m
Exit 4: $K_4 =$	1.00	1	Energy loss $h_{L4} =$ 0.95 m
Element 5: $K_5 =$	1.00	1	Energy loss $h_{L5} =$ 0.00 m
Element 6: $K_6 =$	0.00	1	Energy loss $h_{L6} =$ 0.00 m
Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} =$ 0.00 m
Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} =$ 0.00 m
		Total energy loss $h_{Ltot} =$	15.00 m

**Actual volume flow rate when  $p_2 =$  0.00 kPa**  
 Actual volume flow rate:  $Q = 0.002566 \text{ m}^3/\text{s}$   
 Actual volume flow rate:  $Q = 153.93 \text{ L/min}$

<b>APPLIED FLUID MECHANICS</b>		<b>II-A &amp; II-B SI: CLASS II SERIES SYSTEMS</b>	
<b>Objective: Volume flow rate</b>		<b>Method II-A: No minor losses</b>	
Problem 11.48 Figure 11.31 Propyl alcohol at 25°C		Uses Equation 11-3 to estimate the allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data:</b>		<b>SI Metric Units</b>	
Pressure at point 1 =	0 kPa	Elevation at point 1 =	12.8 m
Pressure at point 2 =	0 kPa	Elevation at point 2 =	2.4 m
Energy loss: $h_L =$		10.40 m	
<b>Fluid Properties:</b>		May need to compute: $v = \eta/\rho$	
Specific weight =	7.87 kN/m <sup>3</sup>	Kinematic viscosity =	2.39E-06 m <sup>2</sup> /s
<b>Pipe data: 1 1/4-in steel tube; t = 0.083</b>		<b>Results: Maximum values</b>	
Diameter: D =	0.02753 m	Volume flow rate: Q =	0.0038 m <sup>3</sup> /s
Wall roughness: $\epsilon =$	1.50E-06 m	Velocity: v =	6.42 m/s
Length: L =	7 m	Using Eq. 11-3	
Area: A =	0.0005953 m <sup>2</sup>		
D/ $\epsilon$ =	18353.333		

<b>CLASS II SERIES SYSTEMS</b>		Volume flow rate: Q = 0.002121 m <sup>3</sup> /s	
<b>Method II-B: Use results of Method IIA;</b> Include minor losses; then pressure at Point 2 is computed		Given: Pressure $p_1 =$	0 kPa
		Pressure $p_2 =$	0.00 kPa
		<b>NOTE: Should be &gt;</b>	<b>0 kPa</b>
<b>Additional Pipe Data:</b>		<b>Adjust estimate for Q until <math>p_2</math></b> <b>is greater than desired pressure.</b>	
L/D =	254	Velocity at point 1 =	0.00 m/s  --> If velocity is in pipe:
Flow Velocity =	3.56 m/s	Velocity at point 2 =	0.00 m/s  --> Enter "=B24"
Velocity head =	0.647 m	Vel. head at point 1 =	0.000 m
Reynolds No. =	4.10E+04	Vel. head at point 2 =	0.000 m
Friction factor: f =	0.0219		
<b>Energy losses in Pipe:</b>	K	Qty.	
Pipe: $K_1 = f(L/D) =$	5.57	1	Energy loss $h_{L1} =$ 3.61 m Friction
Filter: $K_2 =$	8.500	1	Energy loss $h_{L2} =$ 5.50 m
Entrance: $K_3 =$	1.00	1	Energy loss $h_{L3} =$ 0.65 m
Exit 4: $K_4 =$	1.00	1	Energy loss $h_{L4} =$ 0.65 m
Element 5: $K_5 =$	0.00	1	Energy loss $h_{L5} =$ 0.00 m
Element 6: $K_6 =$	0.00	1	Energy loss $h_{L6} =$ 0.00 m
Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} =$ 0.00 m
Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} =$ 0.00 m
		Total energy loss $h_{Ltot} =$ 10.40 m	

**Actual volume flow rate when  $p_2 = 0.00$  kPa**  
 Actual volume flow rate: Q = 0.002121 m<sup>3</sup>/s  
 Actual volume flow rate: Q = 127.26 L/min  
 Change from Problem 11.47A: -26.67 L/min  
 Percent change: -17.3 %

<b>APPLIED FLUID MECHANICS</b>		<b>II-A &amp; II-B SI: CLASS II SERIES SYSTEMS</b>	
<b>Objective: Volume flow rate</b>		<b>Method II-A: No minor losses</b>	
Problem 11.49 Figure 11.31 Propyl alcohol at 25C		Uses Equation 11-3 to estimate the allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data: SI Metric Units</b>			
Pressure at point 1 =	0 kPa	Elevation at point 1 =	17.4 m
Pressure at point 2 =	0 kPa	Elevation at point 2 =	2.4 m
Energy loss: $h_L = 10.87$ m			
<b>Fluid Properties:</b>		May need to compute: $v = \eta/\rho$	
Specific weight =	7.87 kN/m <sup>3</sup>	Kinematic viscosity =	2.39E-06 m <sup>2</sup> /s
<b>Pipe data: 1 1/4-in steel tube; <math>t = 0.083</math></b>		<b>Results: Maximum values</b>	
Diameter: $D = 0.02753$ m		Volume flow rate: $Q = 0.0039$ m <sup>3</sup> /s Using Eq. 11-3	
Wall roughness: $\epsilon = 1.50E-06$ m		Velocity: $v = 6.58$ m/s	
Length: $L = 7$ m			
Area: $A = 0.0005953$ m <sup>2</sup>			
$D/\epsilon = 18353.333$			

<b>CLASS II SERIES SYSTEMS</b>		Volume flow rate: $Q = 0.002170$ m <sup>3</sup> /s = 130.2 L/min	
<b>Method II-B: Use results of Method IIA; Include minor losses; then pressure at Point 2 is computed</b>		Given: Pressure $p_1 = -32.5$ kPa Pressure $p_2 = 0.00$ kPa <b>NOTE: Should be &gt; 0 kPa</b>	
<b>Additional Pipe Data:</b>		<b>Adjust estimate for Q until <math>p_2</math> is greater than desired pressure.</b>	
$L/D = 254$		Velocity at point 1 = 0.00 m/s  --> If velocity is in pipe:	
Flow Velocity = 3.65 m/s		Velocity at point 2 = 0.00 m/s  --> Enter "=B24"	
Velocity head = 0.678 m		Vel. head at point 1 = 0.000 m	
Reynolds No. = 4.20E+04		Vel. head at point 2 = 0.000 m	
Friction factor: $f = 0.0218$			
<b>Energy losses in Pipe:</b>			
	K	Qty.	
Pipe: $K_1 = f(L/D) =$	5.54	1	Energy loss $h_{L1} = 3.76$ m Friction
Filter: $K_2 =$	8.500	1	Energy loss $h_{L2} = 5.76$ m
Entrance: $K_3 =$	1.00	1	Energy loss $h_{L3} = 0.68$ m
Exit 4: $K_4 =$	1.00	1	Energy loss $h_{L4} = 0.68$ m
Element 5: $K_5 =$	0.00	1	Energy loss $h_{L5} = 0.00$ m
Element 6: $K_6 =$	0.00	1	Energy loss $h_{L6} = 0.00$ m
Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} = 0.00$ m
Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} = 0.00$ m
			Total energy loss $h_{Ltot} = 10.87$ m

**Actual volume flow rate when  $p_2 = 0.00$  kPa**  
 Actual volume flow rate:  $Q = 0.002170$  m<sup>3</sup>/s  
 Actual volume flow rate:  $Q = 130.218$  L/min  
 Change from Problem 11.47A:  $-23.712$  L/min  
 Percent change:  $-15.4$  %

APPLIED FLUID MECHANICS		II-A & II-B SI: CLASS II SERIES SYSTEMS	
<b>Objective: Volume flow rate</b>		<b>Method II-A: No minor losses</b>	
Problem 11.50 Figure 11.31 Propyl alcohol at 25C		Uses Equation 11-3 to estimate the allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data: SI Metric Units</b>			
Pressure at point 1 =	0 kPa	Elevation at point 1 =	17.4 m
Pressure at point 2 =	0 kPa	Elevation at point 2 =	2.4 m
Energy loss: $h_L = 15.00$ m			
<b>Fluid Properties:</b>		May need to compute: $v = \eta/\rho$	
Specific weight =	7.87 kN/m <sup>3</sup>	Kinematic viscosity =	2.39E-06 m <sup>2</sup> /s
<b>Pipe data: 1 1/4-in steel tube; t = 0.083</b>		<b>Results: Maximum values</b> Volume flow rate: Q = 0.0047 m <sup>3</sup> /s Using Eq. 11-3 Velocity: v = 7.87 m/s	
Diameter: D = 0.02753 m			
Wall roughness: $\epsilon = 1.50E-06$ m			
Length: L = 7 m			
Area: A = 0.0005953 m <sup>2</sup> D/ $\epsilon$ = 18353.333			

CLASS II SERIES SYSTEMS		Volume flow rate: Q = 0.002430 m <sup>3</sup> /s	
<b>Method II-B: Use results of Method IIA; Include minor losses; then pressure at Point 2 is computed</b>		Given: Pressure $p_1 = 0$ kPa <b>Pressure <math>p_2 = 0.00</math> kPa</b> <b>NOTE: Should be &gt; 0 kPa</b>	
<b>Additional Pipe Data:</b>		<b>Adjust estimate for Q until <math>p_2</math> is greater than desired pressure.</b>	
L/D =	254	Velocity at point 1 =	0.00 m/s  --> If velocity is in pipe:
Flow Velocity =	4.08 m/s	Velocity at point 2 =	0.00 m/s  --> Enter "=B24"
Velocity head =	0.849 m	Vel. head at point 1 =	0.000 m
Reynolds No. =	4.70E+04	Vel. head at point 2 =	0.000 m
Friction factor: f =	0.0213		
<b>Energy losses in Pipe:</b>			
Pipe: $K_1 = f(L/D) =$	5.41 1	Energy loss $h_{L1} =$	4.59 m Friction
Filter: $K_2 =$	8.500 1	Energy loss $h_{L2} =$	7.22 m
Entrance: $K_3 =$	1.00 1	Energy loss $h_{L3} =$	0.85 m
Exit 4: $K_4 =$	1.00 1	Energy loss $h_{L4} =$	0.85 m
1/2 op gate valve: $K_5 =$	1.76 1	Energy loss $h_{L5} =$	1.49 m $f_T = 0.011$
Element 6: $K_6 =$	0.00 1	Energy loss $h_{L6} =$	0.00 m
Element 7: $K_7 =$	0.00 1	Energy loss $h_{L7} =$	0.00 m
Element 8: $K_8 =$	0.00 1	Energy loss $h_{L8} =$	0.00 m
		Total energy loss $h_{Ltot} = 15.00$ m	

**Actual volume flow rate when  $p_2 = 0.00$  kPa**  
 Actual volume flow rate: Q = 0.002430 m<sup>3</sup>/s  
 Actual volume flow rate: Q = 145.77 L/min  
 Change from Problem 11.47A: -8.16 L/min  
 Percent change: -5.3 %

# CHAPTER TWELVE

## PARALLEL PIPE LINE SYSTEMS

### Systems with two branches

$$12.1 \quad \frac{p_A}{\gamma} + z_A + \frac{v_A^2}{2g} - h_L = \frac{p_B}{\gamma} + z_B + \frac{v_B^2}{2g} : z_A = z_B, v_A = v_B$$

$$\frac{p_A - p_B}{\gamma} = h_L = h_{L_a} = h_{L_b} = \frac{(700 - 550) \text{ kN/m}^2}{8.80 \text{ kN/m}^3} = 17.05 \text{ m}$$

$$\text{Upper branch a: } h_{L_a} = f_a \frac{60}{0.1023} \frac{v_a^2}{2g} + 2f_{aT}(30) \frac{v_a^2}{2g} = [587f_a + 1.02] \frac{v_a^2}{2g}$$

$$f_{aT} = 0.017$$

Friction      Elbows

$$\text{Lower branch b: } h_{L_b} = f_b \frac{60}{0.0779} \frac{v_b^2}{2g} + f_{bT}(240) \frac{v_b^2}{2g} + 2f_{bT}(30) \frac{v_b^2}{2g} = [770f_b + 5.4] \frac{v_b^2}{2g}$$

$$f_{bT} = 0.018$$

Friction      Valve      Elbows

**Assume  $f_a = f_b = 0.02$ :**

$$h_{L_a} = 17.05 \text{ m} = [587f_a + 1.02] \frac{v_a^2}{2g}; v_a = \sqrt{\frac{2(9.81)(17.05)}{[587f_a + 1.02]}} = 5.08 \text{ m/s}$$

$$N_{R_a} = \frac{v_a D_a}{\nu} = \frac{(5.08)(0.1023)}{4.8 \times 10^{-6}} = 1.08 \times 10^5 : \frac{D}{\epsilon} = \frac{0.1023}{4.6 \times 10^{-5}} = 2224 \rightarrow f_a = 0.02$$

**No change**

$$h_{L_b} = 17.05 \text{ m} = [770f_b + 5.4] \frac{v_b^2}{2g}; v_b = \sqrt{\frac{2(9.81)(17.05)}{[770f_b + 5.4]}} = 4.01 \text{ m/s}$$

$$N_{R_b} = \frac{v_b D_b}{\nu} = \frac{(4.01)(0.0779)}{4.8 \times 10^{-6}} = 6.51 \times 10^4 : \frac{D}{\epsilon} = \frac{0.0779}{4.6 \times 10^{-5}} = 1693 \rightarrow f_b = 0.022$$

**Recompute  $v_b$ :**

$$v_b = \sqrt{\frac{2(9.81)(17.05)}{[770f_b + 5.4]}} = 3.87 \text{ m/s}; N_{R_b} = 6.28 \times 10^4 \rightarrow f_b = 0.022 \text{ No change}$$

$$\text{Then } \left. \begin{aligned} Q_a &= A_a v_a = (8.213 \times 10^{-3} \text{ m}^2)(5.08 \text{ m/s}) = 4.17 \times 10^{-2} \text{ m}^3/\text{s} \\ Q_b &= A_b v_b = (4.768 \times 10^{-3} \text{ m}^2)(3.87 \text{ m/s}) = 1.85 \times 10^{-2} \text{ m}^3/\text{s} \end{aligned} \right\} Q_T = 6.02 \times 10^{-2} \text{ m}^3/\text{s}$$

12.2 Data from example Problem 12.1  $Q_1 = 0.223 \text{ ft}^3/\text{s} = A_a v_a + A_b v_b$ ;

$$f_{aT} = 0.019; f_{bT} = 0.022$$

$$h_{L_a} = f_{aT}(160) \frac{v_a^2}{2g} + f_{aT}(8) \frac{v_a^2}{2g} + 7.5 \frac{v_a^2}{2g} = (168f_{aT} + 7.5) \frac{v_a^2}{2g} = 10.69 \left( \frac{v_a^2}{2g} \right)$$

Valve 1 Valve 2 Heat exch.

$$h_{L_b} = 2f_{bT}(30) \frac{v_b^2}{2g} + f_{bT}(340) \frac{v_b^2}{2g} + f_b \frac{20}{0.115} \frac{v_b^2}{2g} = [174f_b + 400f_{bT}] \frac{v_b^2}{2g} [174f_b + 8.80] \frac{v_b^2}{2g}$$

2 Elbows Valve Friction

$$(D/\epsilon)_b = 768; \text{ Try } f_b = 0.023$$

$$h_{L_b} = [174(0.023) + 8.80] \frac{v_b^2}{2g} = 12.80 \frac{v_b^2}{2g}$$

$$\text{Let } h_{L_a} = h_{L_b} : 10.69 \frac{v_a^2}{2g} = 12.8 \frac{v_b^2}{2g} : v_a = 1.094 v_b$$

$$Q_1 = A_a v_a + A_b v_b = A_a(1.094 v_b) + A_b v_b = v_b [1.094 A_a + A_b]$$

$$v_b = \frac{Q_1}{1.094 A_a + A_b} = \frac{0.223}{1.094(0.0233) + 0.01039} = 6.21 \text{ ft/s}; v_a = 1.094 v_b = 6.79 \text{ ft/s}$$

$$N_{R_b} = \frac{v_b D_b}{\nu} = \frac{6.21(0.115)}{1.21 \times 10^{-5}} = 5.90 \times 10^4; f_b = 0.025$$

$$\text{Repeat: } h_{L_b} = 13.15 \frac{v_b^2}{2g}; v_a = 1.109 v_b; v_b = 6.15 \text{ ft/s}; v_a = 6.83 \text{ ft/s}$$

$$N_{R_b} = 5.85 \times 10^4; f_b = 0.025 \text{ No change}$$

$$Q_a = A_a v_a = (0.0233)(6.83) = 0.159 \text{ ft}^3/\text{s}; Q_b = A_b v_b = 0.01039(6.15) = \mathbf{0.0639 \text{ ft}^3/\text{s}}$$

$$h_L = h_{L_a} = 10.69 \frac{v_a^2}{2g} = \frac{(10.69)(6.83)^2}{2(32.2)} = 7.74 \text{ ft}$$

$$p_1 - p_2 = \gamma h_L \left( \frac{62.4 \text{ lb}}{\text{ft}^3} \right) (7.74 \text{ ft}) \left( \frac{1 \text{ ft}^2}{144 \text{ in}^2} \right) = \mathbf{3.36 \text{ psi}}$$

$$12.3 \quad h_{L_a} = f_a \frac{30}{0.0525} \frac{v_a^2}{2g} = (571 f_a) \frac{v_a^2}{2g} \text{ and } h_{L_a} = h_{L_b} : f_{bT} = 0.019$$

Friction

$$h_{L_b} = f_b \frac{60}{0.0525} \frac{v_b^2}{2g} + 3f_{bT}(30) \frac{v_b^2}{2g} + f_{bT}(150) \frac{v_b^2}{2g} = [1142f_b + 4.56] \frac{v_b^2}{2g}$$

① Assume  $f_a = f_b = 0.02$  and set  $h_{L_a} = h_{L_b}$

$$571(0.02) \frac{v_a^2}{2g} = [1142(0.02) + 4.56] \frac{v_b^2}{2g}$$

$$11.42 v_a^2 = 27.4 v_b^2$$

$$v_a = \sqrt{27.4/11.42} v_b = 1.55 v_b$$

$$Q_A = A_a v_a + A_b v_b = A_a(1.55 v_b) + A_b v_b = v_b [2.55 A_b]$$

$$v_b = \frac{Q_A}{2.55 A_b} = \frac{850 \text{ L/min } 1 \text{ m}^3/\text{s}}{2.55(2.168 \times 10^{-3} \text{ m}^2)(60000 \text{ L/min})} = 2.56 \text{ m/s}$$

$$v_a = 1.55 v_b = 3.97 \text{ m/s}$$

$$N_{R_a} = \frac{v_a D_a}{\nu} = \frac{(3.97)(0.0525)}{1.30 \times 10^{-6}} = 1.60 \times 10^5 : \frac{D}{\varepsilon} = \frac{0.0525}{4.6 \times 10^{-5}} = 1141 \rightarrow f_a = 0.021$$

$$N_{R_b} = \frac{v_b D_b}{\nu} = \frac{(2.56)(0.0525)}{1.30 \times 10^{-6}} = 1.03 \times 10^5 : \frac{D}{\varepsilon} = 1141 \rightarrow f_b = 0.0215$$

Recompute from ①:

$$571(0.021) \frac{v_a^2}{2g} = [1142(0.0215) + 4.56] \frac{v_b^2}{2g}$$

$$11.91 v_a^2 = 29.11 v_b^2$$

$$v_a = 1.56 v_b$$

$$v_b = \frac{Q_A}{2.56 A_b} = \frac{850/60000}{(2.56)(2.168 \times 10^{-3})} = 2.55 \text{ m/s} : v_a = 1.56 v_b = 3.98 \text{ m/s}$$

No change in  $f_a$  or  $f_b$

$$Q_a = A_a v_a = (2.168 \times 10^{-3} \text{ m}^2)(3.98 \text{ m/s})[60000 \text{ L/min}/1 \text{ m}^3/\text{s}] = 518 \text{ L/min}$$

$$Q_b = A_b v_b = (2.168 \times 10^{-3})(2.55)(60000) = \mathbf{332 \text{ L/min}}$$

$$p_a - p_b = \gamma h_L = \gamma h_{L_a} = \frac{9.81 \text{ kN}}{\text{m}^3} \left[ 571(0.021) \frac{(3.98)^2}{2(9.81)} \right] = \mathbf{95.0 \text{ kPa}}$$

12.4  $Q_{8\text{-in}} = 1350 \text{ gal/min} \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 3.01 \text{ ft}^3/\text{s}$ ; Benzene:  $\rho = 0.87(1.94) = 1.69 \text{ slugs/ft}^3$

$$f_{6T} = 0.015; f_{2T} = 0.019$$

$$\eta = 8 \times 10^{-6} \text{ lb-s/ft}^2$$

$$h_{L_6} = f_6 \frac{500}{0.5054} \frac{v_6^2}{2g} + f_{6T}(340) \frac{v_6^2}{2g} + f_{6T}(100) \frac{v_6^2}{2g} + 2f_{6T}(30) \frac{v_6^2}{2g} = [989f_6 + 7.5] \frac{v_6^2}{2g}$$

$$h_{L_2} = f_2 \frac{500}{0.1723} \frac{v_2^2}{2g} + 2f_{2T}(30) \frac{v_2^2}{2g} + [2902f_2 + 1.14] \frac{v_2^2}{2g}$$

$$\text{But } h_{L_6} = h_{L_2} : [989f_6 + 7.5] \frac{v_6^2}{2g} = [2902f_2 + 1.14] \frac{v_2^2}{2g}$$

$$v_6 = v_2 \sqrt{\frac{2902f_2 + 1.14}{989f_6 + 7.5}}$$

$$\left(\frac{D}{\varepsilon}\right)_6 = \frac{0.5054}{1.5 \times 10^{-4}} = 3369 : \text{Try } f_6 = 0.016 : \left(\frac{D}{\varepsilon}\right)_2 = \frac{0.1723}{1.5 \times 10^{-4}} = 1149;$$

$$\text{Try } f_2 = 0.02$$

$$v_6 = v_2 \sqrt{\frac{2902(0.02) + 1.14}{989(0.016) + 7.5}} = 1.59 v_2$$

$$Q_8 = Q_6 + Q_2 = A_6 v_6 + A_2 v_2 = A_6(1.59 v_2) + A_2 v_2 = v_2 [1.59 A_6 + A_2] = 3.01 \text{ ft}^3/\text{s}$$

$$v_2 = \frac{3.01 \text{ ft}^3/\text{s}}{1.59(0.2006) + (0.02333) \text{ ft}^2} = 8.79 \text{ ft/s}; v_6 = 1.59v_2 = 13.98 \text{ ft/s}$$

$$N_{R_6} = \frac{v_6 D_6 \rho}{\mu} = \frac{(13.98)(0.5054)(1.69)}{8 \times 10^{-6}} = 1.49 \times 10^6 \rightarrow f_6 = 0.016$$

$$N_{R_2} = \frac{v_2 D_2 \rho}{\mu} = \frac{(8.79)(0.1723)(1.69)}{8 \times 10^{-6}} = 3.20 \times 10^5 \rightarrow f_2 = 0.020$$

**No change** in  $f_6$  or  $f_2$

$$Q_6 = A_6 v_6 = (0.2006 \text{ ft}^2)(13.98 \text{ ft/s}) = \mathbf{2.80 \text{ ft}^3/\text{s}} \text{ [1258 gal/min]}$$

$$Q_2 = A_2 v_2 = (0.02333)(8.79) = \mathbf{0.205 \text{ ft}^3/\text{s}} \text{ [92 gal/min]}$$

12.5 For illustration, use water at  $10^\circ\text{C}$ ;  $Q_a = Q_b = 500 \text{ L/min} = 8.33 \times 10^{-3} \text{ m}^3/\text{s}$ .

$$v_a = \frac{Q}{A_a} = \frac{8.33 \times 10^{-3} \text{ m}^3/\text{s}}{\pi(0.100)^2 \text{ m}^2/4} = 1.061 \text{ m/s}; \left(\frac{D}{\varepsilon}\right)_a = \frac{0.100}{1.5 \times 10^{-6}} = 66667$$

$$N_{R_a} = \frac{v_a D_a}{\nu} = \frac{(1.061)(0.100)}{1.30 \times 10^{-6}} = 8.18 \times 10^4 \rightarrow f_a = 0.0186; f_{aT} = (0.010) \text{ (approx.)}$$

$$v_b = \frac{Q}{A_b} = \frac{8.33 \times 10^{-3} \text{ m}^3/\text{s}}{\pi(0.05)^2 \text{ m}^2/4} = 4.24 \text{ m/s}; \left(\frac{D}{\varepsilon}\right)_b = \frac{0.05}{1.5 \times 10^{-6}} = 33333$$

$$N_{R_b} = \frac{v_b D_b}{\nu} = \frac{(4.24)(0.05)}{1.30 \times 10^{-6}} = 1.63 \times 10^5 \rightarrow f_b = 0.0163; f_{bT} = 0.010 \text{ (approx.)}$$

$$h_{L_a} = f_a \frac{30 \text{ m}}{0.100 \text{ m}} \frac{v_a^2}{2g} + 2f_{aT}(30) \frac{v_a^2}{2g} + K \frac{v_a^2}{2g} = (300f_a + 0.60 + K) \frac{v_a^2}{2g}$$

Friction      2 Elbows      Valve

$$h_{L_b} = f_b \frac{30}{0.05} \frac{v_b^2}{2g} + 2f_{bT}(30) \frac{v_b^2}{2g} = (600f_b + 0.60) \frac{v_b^2}{2g}$$

Friction      2 Elbows

$$h_{L_a} = [300(0.0186) + 0.60 + K] \frac{v_a^2}{2g} = (6.18 + K) \frac{v_a^2}{2g}$$

$$h_{L_b} = (600(0.0163) + 0.60) \frac{v_b^2}{2g} = 10.38 \frac{v_b^2}{2g}$$

$$Q_a = Q_b = A_a v_a = A_b v_b; v_b = v_a \frac{A_a}{A_b} = v_a \left(\frac{D_a}{D_b}\right)^2 = 4v_a; v_b^2 = 16v_a^2$$

Equate  $h_{L_a} = h_{L_b}$

$$(6.18 + K) \frac{v_a^2}{2g} = 10.38 \frac{v_b^2}{2g} = 10.38 \frac{16v_a^2}{2g} = \frac{166v_a^2}{2g}; \text{ then } 6.18 + K = 166$$

$$K = 166 - 6.18 = \mathbf{160}$$

$$12.6 \quad \frac{p_A}{\gamma} + z_A + \frac{v_A^2}{2g} - h_L = \frac{p_B}{\gamma} + z_B + \frac{v_B^2}{2g}; \quad v_A = v_B, p_B = 0, z_A = z_B$$

$$h_L = \frac{p_A}{\gamma} = \frac{20 \text{ lb ft}^3}{\text{in}^2 (62.4 \text{ lb}) \text{ft}^2} \cdot 144 \text{ in}^2 = 46.2 \text{ ft} = h_1 = h_2$$

$$h_1 = 2(0.9) \frac{v_1^2}{2g} + 5 \frac{v_1^2}{2g} = 6.8 \frac{v_1^2}{2g}; \quad h_2 = 2(0.9) \frac{v_2^2}{2g} + 10 \frac{v_2^2}{2g} = 11.8 \frac{v_2^2}{2g}$$

a. Both valves open:

$$v_1 = \sqrt{\frac{2gh_L}{6.8}} = \sqrt{\frac{2(32.2)(46.2)}{6.8}} = 20.9 \text{ ft/s}; \quad A_1 = \frac{\pi(2 \text{ in})^2}{4} \frac{\text{ft}^2}{144 \text{ in}^2} = 0.0218 \text{ ft}^2$$

$$Q_1 = A_1 v_1 = (0.0218 \text{ ft}^2)(20.9 \text{ ft/s}) = \mathbf{0.456 \text{ ft}^3/\text{s}}$$

$$v_2 = \sqrt{\frac{2gh_L}{11.8}} = \sqrt{\frac{2(32.2)(46.2)}{11.8}} = 15.87 \text{ ft/s}; \quad A_2 = \frac{\pi(4 \text{ in})^2}{4} \frac{\text{ft}^2}{144 \text{ in}^2} = 0.0873 \text{ ft}^2$$

$$Q_2 = A_2 v_2 = (0.0873 \text{ ft}^2)(15.87 \text{ ft/s}) = \mathbf{1.385 \text{ ft}^3/\text{s}}$$

$$Q_{\text{total}} = Q_1 + Q_2 = 0.456 + 1.385 = \mathbf{1.841 \text{ ft}^3/\text{s}}$$

b. Valve in branch 2 open:

$$Q = Q_2 = \mathbf{1.385 \text{ ft}^3/\text{s}}$$

c. Valve in branch 1 open:

$$Q = Q_1 = \mathbf{0.456 \text{ ft}^3/\text{s}}$$

## 12.7 Hardy Cross technique - Data from Prob. 12.4

$$Q_8 = 3.01 \text{ ft}^3/\text{s}; \quad h_6 = [989f_6 + 7.5] \frac{v_6^2}{2g}$$

$$h_2 = [2902f_2 + 1.14] \frac{v_2^2}{2g}$$

Restate  $h_6$  and  $h_2$  in terms of  $Q_6$  and  $Q_2$

$$h_6 = [989f_6 + 7.5] \frac{Q_6^2}{2gA_6^2} = [989f_6 + 7.5] \frac{Q_6^2}{2(32.2)(0.2006)^2}$$

$$h_6 = [989f_6 + 7.5](0.3859) Q_6^2 = [381.6f_6 + 2.894] Q_6^2$$

$$h_2 = [2902f_2 + 1.14] \frac{Q_2^2}{2gA_2^2} = [2902f_2 + 1.14] \frac{Q_2^2}{2(32.2)(0.02333)^2}$$

$$h_2 = [2902f_2 + 1.14](28.53) Q_2^2 = [82791f_2 + 32.52] Q_2^2$$

$$N_{R_6} = \frac{v_6 D_6 \rho}{\eta} = \frac{Q_6 D_6 \rho}{A_6 \mu}$$

$$N_{R_6} = \frac{Q_6 (0.5054)(1.69)}{(0.2006)(8 \times 10^{-6})} = (5.322 \times 10^5) Q_6$$

$$N_{R_2} = \frac{v_2 D_2 \rho}{\eta} = \frac{Q_2 D_2 \rho}{A_2 \mu}$$

$$N_{R_2} = \frac{Q_2 (0.1723)(1.69)}{(0.2333)(8 \times 10^{-6})} = (1.560 \times 10^6) Q_2$$

$$\left(\frac{D}{\varepsilon}\right)_6 = 3369; \left(\frac{D}{\varepsilon}\right)_2 = 1149 \quad (\text{From Prob. 12.4})$$

---


$$\text{Try } Q_6 = 2.50 \text{ ft}^3/\text{s}; Q_2 = 3.01 - Q_6 = 0.51 \text{ ft}^3/\text{s}$$

$$N_{R_6} = (5.322 \times 10^5)(2.50) = 1.33 \times 10^6; f_6 = 0.0160$$

$$N_{R_2} = (1.560 \times 10^6)(0.51) = 7.96 \times 10^5; f_2 = 0.0195$$

Friction factors found from Moody's diagram.

$$h_6 = [381.6(0.016) + 2.894]Q_6^2 = 9.000Q_6^2 = k_6Q_6^2$$

$$h_2 = [82791(0.0195) + 32.52]Q_2^2 = 1647Q_2^2 = k_2Q_2^2$$

TRIAL	PIPE	$Q$	$N_R$	$f$	$k$	Ⓘ $h = kQ^2$	Ⓜ $2kQ$	$\Delta Q = \text{Ⓘ} / \text{Ⓜ}$
1	6	2.50	$1.33 \times 10^6$	0.0160	9.000	56.25	45.00	-0.21575
	2	-0.51	$7.96 \times 10^5$	0.0195	1647	<u>-428.4</u>	<u>1679.94</u>	
						-372.15	1724.94	
2	6	2.716	$1.45 \times 10^6$	0.016	9.000	66.39	48.89	-0.07635
	2	-0.294	$4.59 \times 10^5$	0.020	1688	<u>-145.9</u>	<u>992.5</u>	
						-79.51	1041.4	
3	6	2.792	$1.49 \times 10^6$	0.016	9.000	70.16	50.26	-0.01253
	2	-0.2177	$3.40 \times 10^5$	0.020	1688	<u>-80.00</u>	<u>734.95</u>	
						-9.84	785.21	
4	6	2.805	$1.49 \times 10^6$	0.016	9.000	70.81	50.49	-0.00037
	2	-0.205	$3.20 \times 10^5$	0.020	1688	<u>-71.05</u>	<u>692.65</u>	
						-0.24	642.16	(Negligible)

$$Q_6 = 2.805 \text{ ft}^3/\text{s}; Q_2 = 0.205 \text{ ft}^3/\text{s}$$

12.8 Data from Prob. 12.3 - Hardy Cross technique

$$A_a = A_b = 2.168 \times 10^{-3} \text{ m}^2; \nu = 1.30 \times 10^{-6} \text{ m}^2/\text{s}$$

$$Q_A = 850 \text{ L/min} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 1.417 \times 10^{-2} \text{ m}^3/\text{s}$$

---


$$h_a = 571f_a \frac{v_a^2}{2g} = \frac{571f_a Q_a^2}{2gA_a^2}$$

$$h_a = \frac{571f_a Q_a^2}{2(9.81)(2.168 \times 10^{-3})^2} = (6.192 \times 10^6)f_a Q_a^2$$

---


$$h_b = [1142f_b + 4.56] \frac{v_b^2}{2g} = \frac{[1142f_b + 4.56]Q_b^2}{2gA^2}$$

$$h_b = \frac{[1142f_b + 4.56]Q_b^2}{2(9.81)(2.168 \times 10^{-3})^2} = [1142f_b + 4.56](1.084 \times 10^4)Q_b^2$$


---

$$N_{R_a} = \frac{v_a D_a}{\nu} = \frac{Q_a D_a}{A_a \nu} = \frac{Q_a (0.0525)}{(2.168 \times 10^{-3})(1.30 \times 10^{-6})}$$

$$N_{R_a} = (1.863 \times 10^7) Q_a; \quad N_{R_b} = (1.863 \times 10^7) Q_b$$


---

### Trial 1

Try  $Q_a = 0.0100 \text{ m}^3/\text{s}$

$$Q_b = Q_A - Q_a = 0.01417 - 0.0100 = 0.00417 \text{ m}^3/\text{s}$$

Then  $N_{R_a} = (1.863 \times 10^7)(0.010) = 1.86 \times 10^5$

$$N_{R_b} = (1.863 \times 10^7)(0.00417) = 7.77 \times 10^4$$

$$(D/\varepsilon)_a = (D/\varepsilon)_b = (0.0525/4.6 \times 10^{-5}) = 1141$$

Compute  $f$  using Eq. (9.9):

$$f_a = \frac{0.25}{\left[ \log \left( \frac{1}{3.7(1141)} + \frac{5.74}{(1.86 \times 10^5)^{0.9}} \right) \right]^2} = 0.0208$$

$$f_b = \frac{0.25}{\left[ \log \left( \frac{1}{3.7(1141)} + \frac{5.74}{(7.77 \times 10^4)^{0.9}} \right) \right]^2} = 0.0225$$

NETWORK ANALYSIS USING HARDY CROSS TECHNIQUE  
 PROBLEM 12.8 (DATA FROM PROBLEM 12.3)  
 TWO BRANCHES

TRIAL	CIRCUIT	PIPE	Q	REY. NO.	FR. FACT.	k	h = kQ <sup>2</sup>	2kQ	DELTA Q	% CHANGE
1	1	a	1.000E-02	1.86E+05	0.0208	1.29E+05	12.873	2575	1.350E-03	13.50
		b	-4.170E-03	7.77E+04	0.0225	3.28E+05	-5.704	2736		-32.37
			SUM OF h AND 2kQ =			7.168	5310			
2	1	a	8.650E-03	1.61E+05	0.0210	1.30E+05	9.733	2250	-2.005E-06	-0.02
		b	-5.520E-03	1.03E+05	0.0218	3.20E+05	-9.745	3531		0.04
			SUM OF h AND 2kQ =			-0.012	5781			
3	1	a	8.652E-03	1.61E+05	0.0210	1.30E+05	9.737	2251	-8.069E-06	0.00
		b	-5.518E-03	1.03E+05	0.0218	3.20E+05	-9.738	3530		0.00
			SUM OF h AND 2kQ =			0.000	5781			

FINAL VALUES FOR FLOW RATES FROM TRIAL 3:

PIPE a: Q = 0.00865 cu. m/s      PIPE a: Q = 519 L/min  
 PIPE b: Q = 0.00552 cu. m/s      PIPE b: Q = 331 L/min

12.9 2 1/2-in Sch. 40 pipes:  $D = 0.2058$  ft;  $A = 0.03326$  ft<sup>2</sup>

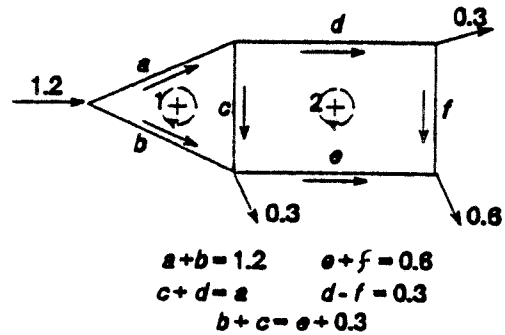
General form for  $k$

$$h = kQ^2 = \frac{fL v^2}{D 2g} = \frac{fLQ^2}{D2gA^2}$$

$$\therefore k = \frac{fL}{D2gA^2}$$

$$k_a = k_b = k_d = k_e = \frac{f(50)}{(0.2058)(64.4)(0.03326)^2} = 3410f$$

$$k_c = k_f = \frac{f(30)}{(0.2058)(64.4)(0.03326)^2} = 2046f$$



Values of  $f$  to be computed.

For all pipes  $D/\epsilon = 0.2058/1.5 \times 10^{-4} = 1372$

Use water at 60°F;  $\nu = 1.21 \times 10^{-5}$  ft<sup>2</sup>/s

$$N_R = \frac{\nu D}{\nu} = \frac{QD}{Av} = \frac{Q(0.2058)}{(0.03326)(1.21 \times 10^{-5})} = (5.114 \times 10^5)Q$$

Use Eq. (9.9) to compute  $f$ :

$$f = \frac{0.25}{\left[ \log \left( \frac{1}{3.7(1372)} + \frac{5.74}{(N_R)^{0.9}} \right) \right]^2}$$

$$f = \frac{0.25}{\left[ \log \left( \frac{1}{1.970 \times 10^{-4}} + \frac{5.74}{(N_R)^{0.9}} \right) \right]^2}$$

For Trial 1: Flow equations at nodes:

$$Q_a + Q_b = 1.2 \text{ ft}^3/\text{s}$$

Try  $Q_a = 0.50$ ;  $Q_b = 0.70$

$$Q_c + Q_d = Q_a = 0.50$$

Try  $Q_c = 0.10$ ;  $Q_d = 0.40$

$$Q_d - Q_f = 0.30 \text{ ft}^3/\text{s}$$

Try  $Q_d = 0.40$ ,  $Q_f = 0.10$

$$Q_e + Q_f = 0.60 \text{ ft}^3/\text{s}$$

Try  $Q_f = 0.10$ ;  $Q_e = 0.50$

$$Q_b + Q_c = Q_e + 0.30 \text{ ft}^3/\text{s}$$

$0.70 + 0.10 = 0.50 + 0.30$  (check)

Compute  $N_R$  values for Trial 1:

$$N_{R_a} = (5.114 \times 10^5)(Q_a) = (5.114 \times 10^5)(0.50) = 2.557 \times 10^5$$

Similarly,

$$N_{R_b} = 3.580 \times 10^5; \quad N_{R_c} = 5.114 \times 10^4; \quad N_{R_d} = 2.045 \times 10^5$$

$$N_{R_e} = 2.557 \times 10^5; \quad N_{R_f} = 5.114 \times 10^4$$

Compute  $f$  values for Eq. 9.9:

$$f_a = \frac{0.25}{\left[ \log \left( (1.970 \times 10^{-4}) + \frac{5.74}{(2.557 \times 10^5)^{0.9}} \right) \right]^2} = 0.0197$$

$$k_a = (3410)(0.0197) = 67.18$$

Similarly:

PIPE	$f$	$k$	Eq. for $k$
a	0.0197	67.18	$k_a = 3410f_a$
b	0.0194	66.00	$k_b = 3410f_b$
c	0.0233	47.65	$k_c = 2046f_c$
d	0.0200	68.26	$k_d = 3410f_d$
e	0.0197	67.18	$k_e = 3410f_e$
f	0.0233	47.65	$k_f = 2046f_f$

NETWORK ANALYSIS USING HARDY CROSS TECHNIQUE  
TWO CIRCUITS  
PROBLEM 12.9

TRIAL	CIRCUIT	PIPE	Q	REY. NO.	FR. FACT.	k	h = kQ <sup>2</sup>	2kQ	DELTA Q	% CHANGE	
1	1	a	0.5000	2.56E+05	0.0197	67.24	16.810	67.24		-17.79	
		b	-0.7000	3.58E+05	0.0194	65.99	-32.337	92.39		12.71	
		c	0.1000	5.11E+04	0.0233	47.64	0.476	9.53		-88.97	
					SUM OF h AND 2kQ =	-15.051	169.16	-8.897E-02			
2	2	c	-0.1000	5.11E+04	0.0233	47.64	-0.476	9.53		41.80	
		d	0.4000	2.05E+05	0.0200	68.25	10.921	54.60		-10.45	
		e	-0.5000	2.56E+05	0.0197	67.24	-16.810	67.24		8.36	
		f	0.1000	5.11E+04	0.0233	47.64	0.476	9.53		-41.80	
						SUM OF h AND 2kQ =	-5.889	140.90	-4.180E-02		
2	2	a	0.5890	3.01E+05	0.0195	66.59	23.101	78.44		-0.72	
		b	-0.6110	3.12E+05	0.0195	66.46	-24.813	81.22		0.69	
		c	0.1472	7.53E+04	0.0221	45.17	0.978	13.30		-2.88	
						SUM OF h AND 2kQ =	-0.734	172.96	-4.241E-03		
		c	-0.1472	7.53E+04	0.0221	45.17	-0.978	13.30		4.74	
		d	0.4418	2.26E+05	0.0189	67.78	13.230	59.89		-1.58	
3	3	e	-0.4582	2.34E+05	0.0188	67.82	-14.196	81.96		1.52	
		f	0.1418	7.25E+04	0.0222	45.38	0.913	12.87		-4.92	
						SUM OF h AND 2kQ =	-1.032	148.02	-6.972E-03		
		a	0.5932	3.03E+05	0.0195	66.57	23.425	78.98		-0.11	
		b	-0.6068	3.10E+05	0.0195	66.48	-24.479	80.68		0.10	
		c	0.1444	7.39E+04	0.0221	45.28	0.945	13.08		-0.44	
				SUM OF h AND 2kQ =	-0.109	172.74	-6.294E-04				
3	3	c	-0.1444	7.39E+04	0.0221	45.28	-0.945	13.08		0.43	
		d	0.4488	2.30E+05	0.0199	67.71	13.636	60.77		-0.14	
		e	-0.4512	2.31E+05	0.0198	67.69	-13.781	61.08		0.14	
		f	0.1488	7.61E+04	0.0220	45.11	0.998	13.42		-0.41	
						SUM OF h AND 2kQ =	-0.091	148.36	-6.150E-04		

continued

12.9 (continued)

TRIAL	CIRCUIT	PIPE	Q	REY. NO.	FR. FACT.	k	h = kQ <sup>2</sup>	2kQ	DELTA Q	% CHANGE	
4	1	a	0.5938	3.04E+05	0.0195	66.56	23.474	79.06		-0.01	
		b	-0.6062	3.10E+05	0.0195	66.49	-24.429	80.60		0.01	
		c	0.1445	7.39E+04	0.0221	45.28	0.945	13.08		-0.04	
	2			SUM OF h AND 2kQ =			-0.011	172.74		-6.261E-05	
		c	-0.1445	7.39E+04	0.0221	45.28	-0.945	13.08		0.05	
		d	0.4494	2.30E+05	0.0199	67.70	13.673	60.85		-0.02	
		e	-0.4506	2.30E+05	0.0199	67.69	-13.745	61.01		0.02	
		f	0.1494	7.64E+04	0.0220	45.09	1.006	13.47		-0.05	
				SUM OF h AND 2kQ =			-0.011	148.41		-7.565E-05	

SUMMARY OF RESULTS FROM TRIAL 4: (All flow rates in cubic feet /sec)

PIPE a: Q = 0.5938      PIPE d: Q = 0.4494  
 PIPE b: Q = 0.6062      PIPE e: Q = 0.4506  
 PIPE c: Q = 0.1445      PIPE f: Q = 0.1494

$$12.10 \quad Q_{in} = 6000 \text{ L/min} \times \frac{1.0 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = 0.100 \text{ m}^3/\text{s} = 1.0 \times 10^{-1} \text{ m}^3/\text{s}$$

$$Q_{out} = 1500 \text{ L/min} = 0.025 \text{ m}^3/\text{s} \text{ (Each)} = 2.5 \times 10^{-2} \text{ m}^3/\text{s}$$

$$h = f \frac{L}{D} \frac{v^2}{2g} = f \frac{L}{D} \frac{Q^2}{2gA^2} = kQ^2; k = \frac{fL}{D(2)gA^2}$$

$$\text{3-in Type K copper tubes: } D = 0.07384 \text{ m; } A = 4.282 \times 10^{-3} \text{ m}^2$$

$$k = \frac{fL}{D(2)gA^2} = \frac{fL}{(0.07384)(2)(9.81)(4.282 \times 10^{-3})^2} = (3.765 \times 10^4)fL$$

$$\text{For tubes c, f: } L = 6.0 \text{ m; } k = (2.259 \times 10^5)f$$

$$\text{For tubes d, b, e, h: } L = 15 \text{ m; } k = (5.647 \times 10^5)f$$

$$\text{For tubes a, g: } L = 18 \text{ m (Ignore minor losses); } k = (6.776 \times 10^5)f$$

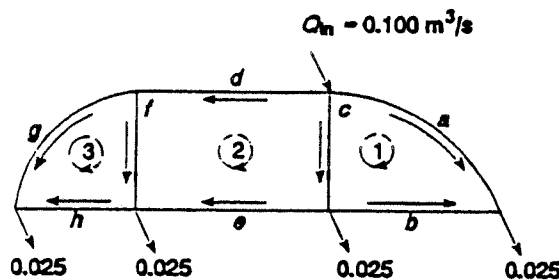
$$\text{For all tubes: Water at } 15^\circ\text{C; } \nu = 1.15 \times 10^{-6} \text{ m}^2/\text{s}$$

$$N_R = \frac{vD}{\nu} = \frac{QD}{Av} = \frac{Q(0.07384)}{(4.282 \times 10^{-3})(1.15 \times 10^{-6})} = (1.500 \times 10^7)Q$$

$$D/\varepsilon = (0.07384)/(1.5 \times 10^{-6} \text{ m}) = 49227$$

Use Eq. 9.9 to compute  $f$ :

$$f = \frac{0.25}{\left[ \log \left( \frac{1}{3.7D/\varepsilon} + \frac{5.74}{(N_R)^{0.9}} \right) \right]^2} = \frac{0.25}{\left[ \log \left( 5.49 \times 10^{-6} + \frac{5.74}{(N_R)^{0.9}} \right) \right]^2}$$



For continuity at joints:

$$\textcircled{\text{I}} Q_a + Q_c + Q_d = 0.100$$

$$\textcircled{\text{II}} Q_a + Q_b = 0.025$$

$$\textcircled{\text{III}} Q_c = 0.025 + Q_b + Q_e$$

$$\textcircled{\text{IV}} Q_f + Q_e = Q_h + 0.025$$

$$\textcircled{\text{V}} Q_d = Q_f + Q_g$$

$$\textcircled{\text{VI}} Q_g + Q_h = 0.025$$

For Trial 1:

$$Q_a = 2.0 \times 10^{-2} \text{ (Assume)}$$

$$Q_b = 0.5 \times 10^{-2} \textcircled{\text{II}}$$

$$Q_c = 4.0 \times 10^{-2} \text{ (Assume)}$$

$$Q_d = 4.0 \times 10^{-2} \textcircled{\text{I}}$$

$$Q_e = 1.0 \times 10^{-2} \textcircled{\text{III}}$$

$$Q_f = 2.0 \times 10^{-2} \text{ (Assume)}$$

$$Q_g = 2.0 \times 10^{-2} \textcircled{\text{V}}$$

$$Q_h = 0.5 \times 10^{-2} \textcircled{\text{VI}}$$

NETWORK ANALYSIS USING HARDY CROSS TECHNIQUE  
THREE CIRCUITS PROBLEM 12.10

TRIAL	CIRCUIT	PIPE	Q	REV. NO.	FR. FACT.	k	h = kQ <sup>2</sup>	2kQ	DELTA Q	% CHANGE	
1	1	a	0.0200	3.00E+05	0.0146	9900	3.960	396.00		-6.89	
		b	-0.0050	7.50E+04	0.0191	10781	-0.270	107.81		27.58	
		c	-0.0400	6.00E+05	0.0130	2944	-4.710	235.49		3.45	
					SUM OF h AND 2kQ =	-1.019	739.31		-1.379E-03		
	2		c	0.0400	6.00E+05	0.0130	2944	4.710	235.49		-16.28
			d	-0.0400	6.00E+05	0.0130	7359	-11.774	588.69		16.28
			e	0.0100	1.50E+05	0.0166	9373	0.937	187.45		-65.11
			f	-0.0200	3.00E+05	0.0146	3300	-1.320	132.02		32.56
						SUM OF h AND 2kQ =	-7.447	1143.65		-6.511E-03	
						SUM OF h AND 2kQ =	-2.370	635.83		-3.728E-03	
2	1	a	0.0214	3.21E+05	0.0144	9786	4.473	418.42		-9.60	
		b	-0.0036	5.43E+04	0.0205	11557	-0.152	83.70		56.65	
		c	-0.0451	6.77E+05	0.0128	2890	-5.886	260.85		4.55	
					SUM OF h AND 2kQ =	-1.565	762.97		-2.051E-03		
	2		c	0.0451	6.77E+05	0.0128	2890	5.886	260.85		-2.43
			d	-0.0335	5.02E+05	0.0134	7568	-8.487	506.85		3.27
			e	0.0165	2.48E+05	0.0151	8536	2.327	281.88		-6.64
			f	-0.0172	2.56E+05	0.0150	3389	-1.005	116.70		6.37
						SUM OF h AND 2kQ =	-1.276	1166.27		-1.096E-03	
						SUM OF h AND 2kQ =	-0.981	618.90		-1.586E-03	
	3		f	0.0172	2.58E+05	0.0150	3389	1.005	116.70		-9.21
			g	-0.0163	2.44E+05	0.0152	10269	-2.719	334.21		8.75
h			0.0087	1.31E+05	0.0170	9624	0.733	168.00		-18.17	
				SUM OF h AND 2kQ =	-0.981	618.90		-1.586E-03			

continued

12.10 (continued)

TRIAL	CIRCUIT	PIPE	Q	REY. NO.	FR. FACT.	k	h = kQ <sup>2</sup>	2kQ	DELTA Q	% CHANGE
3	1	a	0.0234	3.51E+05	0.0142	9633	5.288	451.42		-2.30
		b	-0.0016	2.35E+04	0.0248	14029	-0.035	44.04		34.26
		c	-0.0442	6.63E+05	0.0128	2899	-5.658	256.15	-5.378E-04	1.22
				SUM OF h AND 2kQ =	-0.404	751.61				
	2	c	0.0442	6.63E+05	0.0128	2899	5.658	256.15		-1.49
		d	-0.0324	4.86E+05	0.0135	7608	-7.983	492.90		2.03
		e	0.0176	2.64E+05	0.0149	8438	2.616	297.15		-3.73
		f	-0.0177	2.66E+05	0.0149	3372	-1.057	119.42		3.71
				SUM OF h AND 2kQ =	-0.766	1165.61		-6.575E-04		
	3	f	0.0177	2.66E+05	0.0149	3372	1.057	119.42		-1.90
		g	-0.0147	2.20E+05	0.0154	10462	-2.257	307.31		2.29
		h	0.0103	1.55E+05	0.0165	9317	0.991	192.18		-3.26
				SUM OF h AND 2kQ =	-0.208	618.91		-3.366E-04		
4	1	a	0.0240	3.60E+05	0.0142	9596	5.513	460.00		-1.06
		b	-0.0010	1.55E+04	0.0276	15588	-0.017	32.17		24.63
		c	-0.0443	6.64E+05	0.0128	2898	-5.686	256.74		0.57
				SUM OF h AND 2kQ =	-0.190	748.91		-2.542E-04		
	2	c	0.0443	6.64E+05	0.0128	2898	5.686	256.74		-0.44
		d	-0.0317	4.76E+05	0.0135	7633	-7.688	484.50		0.61
		e	0.0183	2.74E+05	0.0148	8383	2.787	306.24		-1.07
		f	-0.0174	2.61E+05	0.0150	3383	-1.023	117.64		1.12
				SUM OF h AND 2kQ =	-0.227	1165.11		-1.951E-04		
	3	f	0.0174	2.61E+05	0.0150	3383	1.023	117.64		-0.85
		g	-0.0143	2.15E+05	0.0155	10507	-2.164	301.54		1.02
		h	0.0107	1.60E+05	0.0164	9260	1.050	197.24		-1.38
				SUM OF h AND 2kQ =	-0.091	616.42		-1.470E-04		

continued

12.10 (continued)

TRIAL	CIRCUIT	PIPE	Q	REY. NO.	FR. FACT.	k	h = kQ <sup>2</sup>	2kQ	DELTA Q	% CHANGE
5	1	a	0.0242	3.63E+05	0.0141	9579	5.620	464.04		-0.35
		b	-0.0008	1.17E+04	0.0297	16793	-0.010	26.12		
		c	-0.0442	6.64E+05	0.0128	2899	-5.672	256.45		
				SUM OF h AND 2kQ =			-0.062	746.62	-8.361E-05	0.19
	2	c	0.0442	6.64E+05	0.0128	2899	5.672	256.45		-0.18
		d	-0.0315	4.73E+05	0.0135	7641	-7.601	482.00		
e		0.0185	2.77E+05	0.0148	8368	2.851	308.93			
					0.0150	-1.017	117.37	-8.142E-05	0.47	
			SUM OF h AND 2kQ =			-0.095	1164.75			
3	f	0.0173	2.60E+05	0.0150	3385	1.017	117.37		-0.27	
	g	-0.0142	2.13E+05	0.0155	10527	-2.123	299.02			
	h	0.0108	1.62E+05	0.0164	9236	1.077	199.44			
			SUM OF h AND 2kQ =			-0.029	615.83	-4.759E-05	-0.44	
6	1	a	2.431E-02	3.65E+05	0.0141	9573	5.656	465.37		-0.14
		b	-6.941E-04	1.04E+04	0.0307	17318	-0.008	24.04		
		c	-4.424E-02	6.64E+05	0.0128	2899	-5.672	256.44		
				SUM OF h AND 2kQ =			-0.025	745.86	-3.289E-05	0.07
	2	c	4.424E-02	6.64E+05	0.0128	2899	5.672	256.44		-0.06
		d	-3.146E-02	4.72E+05	0.0135	7644	-7.565	480.96		
e		1.854E-02	2.78E+05	0.0148	8361	2.874	310.05			
					0.0150	-1.014	117.18	-2.812E-05	0.16	
			SUM OF h AND 2kQ =			-0.033	1164.63			
3	f	1.730E-02	2.60E+05	0.0150	3386	1.014	117.18		-0.11	
	g	-1.416E-02	2.12E+05	0.0155	10533	-2.111	298.20			
	h	1.084E-02	1.63E+05	0.0163	9228	1.085	200.15			
			SUM OF h AND 2kQ =			-0.011	615.53	-1.855E-05	-0.17	

continued

12.10 (continued)

TRIAL 6 PRODUCED % CHANGE < 0.2% FOR ALL BUT PIPE b WHICH CARRIES VERY LOW FLOW.  
RESULTS SUMMARIZED BELOW WITH FLOW RATES CONVERTED TO L/min.

PIPE a: Q = 1458

PIPE c: Q = 2654

PIPE e: Q = 1112

PIPE g: Q = 849

PIPE b: Q = 42

PIPE d: Q = 1888

PIPE f: Q = 1038

PIPE h: Q = 651

12.11 Hardy Cross technique = Data preparation

$$h = kQ^2 = \frac{fL}{D} \frac{v^2}{2g} = \frac{fLQ^2}{D2gA^2}; k = \frac{fL}{D2gA^2}$$

$$\textcircled{1}, \textcircled{2}, \textcircled{6} k = \frac{f(1500)}{(1.25)(64.4)(1.227)^2} = 12.38f$$

16-in pipe

$$\textcircled{3} k = \frac{f(2000)}{(1.406)(64.4)(1.553)^2} = 9.158f$$

18-in pipe

$$\textcircled{4} k = \frac{f(2000)}{(0.9948)(64.4)(0.7771)^2} = 51.70f$$

12-in pipe

$$\textcircled{5} k = \frac{f(2000)}{(1.25)(64.4)(1.227)^2} = 16.50f$$

16-in pipe

$$\textcircled{7}, \textcircled{1} k = \frac{f(1500)}{(0.9948)(64.4)(0.7771)^2} = 38.77f$$

12-in pipe

$$\textcircled{8} k = \frac{f(4000)}{(1.094)(64.4)(0.9396)^2} = 64.31f$$

14-in pipe

$$\textcircled{9} k = \frac{f(4000)}{(0.9948)(64.4)(0.7771)^2} = 103.39f$$

12-in pipe

$$\textcircled{10} k = \frac{f(4000)}{(0.6651)(64.4)(0.3472)^2} = 774.69f$$

8-in pipe

$$\textcircled{12} k = \frac{f(1500)}{(0.6651)(64.4)(0.3472)^2} = 290.51f$$

8-in pipe

Reynolds numbers: Assume water at 60°F;  $v = 1.21 \times 10^{-5}$  ft<sup>2</sup>/s

16-in pipes:

**①, ②, ⑤, ⑥**

$$N_R = \frac{vD}{\nu} = \frac{QD}{Av} = \frac{Q(1.25)}{(1.227)(1.21 \times 10^{-5})} = (8.419 \times 10^4)Q$$

$$D/\varepsilon = 1.25/1.5 \times 10^{-4} = 8333$$

Similarly:

18-in pipe: **③**:  $N_R = (7.482 \times 10^4)Q$ ;  $D/\varepsilon = 9373$

14-in pipe: **⑧**:  $N_R = (9.623 \times 10^4)Q$ ;  $D/\varepsilon = 7293$

12-in pipes: **④**, **⑦**, **⑨**, **⑪**:  $N_R = (1.058 \times 10^5)Q$ ;  $D/\varepsilon = 6632$

8-in pipes: **⑩**, **⑫**,  $N_R = (1.583 \times 10^5)Q$ ;  $D/\varepsilon = 4434$

To satisfy continuity at joints:

$$\textcircled{3} + \textcircled{1} = 15.5 \text{ ft}^3/\text{s}$$

$$\textcircled{2} + \textcircled{4} = \textcircled{1}$$

$$\textcircled{2} = 1.5 \text{ ft}^3/\text{s} + \textcircled{5}$$

$$\textcircled{3} = \textcircled{6} + \textcircled{8}$$

$$\textcircled{4} + \textcircled{6} = \textcircled{7} + \textcircled{9} + 1 \text{ ft}^3/\text{s}$$

$$\textcircled{7} + \textcircled{5} = \textcircled{10} + 4 \text{ ft}^3/\text{s}$$

$$\textcircled{8} = \textcircled{11} + 3 \text{ ft}^3/\text{s}$$

$$\textcircled{9} + \textcircled{11} = \textcircled{12} + 3 \text{ ft}^3/\text{s}$$

$$\textcircled{10} + \textcircled{12} = 3 \text{ ft}^3/\text{s}$$

Initial estimates for flow rates for Trial 1: See spreadsheet.

NETWORK ANALYSIS USING THE HARDY CROSS TECHNIQUE						U.S. Cust Units	
Prob #	12.11		4 Circuits		12 Pipes		
Fluid: Water at 60 deg F			Fluid kinematic viscosity:			1.21E-05 ft <sup>2</sup> /s	
Pipe #	ID (ft)	Length (ft)	Roughness $\epsilon$ (ft)	D/ $\epsilon$	C1 ( $k=C1*f$ )	C2 ( $N_R=C2*Q$ )	
1	1.2500	1500	1.50E-04	8333	12.37	8.42E+04	
2	1.2500	1500	1.50E-04	8333	12.37	8.42E+04	
3	1.4060	2000	1.50E-04	9373	9.16	7.48E+04	
4	0.9948	2000	1.50E-04	6632	51.68	1.06E+05	
5	1.2500	2000	1.50E-04	8333	16.50	8.42E+04	
6	1.2500	1500	1.50E-04	8333	12.37	8.42E+04	
7	0.9948	1500	1.50E-04	6632	38.76	1.06E+05	
8	1.0940	4000	1.50E-04	7293	64.26	9.62E+04	
9	0.9948	4000	1.50E-04	6632	103.35	1.06E+05	
10	0.6651	4000	1.50E-04	4434	773.68	1.58E+05	
11	0.9948	1500	1.50E-04	6632	38.76	1.06E+05	
12	0.6651	1500	1.50E-04	4434	290.13	1.58E+05	

Trial 1									
Circuit	Pipe	Q (ft <sup>3</sup> /s)	N <sub>R</sub>	f	k	h = kQ <sup>2</sup>	2kQ	$\Delta Q$	% Chg
1	1	7.0000	5.89E+05	0.0144	0.1788	8.7592	2.5026		2.12
	4	2.5000	2.64E+05	0.0162	0.8347	5.2171	4.1737		5.94
	6	-4.0000	3.37E+05	0.0154	0.1904	-3.0472	1.5236		-3.71
	3	-8.5000	6.36E+05	0.0142	0.1299	-9.3847	2.2082		-1.75
Summations:						1.5445	10.4081	0.14839	
2	2	4.5000	3.79E+05	0.0152	0.1877	3.8008	1.6892		-3.60
	5	3.0000	2.53E+05	0.0160	0.2639	2.3748	1.5832		-5.39
	7	-2.0000	2.12E+05	0.0166	0.6451	-2.5806	2.5806		8.09
	4	-2.5000	2.64E+05	0.0162	0.8347	-5.2171	4.1737		6.47
Summations:						-1.6221	10.0267	-0.16178	
3	6	4.0000	3.37E+05	0.0154	0.1904	3.0472	1.5236		1.60
	9	3.5000	3.70E+05	0.0155	1.6029	19.6360	11.2206		1.83
	11	-1.5000	1.59E+05	0.0174	0.6730	-1.5142	2.0190		-4.28
	8	-4.5000	4.33E+05	0.0151	0.9710	-19.6619	8.7386		-1.43
Summations:						1.5071	23.5017	0.06413	
4	7	2.0000	2.12E+05	0.0166	0.6451	2.5806	2.5806		-18.43
	10	1.0000	1.58E+05	0.0179	13.8120	13.8120	27.6240		-36.87
	12	-2.0000	3.16E+05	0.0164	4.7639	-19.0556	19.0556		18.43
	9	-3.5000	3.70E+05	0.0155	1.6029	-19.6360	11.2206		10.53
Summations:						-22.2991	60.4808	-0.3687	

*continued*

12.11 (continued)

<b>Trial 2</b>									
Circuit	Pipe	Q (ft <sup>3</sup> /s)	N <sub>R</sub>	f	k	h = kQ <sup>2</sup>	2kQ	ΔQ	% Chg
1	1	6.8516	5.77E+05	0.0145	0.1791	8.4099	2.4549		-0.56
	4	2.1898	2.32E+05	0.0164	0.8495	4.0737	3.7205		-1.76
	6	-4.0843	3.44E+05	0.0154	0.1899	-3.1686	1.5516		0.94
	3	-8.6484	6.47E+05	0.0142	0.1297	-9.6983	2.2428		0.44
						Summations:	-0.3833	9.9698	-0.03845
2	2	4.6618	3.92E+05	0.0151	0.1869	4.0617	1.7426		-1.07
	5	3.1618	2.66E+05	0.0159	0.2619	2.6186	1.6564		-1.57
	7	-2.2069	2.33E+05	0.0164	0.6365	-3.0999	2.8092		2.25
	4	-2.1898	2.32E+05	0.0164	0.8495	-4.0737	3.7205		2.27
						Summations:	-0.4932	9.9287	-0.04967
3	6	4.0843	3.44E+05	0.0154	0.1899	3.1686	1.5516		-3.65
	9	3.0672	3.24E+05	0.0157	1.6276	15.3121	9.9845		-4.86
	11	-1.5641	1.65E+05	0.0173	0.6687	-1.6360	2.0919		9.53
	8	-4.5641	4.39E+05	0.0151	0.9695	-20.1952	8.8495		3.27
						Summations:	-3.3504	22.4775	-0.14906
4	7	2.2069	2.33E+05	0.0164	0.6365	3.0999	2.8092		-0.23
	10	1.3687	2.17E+05	0.0171	13.2579	24.8364	36.2921		-0.38
	12	-1.6313	2.58E+05	0.0168	4.8700	-12.9597	15.8888		0.32
	9	-3.0672	3.24E+05	0.0157	1.6276	-15.3121	9.9845		0.17
						Summations:	-0.3356	64.9746	-0.00517
<b>Trial 3</b>									
Circuit	Pipe	Q (ft <sup>3</sup> /s)	N <sub>R</sub>	f	k	h = kQ <sup>2</sup>	2kQ	ΔQ	% Chg
1	1	6.8901	5.80E+05	0.0145	0.1790	8.4997	2.4672		-0.60
	4	2.1786	2.30E+05	0.0165	0.8501	4.0348	3.7041		-1.90
	6	-4.1949	3.53E+05	0.0153	0.1893	-3.3314	1.5883		0.99
	3	-8.6099	6.44E+05	0.0142	0.1297	-9.6165	2.2338		0.48
						Summations:	-0.4134	9.9934	-0.04136
2	2	4.7115	3.97E+05	0.0151	0.1867	4.1435	1.7589		-0.39
	5	3.2115	2.70E+05	0.0158	0.2614	2.6958	1.6788		-0.57
	7	-2.1624	2.29E+05	0.0165	0.6382	-2.9843	2.7602		0.84
	4	-2.1786	2.30E+05	0.0165	0.8501	-4.0348	3.7041		0.83
						Summations:	-0.1799	9.9020	-0.01817
3	6	4.1949	3.53E+05	0.0153	0.1893	3.3314	1.5883		-0.32
	9	3.2111	3.40E+05	0.0157	1.6189	16.6920	10.3965		-0.42
	11	-1.4151	1.50E+05	0.0175	0.6791	-1.3599	1.9220		0.95
	8	-4.4151	4.25E+05	0.0151	0.9730	-18.9662	8.5916		0.30
						Summations:	-0.3027	22.4984	-0.01345
4	7	2.1624	2.29E+05	0.0165	0.6382	2.9843	2.7602		-1.12
	10	1.3739	2.17E+05	0.0171	13.2518	25.0127	36.4123		-1.76
	12	-1.6261	2.57E+05	0.0168	4.8717	-12.8824	15.8442		1.48
	9	-3.2111	3.40E+05	0.0157	1.6189	-16.6920	10.3965		0.75
						Summations:	-1.5774	65.4132	-0.02411

continued

12.11 (continued)

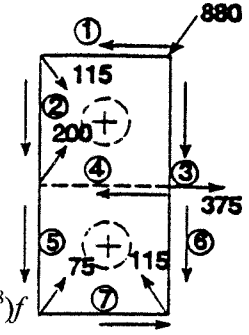
<b>Trial 4</b>									
Circuit	Pipe	Q (ft <sup>3</sup> /s)	N <sub>R</sub>	f	k	h = kQ <sup>2</sup>	2kQ	ΔQ	% Chg
1	1	6.9314	5.83E+05	0.0145	0.1789	8.5969	2.4806		-0.15
	4	2.2018	2.33E+05	0.0164	0.8489	4.1153	3.7381		-0.48
	6	-4.1670	3.51E+05	0.0153	0.1895	-3.2899	1.5791		0.26
	3	-8.5686	6.41E+05	0.0142	0.1298	-9.5290	2.2242		0.12
						Summations:	-0.1067	10.0219	-0.01065
2	2	4.7296	3.98E+05	0.0151	0.1866	4.1736	1.7649		-0.46
	5	3.2296	2.72E+05	0.0158	0.2612	2.7242	1.6870		-0.68
	7	-2.1684	2.29E+05	0.0165	0.6380	-2.9996	2.7667		1.01
	4	-2.2018	2.33E+05	0.0164	0.8489	-4.1153	3.7381		0.99
						Summations:	-0.2171	9.9568	-0.02180
3	6	4.1670	3.51E+05	0.0153	0.1895	3.2899	1.5791		-0.34
	9	3.2004	3.39E+05	0.0157	1.6195	16.5878	10.3661		-0.44
	11	-1.4016	1.48E+05	0.0175	0.6801	-1.3361	1.9065		1.00
	8	-4.4016	4.23E+05	0.0151	0.9733	-18.8571	8.5683		0.32
						Summations:	-0.3155	22.4199	-0.01407
4	7	2.1684	2.29E+05	0.0165	0.6380	2.9996	2.7667		-0.19
	10	1.3980	2.21E+05	0.0171	13.2238	25.8437	36.9730		-0.29
	12	-1.6020	2.53E+05	0.0168	4.8800	-12.5245	15.6358		0.26
	9	-3.2004	3.39E+05	0.0157	1.6195	-16.5878	10.3661		0.13
						Summations:	-0.2689	65.7416	-0.00409
<b>Trial 5</b>									
Circuit	Pipe	Q (ft <sup>3</sup> /s)	N <sub>R</sub>	f	k	h = kQ <sup>2</sup>	2kQ	ΔQ	% Chg
1	1	6.9421	5.84E+05	0.0145	0.1789	8.6220	2.4840		-0.15
	4	2.1906	2.32E+05	0.0164	0.8495	4.0765	3.7217		-0.47
	6	-4.1704	3.51E+05	0.0153	0.1895	-3.2950	1.5802		0.25
	3	-8.5579	6.40E+05	0.0142	0.1298	-9.5065	2.2217		0.12
						Summations:	-0.1030	10.0076	-0.01029
2	2	4.7514	4.00E+05	0.0151	0.1865	4.2099	1.7721		-0.13
	5	3.2514	2.74E+05	0.0158	0.2609	2.7586	1.6969		-0.19
	7	-2.1506	2.27E+05	0.0165	0.6387	-2.9541	2.7472		0.29
	4	-2.1906	2.32E+05	0.0164	0.8495	-4.0765	3.7217		0.29
						Summations:	-0.0621	9.9379	-0.00625
3	6	4.1704	3.51E+05	0.0153	0.1895	3.2950	1.5802		-0.08
	9	3.2104	3.40E+05	0.0157	1.6189	16.6854	10.3946		-0.10
	11	-1.3875	1.47E+05	0.0176	0.6812	-1.3115	1.8904		0.24
	8	-4.3875	4.22E+05	0.0152	0.9737	-18.7434	8.5439		0.08
						Summations:	-0.0745	22.4091	-0.00332
4	7	2.1506	2.27E+05	0.0165	0.6387	2.9541	2.7472		-0.15
	10	1.4021	2.22E+05	0.0171	13.2191	25.9860	37.0681		-0.23
	12	-1.5979	2.53E+05	0.0168	4.8814	-12.4642	15.6004		0.20
	9	-3.2104	3.40E+05	0.0157	1.6189	-16.6854	10.3946		0.10
						Summations:	-0.2095	65.8103	-0.00318

$$12.12 \quad h = kQ^2 = f \frac{L v^2}{D 2g} = \frac{fLQ^2}{D(2g)A^2}; \quad k = \frac{fL}{D(2g)A^2}$$

$$\textcircled{1} \textcircled{3} \quad k = \frac{f(7.5)}{(0.0475)(2)(9.81)(1.772 \times 10^{-3})^2} = (2.56 \times 10^6)f$$

$$\textcircled{2} \quad k = \frac{f(7.5)}{(0.0348)(2)(9.81)(9.510 \times 10^{-4})^2} = (1.21 \times 10^7)f$$

$$\textcircled{4} \textcircled{5} \textcircled{6} \textcircled{7} \quad k = \frac{f(7.5)}{(0.0221)(2)(9.81)(3.835 \times 10^{-4})^2} = (1.18 \times 10^8)f$$



Fluid is a coolant:  $sg = 0.92$ ,  $\eta = 2.00 \times 10^{-3} \text{ Pa}\cdot\text{s}$   
 Reynolds numbers and relative roughness

$$\text{Pipes 1, 3: } N_R = \frac{\nu D \rho}{\eta} = \frac{Q D \rho}{A \eta} = \frac{Q(0.0475)(920)}{(1.772 \times 10^{-3})(2.00 \times 10^{-3})}$$

$$N_R = (1.233 \times 10^7)Q$$

$$D/\varepsilon = 0.0475/1.5 \times 10^{-6} = 31667$$

$$\text{Pipe 2: } N_R = \frac{Q D \rho}{A \eta} = \frac{Q(0.0348)(920)}{(9.510 \times 10^{-4})(2.00 \times 10^{-3})} = (1.683 \times 10^7)Q$$

$$D/\varepsilon = 0.0348/1.5 \times 10^{-6} = 23200$$

$$\text{Pipes 4, 5, 6, 7: } N_R = \frac{Q D \rho}{A \eta} = \frac{Q(0.0221)(920)}{(3.835 \times 10^{-4})(2.00 \times 10^{-3})} = (2.651 \times 10^7)Q$$

$$D/\varepsilon = 0.0221/1.5 \times 10^{-6} = 14733$$

Compute  $f$  using Eq. 9.9.

**For continuity at the joints:**

$\textcircled{\text{I}} \quad Q_1 + Q_3 = 880 \text{ L/min} = 1.467 \times 10^{-2} \text{ m}^3/\text{s}$ $\textcircled{\text{II}} \quad Q_1 = Q_2 + 115 \text{ L/min}$ $\quad = Q_2 + 1.917 \times 10^{-3} \text{ m}^3/\text{s}$ $\textcircled{\text{III}} \quad Q_3 = Q_4 + Q_6 + 375 \text{ L/min}$ $\quad = Q_4 + Q_6 + 6.250 \times 10^{-3}$		$\textcircled{\text{IV}} \quad Q_2 + Q_4 = Q_5 + 200 \text{ L/min}$ $\quad = Q_5 + 3.333 \times 10^{-3} \text{ m}^3/\text{s}$ $\textcircled{\text{V}} \quad Q_6 + Q_7 = 115 \text{ L/min}$ $\quad = 1.917 \times 10^{-3} \text{ m}^3/\text{s}$ $\textcircled{\text{VI}} \quad Q_5 = Q_7 + 75 \text{ L/min} = Q_7 + 1.250 \times 10^{-3} \text{ m}^3/\text{s}$
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**Trial 1: Assumptions**

$$Q_1 = 350 \text{ L/min} = 5.833 \times 10^{-3} \text{ m}^3/\text{s} \leftarrow \text{Initial assumption}$$

$$Q_2 = Q_1 - 115 \text{ L/min} = 235 \text{ L/min} = 3.917 \times 10^{-3} \text{ m}^3/\text{s} \downarrow \text{Continuity cond. } \textcircled{\text{II}}$$

$$Q_3 = 880 \text{ L/min} - Q_1 = 530 \text{ L/min} = 8.833 \times 10^{-3} \text{ m}^3/\text{s} \downarrow \text{Cont. cond. } \textcircled{\text{I}}$$

$$Q_4 = 60 \text{ L/min} = 1.000 < 10^{-3} \text{ m}^3/\text{s} \leftarrow \text{Initial assumption}$$

$$Q_5 = Q_2 + Q_4 - 200 \text{ L/min} = 95 \text{ L/min} = 1.583 \times 10^{-3} \text{ m}^3/\text{s} \downarrow \text{Cont. cond. } \textcircled{\text{IV}}$$

$$Q_6 = Q_3 - Q_4 - 375 \text{ L/min} = 95 \text{ L/min} = 1.583 \times 10^{-3} \text{ m}^3/\text{s} \downarrow \text{Cont. cond. } \textcircled{\text{III}}$$

$$Q_7 = 115 \text{ L/min} - Q_6 = 20 \text{ L/min} = 3.333 \times 10^{-4} \text{ m}^3/\text{s} \rightarrow \text{Cont. cond. } \textcircled{\text{V}}$$

NETWORK ANALYSIS USING THE HARDY CROSS TECHNIQUE						U.S. Cust Units	
Prob #	12.12	2 Circuits			7 Pipes-drawn steel tubing		
Fluid:	Coolant	Fluid kinematic viscosity:			2.17E-06 m <sup>2</sup> /s		
Pipe #	D (m)	Length (m)	Roughness $\epsilon$ (m)	D/ $\epsilon$	C1 ( $k=C1*f$ )	C2 ( $N_R=C2*Q$ )	Initial Q L/min
1	0.0475	7.5	1.50E-06	31667	2.56E+06	1.23E+07	350
2	0.0348	7.5	1.50E-06	23200	1.21E+07	1.68E+07	235
3	0.0475	7.5	1.50E-06	31667	2.56E+06	1.23E+07	530
4	0.0221	7.5	1.50E-06	14733	1.18E+08	2.65E+07	60
5	0.0221	7.5	1.50E-06	14733	1.18E+08	2.65E+07	95
6	0.0221	7.5	1.50E-06	14733	1.18E+08	2.65E+07	95
7	0.0221	7.5	1.50E-06	14733	1.18E+08	2.65E+07	20

Trial 1									
Circuit	Pipe	Q (m <sup>3</sup> /s)	N <sub>R</sub>	f	k	h = kQ <sup>2</sup>	2kQ	$\Delta Q$	% Chg
1	1	-5.833E-03	7.19E+04	0.0193	4.95E+04	-1.6845	577.6		-1.99
	2	-3.917E-03	6.59E+04	0.0197	2.40E+05	-3.6759	1876.9		-2.97
	3	8.833E-03	1.09E+05	0.0177	4.55E+04	3.5492	803.6		1.32
	4	1.000E-03	2.65E+04	0.0243	2.85E+06	2.8539	5707.8		11.63
					Summations:	1.0427	8965.9	1.163E-04	
2	4	-1.000E-03	2.65E+04	0.0243	2.85E+06	-2.8539	5707.8		13.36
	5	-1.583E-03	4.20E+04	0.0219	2.57E+06	-6.4387	8134.8		8.44
	6	1.583E-03	4.20E+04	0.0219	2.57E+06	6.4387	8134.8		-8.44
	7	-3.333E-04	8.83E+03	0.0322	3.78E+06	-0.4201	2520.9		40.10
					Summations:	-3.2740	24498.2	-0.000134	

continued

12.12 (continued)

<b>Trial 2</b>									
Circuit	Pipe	Q (m <sup>3</sup> /s)	N <sub>R</sub>	f	k	h = kQ <sup>2</sup>	2kQ	ΔQ	% Chg
1	1	-5.949E-03	7.34E+04	0.0192	4.93E+04	-1.7451	586.67		0.92
	2	-4.033E-03	6.79E+04	0.0196	2.38E+05	-3.8736	1920.79		1.36
	3	8.717E-03	1.07E+05	0.0178	4.56E+04	3.4655	795.13		-0.63
	4	7.501E-04	1.99E+04	0.0260	3.06E+06	1.7210	4588.97		-7.30
						Summations:	-0.4322	7891.55	-5.477E-05
2	4	-7.501E-04	1.988E+04	0.0260	3.06E+06	-1.7210	4588.97		-0.22
	5	-1.449E-03	3.841E+04	0.0223	2.62E+06	-5.5043	7595.56		-0.12
	6	1.717E-03	4.549E+04	0.0215	2.52E+06	7.4382	8665.94		0.10
	7	-1.997E-04	5.291E+03	0.0373	4.38E+06	-0.1747	1750.47		-0.84
						Summations:	0.0381	22600.94	1.684E-06
_____									
_____									
<b>Trial 3</b>									
Circuit	Pipe	Q (m <sup>3</sup> /s)	N <sub>R</sub>	f	k	h = kQ <sup>2</sup>	2kQ	ΔQ	% Chg
1	1	-5.895E-03	7.27E+04	0.0193	4.94E+04	-1.7165	582.39		0.08
	2	-3.979E-03	6.70E+04	0.0197	2.39E+05	-3.7799	1900.15		0.11
	3	8.771E-03	1.08E+05	0.0178	4.56E+04	3.5048	799.13		-0.05
	4	8.065E-04	2.14E+04	0.0256	3.01E+06	1.9547	4847.36		-0.56
						Summations:	-0.0368	8129.03	-4.531E-06
2	4	-8.065E-04	2.137E+04	0.0256	3.01E+06	-1.9547	4847.36		1.21
	5	-1.451E-03	3.845E+04	0.0223	2.62E+06	-5.5157	7602.41		0.67
	6	1.715E-03	4.545E+04	0.0215	2.52E+06	7.4252	8659.29		-0.57
	7	-2.013E-04	5.336E+03	0.0372	4.37E+06	-0.1773	1760.80		4.83
						Summations:	-0.2225	22869.86	-9.731E-06
_____									
_____									

continued

12.12 (continued)

<b>Trial 4</b>									
Circuit	Pipe	Q (m <sup>3</sup> /s)	N <sub>R</sub>	f	k	h = kQ <sup>2</sup>	2kQ	ΔQ	% Chg
1	1	-5.890E-03	7.26E+04	0.0193	4.94E+04	-1.7141	582.04		0.10
	2	-3.974E-03	6.69E+04	0.0197	2.39E+05	-3.7722	1898.44		0.14
	3	8.776E-03	1.08E+05	0.0178	4.55E+04	3.5080	799.46		-0.06
	4	8.013E-04	2.12E+04	0.0256	3.01E+06	1.9327	4823.72		-0.70
Summations:						-0.0456	8103.65	-5.625E-06	
2	4	-8.013E-04	2.124E+04	0.0256	3.01E+06	-1.9327	4823.72		0.25
	5	-1.441E-03	3.820E+04	0.0223	2.62E+06	-5.4502	7562.81		0.14
	6	1.725E-03	4.571E+04	0.0215	2.52E+06	7.5004	8697.68		-0.12
	7	-1.916E-04	5.078E+03	0.0378	4.44E+06	-0.1629	1700.83		1.04
Summations:						-0.0454	22785.04	-1.992E-06	
<b>Trial 5</b>									
Circuit	Pipe	Q (m <sup>3</sup> /s)	N <sub>R</sub>	f	k	h = kQ <sup>2</sup>	2kQ	ΔQ	% Chg
1	1	-5.884E-03	7.26E+04	0.0193	4.94E+04	-1.7112	581.60		0.03
	2	-3.968E-03	6.68E+04	0.0197	2.39E+05	-3.7626	1896.31		0.04
	3	8.782E-03	1.08E+05	0.0178	4.55E+04	3.5121	799.87		-0.02
	4	8.050E-04	2.13E+04	0.0256	3.01E+06	1.9481	4840.24		-0.21
Summations:						-0.0136	8118.03	-1.680E-06	
2	4	-8.050E-04	2.133E+04	0.0256	3.01E+06	-1.9481	4840.24		0.16
	5	-1.439E-03	3.814E+04	0.0223	2.62E+06	-5.4368	7554.70		0.09
	6	1.727E-03	4.576E+04	0.0214	2.52E+06	7.5158	8705.54		-0.07
	7	-1.896E-04	5.025E+03	0.0379	4.45E+06	-0.1601	1688.47		0.67
Summations:						-0.0291	22788.95	-1.278E-06	
<b>Final flows in L/min</b>									
Circuit	Pipe	Q							
1	1	-353.1 L/min							
	2	-238.1 L/min							
	3	526.9 L/min							
	4	48.3 L/min							
2	4	-48.3 L/min							
	5	-86.4 L/min							
	6	103.6 L/min							
	7	-11.4 L/min							

# CHAPTER THIRTEEN

## PUMP SELECTION AND APPLICATION

13.1 to 13.14: Answers to questions in text.

13.15 **Affinity laws** relate the manner in which capacity, head and power vary with either speed or impeller diameter.

$$13.16 \quad Q_2 = Q_1 \frac{N_2}{N_1} = Q_1 \frac{0.5N_1}{N_1} = 0.5Q_1: \text{ Capacity cut in half.}$$

$$13.17 \quad h_{a_2} = h_{a_1} \left( \frac{N_2}{N_1} \right)^2 = h_{a_1} \left( \frac{0.5N_1}{N_1} \right)^2 = 0.25h_{a_1}: h_a \text{ divided by 4.}$$

$$13.18 \quad P_2 = P_1 \left( \frac{N_2}{N_1} \right)^3 = P_1 \left( \frac{0.5N_1}{N_1} \right)^3 = 0.125P_1: P \text{ divided by 8.}$$

$$13.19 \quad Q_2 = Q_1 \frac{D_2}{D_1} = Q_1 \frac{0.75D_1}{D_1} = 0.75Q_1: 25\% \text{ reduction.}$$

$$13.20 \quad h_{a_2} = h_{a_1} \left( \frac{D_2}{D_1} \right)^2 = h_{a_1} \left( \frac{0.75D_1}{D_1} \right)^2 = 0.5625h_{a_1}: 44\% \text{ reduction.}$$

$$13.21 \quad P_2 = P_1 \left( \frac{D_2}{D_1} \right)^3 = P_1 \left( \frac{0.75D_1}{D_1} \right)^3 = 0.422P_1: 58\% \text{ reduction.}$$

$$13.22 \quad 1\frac{1}{2} \times 3 - 6$$

┌	┌	6 in casing-size of largest impeller
	└	3 in nominal suction connection size
	└	1 $\frac{1}{2}$ in nominal discharge connection size

$$13.23 \quad 1\frac{1}{2} \times 3 - 10$$

$$13.24 \quad 1\frac{1}{2} \times 3 - 6$$

$$13.25 \quad Q = 280 \text{ gal/min}; P = 26 \text{ hp}; e = 53\%; NPSH_R = 10.9 \text{ ft}$$

13.26 At  $h_a = 250$  ft,  $e_{\max} = 56\%$ :  $Q = 220$  gal/min;  $P = 24.0$  hp;  $NPSH_R = 8.0$  ft

13.27 From Problem 13.26,  $h_{a_1} = 250$  ft: Let  $h_{a_2} = 1.15 h_{a_1} = 288$  ft

Then  $Q_2 = 125$  gal/min;  $P_2 = 19$  hp;  $e_2 = 45\%$ ;  $NPSH_R = 5.5$  ft (approximate values)

13.28

	6 in	7 in	8 in	9 in	10 in
$h_a$	120 ft	190 ft	250 ft	320 ft	390 ft
$Q$	145 gal/min	187 gal/min	220 gal/min	260 gal/min	290 gal/min
$e_{\max}$	51%	54%	56%	57.3%	58%(Est)

13.29  $NPSH_R$  increases.

13.30 Throttling valves dissipate energy from fluid that was delivered by pump. When a lower speed is used to obtain a lower capacity, power required to drive pump decreases as the cube of the speed. Variable speed control is often more precise and it can be automatically controlled.

13.31 As fluid viscosity increases, capacity and efficiency decrease, power required increases.

13.32 Total capacity doubles.

13.33 The same capacity is delivered but the head capability increases to the sum of the ratings of the two pumps.

- 13.34
- Rotary or 3500 rpm centrifugal
  - Rotary
  - Rotary
  - Reciprocating
  - Rotary or high speed centrifugal
  - 1750 rpm centrifugal
  - 1750 rpm centrifugal or mixed flow
  - Axial flow

13.35  $Q = 390$  gal/min;  $H = 550$  ft;  $D = 12$  in;  $N = 3560$  rpm

$$N_s = \frac{N\sqrt{Q}}{H^{3/4}} = \frac{3560\sqrt{390}}{(550)^{0.75}} = \mathbf{619}; D_s = \frac{DH^{1/4}}{\sqrt{Q}} = \frac{(12)(550)^{0.25}}{\sqrt{390}} = \mathbf{2.94}$$

Point in Fig. 13.48 lies in **radial flow** centrifugal region.

13.36  $Q = 2750$  gal/min;  $H = 200$  ft;  $D = 15$  in;  $N = 1780$  rpm

$$N_s = \frac{N\sqrt{Q}}{H^{3/4}} = \frac{1780\sqrt{2750}}{(200)^{0.75}} = \mathbf{1755}; D_s = \frac{DH^{1/4}}{\sqrt{Q}} = \frac{15(200)^{0.25}}{\sqrt{2750}} = \mathbf{1.08}$$

Point in Figure 13.34 lies in **radial flow** centrifugal region.

$$13.37 \quad N_s = \frac{N\sqrt{Q}}{H^{3/4}}; N = \frac{N_s H^{3/4}}{\sqrt{Q}} = \frac{(5000)(40)^{0.75}}{\sqrt{10000}} = \mathbf{795 \text{ rpm}}$$

$$13.38 \quad N_s = \frac{N\sqrt{Q}}{H^{3/4}} = \frac{(1750)\sqrt{5000}}{(100)^{0.75}} = \mathbf{3913}$$

$$13.39 \quad N_s = \frac{N\sqrt{Q}}{H^{3/4}} = \frac{(1750)\sqrt{12000}}{(300)^{0.75}} = \mathbf{2659}$$

$$13.40 \quad N_s = \frac{N\sqrt{Q}}{H^{3/4}} = \frac{(1750)\sqrt{500}}{(100)^{0.75}} = \mathbf{1237}$$

$$13.41 \quad N_s = \frac{N\sqrt{Q}}{H^{3/4}} = \frac{(3500)\sqrt{500}}{(100)^{0.75}} = \mathbf{2475}; \text{ Twice } N_s \text{ from 13.40.}$$

13.42 Same method as Problems 13.38 to 13.41.

- |                                 |                         |
|---------------------------------|-------------------------|
| a. $N_s = 1463$ radial          | b. $N_s = 260$ too low  |
| c. $N_s = 3870$ radial or mixed | d. $N_s = 18.5$ too low |
| e. $N_s = 104$ too low          | f. $N_s = 2943$ radial  |
| g. $N_s = 7260$ mixed           | h. $N_s = 24277$ axial  |

13.43 to 13.46 See text.

13.47 At inlet to pump. Pressure at this point and fluid properties affect pump operation, particularly the onset of cavitation. Pump manufacturer's  $NPSH_R$  rating related to pump inlet.

13.48 Elevating reservoir raises pressure at pump inlet and increases  $NPSH_a$ .

13.49 Large pipe sizes reduce flow velocity and reduce energy losses, thus increasing  $NPSH_a$ .

13.50 Air pockets will not form in an eccentric reducer as they will in a concentric reducer.

$$13.51 \quad (NPSH_R)_2 = (NPSH_R)_1 \left( \frac{N_2}{N_1} \right)^2 = 7.50 \text{ ft} \left( \frac{2850}{3500} \right)^2 = \mathbf{4.97 \text{ ft}}$$

13.52  $NPSH_a = h_{sp} - h_s - h_f - h_{vp}$ : Some data from Prob. 7.14.

$$\begin{aligned} \text{a. } h_{sp} &= \frac{p_{\text{atm}}}{\gamma} = \frac{14.4 \text{ lb}}{\text{in}^2} \frac{\text{ft}^3}{62.2 \text{ lb}} \frac{144 \text{ in}^2}{\text{ft}^2} = 33.34 \text{ ft} \\ h_s &= 10.0 \text{ ft}; h_f = 6.0 \text{ ft}; \\ h_{vp} &= 1.17 \text{ (Table 13.2)} \\ NPSH_a &= 33.34 - 10 - 6 - 1.17 = \mathbf{16.17 \text{ ft}} \end{aligned}$$

$$\begin{aligned} \text{b. } &\text{Water at } 180^\circ\text{F}, h_{vp} = 17.55 \text{ ft;} \\ &\gamma = 60.6 \text{ lb/ft}^3 \\ &h_{sp} = (14.4)(144)/(60.6) = 34.22 \text{ ft} \\ &NPSH_a = 34.22 - 10 - 6 - 17.55 = 0.67 \text{ ft} \\ &\text{Cavitation will likely occur!} \end{aligned}$$

13.53  $NPSH_a = h_{sp} - h_s - h_f - h_{vp} = 34.48 - 4.8 - 2.2 - 6.78 = \mathbf{20.70 \text{ ft}}$

$$h_{sp} = \frac{14.7 \text{ lb}}{\text{in}^2} \times \frac{\text{ft}^3}{61.4 \text{ lb}} \times \frac{144 \text{ in}^2}{\text{ft}^2} = \frac{p_{\text{atm}}}{\gamma} = 34.48 \text{ ft}$$

$h_s = 4.8 \text{ ft}; h_f = 2.2 \text{ ft}; h_{vp} = 6.78 \text{ ft}$  (Table 13.2) Water at  $140^\circ\text{F}$

$$13.54 \quad NPSH_a = h_{sp} + h_s - h_f - h_{vp} = 11.47 + 2.6 - 0.80 - 1.55 = \mathbf{11.72 \text{ m}}$$

$$h_{sp} = \frac{p_{atm}}{\gamma} = \frac{98.5 \text{ kN}}{\text{m}^2} \frac{\text{m}^3}{8.59 \text{ kN}} = 11.47 \text{ m}; h_s = 2.6 \text{ m}; h_f = 0.80 \text{ m}$$

$$h_{vp} = \frac{p_{vp}}{\gamma} = \frac{13.3 \text{ kN}}{\text{m}^2} \frac{\text{m}^3}{8.59 \text{ kN}} = 1.55 \text{ m}$$

$$13.55 \quad NPSH_a = h_{sp} - h_s - h_f - h_{vp}$$

$$h_{sp} = \frac{p_{atm}}{\gamma} = \frac{101.8 \text{ kN}}{\text{m}^2} \frac{\text{m}^3}{9.53 \text{ kN}} = \mathbf{10.68 \text{ m}; h_s = 2.0 \text{ m}; h_{vp} = 4.8 \text{ m}}$$

$$h_f = f_3 \left( \frac{L}{D} \right)_3 \frac{v_3^2}{2g} + K_1 \frac{v_3^2}{2g} + f_{3T} (20) \frac{v_3^2}{2g} + f_2 \left( \frac{L}{D} \right)_2 \frac{v_2^2}{2g} \quad \text{NOTE: } f_{3T} = 0.018$$

Friction 3 in    Foot valve    Elbow    Friction 2 in     $K_1 = 75f_{3T} = 75(0.018) = 1.35$

$$v_3 = \frac{Q}{A_3} = \frac{300 \text{ L/min}}{4.768 \times 10^{-3} \text{ m}^2} \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = \frac{1.05 \text{ m}}{\text{s}}; \frac{v_3^2}{2g} = \frac{(1.05)^2}{2(9.81)} = 0.0560 \text{ m}$$

$$N_{R_3} = \frac{v_3 D_3}{\nu} = \frac{(1.05)(0.0779)}{3.60 \times 10^{-7}} = 2.3 \times 10^5; \frac{D_3}{\epsilon} = \frac{0.0779}{4.6 \times 10^{-5}} = 1694; f_3 = 0.0195$$

$$v_2 = \frac{Q}{A_2} = \frac{300/60000}{2.168 \times 10^{-3}} = \frac{2.31 \text{ m}}{\text{s}}; \frac{v_2^2}{2g} = \frac{(2.31)^2}{2(9.81)} = 0.271 \text{ m}$$

$$N_{R_2} = \frac{v_2 D_2}{\nu} = \frac{(2.31)(0.0525)}{3.60 \times 10^{-7}} = 3.4 \times 10^5; \frac{D_2}{\epsilon} = 1141; f_2 = 0.0202$$

$$h_f = (0.0195) \frac{2.0 \text{ m}}{0.0779 \text{ m}} (0.056 \text{ m}) + 1.35(0.056) + (0.018)(20)(0.056) \\ + (0.0202) \frac{1.5}{0.0525} (0.271)$$

$$h_f = 0.280 \text{ m}$$

$$NPSH_a = 10.68 - 2.0 - 0.280 - 4.97 = \mathbf{3.43 \text{ m}}$$

For all problems 13.56 – 13.65:  $NPSH_a = h_{sp} \pm h_s - h_f - h_{vp}$

See Section 13.11, Equation 13-14. See Figure 13.37 for vapor pressure head  $h_{vp}$ .

$$13.56 \quad \text{Find } NPSH_a: \text{ Carbon tetrachloride at } 150^\circ\text{F}; \text{ sg} = 1.48; p_{atm} = 14.55 \text{ psia}; h_s = -3.6 \text{ ft}; h_f = 1.84 \text{ ft} \\ h_{vp} = 16.3 \text{ ft}$$

$$\text{Open tank: } h_{sp} = p_{sp}/\gamma = p_{atm}/\gamma = (14.55 \text{ lb/in}^2)(144 \text{ in}^2/\text{ft}^2)/[1.48(62.4 \text{ lb/ft}^3)] = 22.69 \text{ ft}$$

$$NPSH_a = 22.69 - 3.6 - 1.84 - 16.3 = \mathbf{0.95 \text{ ft (Low)}}$$

$$13.57 \quad \text{Find } NPSH_a: \text{ Carbon tetrachloride at } 65^\circ\text{C}; \text{ sg} = 1.48; p_{atm} = 100.2 \text{ kPa}; h_s = -1.2 \text{ m}; h_f = 0.72 \text{ m} \\ h_{vp} = 4.8 \text{ m}$$

$$\text{Open tank: } h_{sp} = p_{sp}/\gamma = p_{atm}/\gamma = (100.2 \text{ kN/m}^2)/[1.48(9.81 \text{ kN/m}^3)] = 6.90 \text{ m}$$

$$NPSH_a = 6.90 - 1.2 - 0.72 - 4.8 = \mathbf{0.18 \text{ m (Very low)}}$$

- 13.58 Find  $NPSH_a$ : Gasoline at 40°C;  $sg = 0.65$ ;  $p_{atm} = 99.2$  kPa;  $h_s = -2.7$  m;  $h_f = 1.18$  m  
 $h_{vp} = 14.0$  m  
 Open tank:  $h_{sp} = p_{sp}/\gamma = p_{atm}/\gamma = (99.2 \text{ kN/m}^2)/[0.65(9.81 \text{ kN/m}^3)] = 15.55$  m  
 $NPSH_a = 15.55 - 2.7 - 1.18 - 14.0 = -2.33$  m (**Cavitation expected**)
- 13.59 Find  $NPSH_a$ : Gasoline at 110°F;  $sg = 0.65$ ;  $p_{atm} = 14.28$  psia;  $h_s = +4.8$  ft;  $h_f = 0.87$  ft  
 $h_{vp} = 51.0$  ft  
 Open tank:  $h_{sp} = p_{sp}/\gamma = p_{atm}/\gamma = (14.28 \text{ lb/in}^2)(144 \text{ in}^2/\text{ft}^2)/[0.65(62.4 \text{ lb/ft}^3)] = 50.70$  ft  
 $NPSH_a = 50.70 + 4.8 - 0.87 - 51.0 = 3.63$  ft
- 13.60 Find  $NPSH_a$ : Carbon tetrachloride at 150°F;  $sg = 1.48$ ;  $p_{atm} = 14.55$  psia;  $h_s = +3.66$  ft;  $h_f = 1.84$  ft  
 $h_{vp} = 16.3$  ft  
 Open tank:  $h_{sp} = p_{sp}/\gamma = p_{atm}/\gamma = (14.55 \text{ lb/in}^2)(144 \text{ in}^2/\text{ft}^2)/[1.48(62.4 \text{ lb/ft}^3)] = 22.69$  ft  
 $NPSH_a = 22.69 + 3.67 - 1.84 - 16.3 = 8.22$  ft
- 13.61 Find  $NPSH_a$ : Gasoline at 110°F;  $sg = 0.65$ ;  $p_{atm} = 14.28$  psia;  $h_s = -2.25$  ft;  $h_f = 0.87$  ft  
 $h_{vp} = 51.0$  ft  
 Open tank:  $h_{sp} = p_{sp}/\gamma = p_{atm}/\gamma = (14.28 \text{ lb/in}^2)(144 \text{ in}^2/\text{ft}^2)/[0.65(62.4 \text{ lb/ft}^3)] = 50.70$  ft  
 $NPSH_a = 50.70 - 2.25 - 0.87 - 51.0 = -3.42$  ft (**Cavitation expected**)
- 13.62 Find  $NPSH_a$ : Carbon tetrachloride at 65°C;  $sg = 1.48$ ;  $p_{atm} = 100.2$  kPa;  $h_s = +1.2$  m;  $h_f = 0.72$  m  
 $h_{vp} = 4.8$  m  
 Open tank:  $h_{sp} = p_{sp}/\gamma = p_{atm}/\gamma = (100.2 \text{ kN/m}^2)/[1.48(9.81 \text{ kN/m}^3)] = 6.90$  m  
 $NPSH_a = 6.90 + 1.2 - 0.72 - 4.8 = 2.58$  m
- 13.63 Find  $NPSH_a$ : Gasoline at 40°C;  $sg = 0.65$ ;  $p_{atm} = 99.2$  kPa;  $h_s = +0.65$  m;  $h_f = 1.18$  m  
 $h_{vp} = 14.0$  m  
 Open tank:  $h_{sp} = p_{sp}/\gamma = p_{atm}/\gamma = (99.2 \text{ kN/m}^2)/[0.65(9.81 \text{ kN/m}^3)] = 15.55$  m  
 $NPSH_a = 15.55 + 0.65 - 1.18 - 14.0 = 1.02$  m
- 13.64 Find required pressure above the fluid in a closed, pressurized tank so that  $NPSH_a \geq 4.0$  ft.  
 Propane at 110°F;  $sg = 0.48$ ;  $p_{atm} = 14.32$  psia;  $h_s = +2.50$  ft;  $h_f = 0.73$  ft  
 $h_{vp} = 1080$  ft  
 Solve Eq. 13-14 for required  $h_{sp} = NPSH_a - h_s + h_f + h_{vp} = 4.0 - 2.5 + 0.73 + 1080 = 1082.2$  ft  
 $P_{sp} = \gamma h_{sp} = (0.48)(62.4 \text{ lb/ft}^3)(1082.2 \text{ ft})(1 \text{ ft}^2/144 \text{ in}^2) = 225.1 \text{ lb/in}^2 = 225.1$  psia  
 Gage pressure:  $p_{tank} = p_{sp} - p_{atm} = 225.1 \text{ psia} - 14.32 \text{ psia} = 210.8$  psig
- 13.65 Find required pressure above the fluid in a closed, pressurized tank so that  $NPSH_a \geq 150.0$  m.  
 Propane at 45°C;  $sg = 0.48$ ;  $p_{atm} = 9.47$  kPa absolute;  $h_s = -1.84$  m;  $h_f = 0.92$  m  
 $h_{vp} = 340$  m  
 Solve Eq. 13-14 for required  $h_{sp} = NPSH_a - h_s + h_f + h_{vp} = 150 + 1.84 + 0.92 + 340 = 344.3$  m  
 $P_{sp} = \gamma h_{sp} = (0.48)(9.81 \text{ kN/m}^3)(344.3 \text{ m}) = 1621 \text{ kN/m}^2 = 1621$  kPa absolute  
 Gage pressure:  $p_{tank} = p_{sp} - p_{atm} = 1621 \text{ kPa} - 98.4 \text{ kPa} = 1523$  kPa gage

# CHAPTER FOURTEEN

## OPEN CHANNEL FLOW

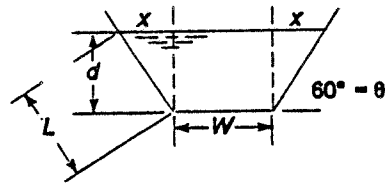
$$14.1 \quad R = \frac{A}{WP} = \frac{\pi D^2}{8} \times \frac{2}{\pi D} = \frac{D}{4} = \frac{300 \text{ mm}}{4} = 75 \text{ mm}$$



$$14.2 \quad R = \frac{A}{WP} = \frac{Wd}{W + 2d} = \frac{(2.75 \text{ m})(0.05 \text{ m})}{[2.75 + 2(0.05)]\text{m}} = 0.367 \text{ m}$$



$$14.3 \quad d = 1.50 \text{ ft}; W = 3.50 \text{ ft}, x = d \tan 30^\circ = 0.866 \text{ ft} \\ L = d/\cos 30^\circ = 1.732 \text{ ft}$$



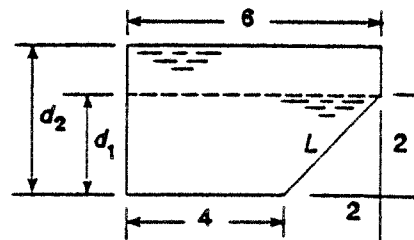
$$A = Wd + 2 \left[ \frac{1}{2} xd \right] = (3.50)(1.50) + (0.866)(1.50) = 6.549 \text{ ft}^2$$

$$WP = W + 2L = 3.50 + 2(1.732) = 6.964 \text{ ft} \\ R = A/WP = 6.549 \text{ ft}^2/6.964 \text{ ft} = 0.940 \text{ ft}$$

$$14.4 \quad \text{Data from Prob. 14.3, but } \theta = 45^\circ. \quad x = d \tan 45^\circ = d = 1.50 \text{ ft} \\ L = d/\cos 45^\circ = 1.50/\cos 45^\circ = 2.121 \text{ ft} \\ A = (3.50)(1.50) + (1.50)(1.50) = 7.50 \text{ ft}^2 \\ WP = 3.50 + 2(2.121) = 7.743 \text{ ft} \\ R = A/WP = 7.50 \text{ ft}^2/7.743 \text{ ft} = 0.969 \text{ ft}$$

$$14.5 \quad W = 150 \text{ mm}; d = 62 \text{ mm}; X = 1.5d = 1.5(62) = 93 \text{ mm} \\ L = \sqrt{X^2 + d^2} = 111.8 \text{ mm} \\ R = \frac{A}{WP} = \frac{Wd + Xd}{W + 2L} = \frac{(150)(62) + (93)(62)}{150 + 2(111.8)} = \frac{15066 \text{ mm}^2}{373.5 \text{ mm}} = 40.3 \text{ mm}$$

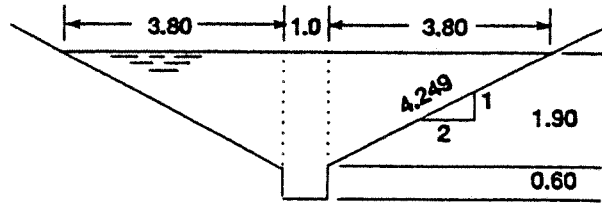
$$14.6 \quad d = d_1 = 2.0 \text{ in}; L = \sqrt{2^2 + 2^2} = 2.828 \text{ in} \\ A = (4)(2) + \frac{1}{2} (2)(2) = 10 \text{ in}^2 \\ WP = 4 + 2 + 2.828 = 8.828 \text{ in} \\ R = A/WP = 1.133 \text{ in}$$



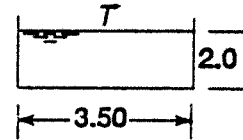
$$14.7 \quad \text{Data from Prob. 14.6. } d = d_2 = 3.50 \text{ in} \\ A = (4)(2) + \frac{1}{2} (2)(2) + (6)(3.50 - 2.00) = 19.0 \text{ in}^2 \\ WP = 3.50 + 4 + 2.828 + 1.50 = 11.828 \text{ in} \\ R = A/WP = 19.0 \text{ in}^2/11.828 \text{ in} = 1.606 \text{ in}$$

14.8  $A = (1.0)(0.5) = 0.50 \text{ m}^2$ ;  $WP = 1.0 + 2(0.5) + 2.0 \text{ m}$   
 $R = A/WP = 0.50/2.0 = \mathbf{0.25 \text{ m}}$

14.9  $A = (1.0)(2.50) + 2 \left[ \frac{1}{2} (1.9)(3.8) \right]$   
 $= 9.72 \text{ m}^2$   
 $WP = 2(4.249) + 2(0.60) + 1.0$   
 $= 10.697 \text{ m}$   
 $R = A/WP = \mathbf{0.909 \text{ m}}$



14.10  $A = (3.50)(2.0) = 7.00 \text{ m}^2$ ;  $WP = 3.50 + 2(2.0) = 7.50 \text{ m}$   
 $R = A/WP = 0.933 \text{ m}$ ;  $n = 0.017$   
 $V = \frac{1.00}{n} R^{2/3} S^{1/2} = \frac{1.00}{0.017} (0.933)^{2/3} (0.001)^{1/2} = 1.777 \text{ m/s}$   
 $Q = AV = (7.00 \text{ m}^2)(1.777 \text{ m/s}) = \mathbf{12.44 \text{ m}^3/\text{s}}$   
 $y_h = A/T = 7.00 \text{ m}^2/3.50 \text{ m} = 2.00 \text{ m}$   
 $N_F = V/\sqrt{gy_h} = \frac{1.777 \text{ m/s}}{\sqrt{(9.81 \text{ m/s}^2)(2.00 \text{ m})}} = \mathbf{0.401}$



14.11 See Prob. 14.7.  $d_2 = 3.50 \text{ in}$ ;  $A = 19.0 \text{ in}^2$ ;  $WP = 11.828 \text{ in}$ ;  $R = 1.606 \text{ in}$   
 $A = 19.0 \text{ in}^2 (1 \text{ ft}^2/144 \text{ in}^2) = 0.132 \text{ ft}^2$   
 $WP = 11.828 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}} = 0.986 \text{ ft}$   
 $R = 1.606 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}} = 0.134 \text{ ft}$   
 $S = \frac{h}{L} = \frac{4.0 \text{ in}}{60 \text{ ft}} \times \frac{\text{ft}}{12 \text{ in}} = 0.00556$ ;  $n = 0.013$  given  
 $Q = \frac{1.49}{n} AR^{2/3} S^{1/2} = \frac{1.49}{0.013} (0.132)(0.134)^{2/3} (0.00556)^{1/2} = \mathbf{0.295 \text{ ft}^3/\text{s}}$

14.12  $S = 1 \text{ ft}/500 \text{ ft} = 0.002$ ;  $n = 0.024$ ;  $A = \frac{\pi D^2}{8} = \frac{\pi(6)^2}{8} = 14.14 \text{ ft}^2$   
 $WP = \pi D/2 = \pi(6)/2 = 9.425 \text{ ft}$ ;  $R = A/WP = 1.50 \text{ ft}$   
 $Q = \frac{1.49}{n} AR^{2/3} S^{1/2} = \frac{1.49}{0.024} (14.14)(1.50)^{2/3} (0.002)^{1/2} = \mathbf{51.4 \text{ ft}^3/\text{s}}$

14.13  $A = (0.205)(0.250) = 0.05125 \text{ m}^2$ ;  $WP = 0.205 + 2(0.250) = 0.705 \text{ m}$   
 $R = A/WP = 0.0727 \text{ m}$ ;  $n = 0.012$ ;  $Q = \frac{1.00}{n} AR^{2/3} S^{1/2}$   
 $S = \left[ \frac{nQ}{AR^{2/3}} \right]^2 = \left[ \frac{(0.012)(0.0833)}{(0.05125)(0.0727)^{2/3}} \right]^2 = \mathbf{0.0125}$   
 where  $Q = 5000 \text{ L/min} \times \frac{1 \text{ m}^3/\text{s}}{60000 \text{ L/min}} = \mathbf{0.0833 \text{ m}^3/\text{s}}$

14.14 See Prob. 14.8 for  $d = 0.50$  m; Prob. 14.9 for  $d = 2.50$  m  
 $S = 0.50\% = 0.005$ ,  $n = 0.017$

a.  $d = 0.50$  m;  $A = 0.50$  m<sup>2</sup>;  $R = 0.25$  m

$$Q = \frac{1.00}{n} AR^{2/3} S^{1/2} = \frac{1.00}{0.017} (0.50)(0.25)^{2/3} (0.005)^{1/2} = 0.825 \text{ m}^3/\text{s}$$

b.  $d = 2.50$  m;  $A = 9.72$  m<sup>2</sup>;  $R = 0.909$  m

$$Q = \frac{1.00}{0.017} (9.72)(0.909)^{2/3} (0.005)^{1/2} = 37.9 \text{ m}^3/\text{s}$$

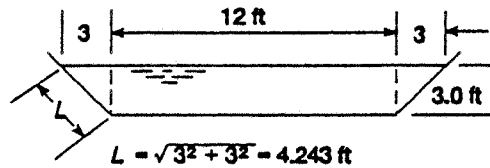
14.15 a. **Depth = 3.0 ft:**

$$A = (3)(12) + 2 \left[ \frac{1}{2} (3)(3) \right] = 45 \text{ ft}^2$$

$$WP = 12 + 2(4.243) = 20.485 \text{ ft}$$

$$R = A/WP = 45/20.485 = 2.197 \text{ ft}$$

$$Q = \frac{1.49}{0.04} (45)(2.197)^{2/3} (0.00015)^{1/2} = 34.7 \text{ ft}^3/\text{s}$$



b. **Depth = 6.0 ft:**

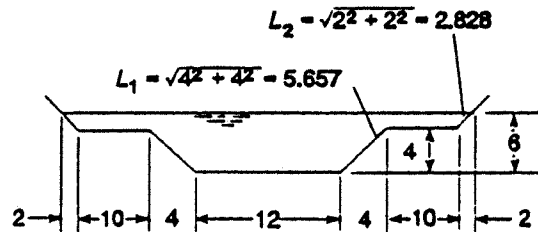
$$A = (4)(12) + 2 \left[ \frac{1}{2} (4)(4) \right] + (2)(40) + 2 \left[ \frac{1}{2} (2)(2) \right]$$

$$A = 148 \text{ ft}^2$$

$$WP = 2(2.828) + 2(10) + 2(5.657) + 12 = 48.97 \text{ ft}$$

$$R = A/WP = 148/48.97 = 3.022 \text{ ft}$$

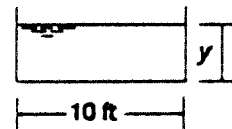
$$Q = \frac{1.49}{0.04} (148)(3.022)^{2/3} (0.00015)^{1/2} = 141.1 \text{ ft}^3/\text{s}$$



14.16  $AR^{2/3} = \frac{nQ}{1.49S^{1/2}} = \frac{(0.015)(150)}{(1.49)(0.001)^{1/2}} = 47.75$

$$A = 10y; WP = 10 + 2y; R = \frac{A}{WP} = \frac{10y}{10 + 2y}$$

$$AR^{2/3} = 10y \left[ \frac{10y}{10 + 2y} \right]^{2/3} \quad \text{Find } y \text{ such that } AR^{2/3} = 47.75$$



By trial and error,  $y = 3.10$  ft;

$$AR^{2/3} = 10(3.1) \left[ \frac{10(3.1)}{10 + 2(3.1)} \right]^{2/3} = 47.78$$

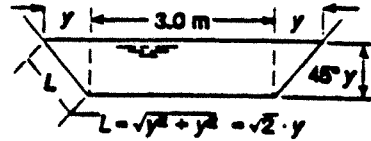
$$14.17 \quad AR^{2/3} = \frac{nQ}{1.00S^{1/2}} = \frac{(0.017)(15)}{(0.001)^{1/2}} = 8.064$$

$$A = 3.0(y) + 2 \left[ \frac{1}{2}(y)(y) \right] = 3y + y^2$$

$$WP = 3.0 + 2L = 3.0 + 2\sqrt{2}y$$

$$AR^{2/3} = (3y + y^2) \left[ \frac{3y + y^2}{3 + 2.828y} \right]^{2/3} \quad \text{: By trial,}$$

$$\text{for } y = 1.69 \text{ m, } AR^{2/3} = 8.02$$



$$14.18 \quad S = 0.075/50 = 0.0015$$

$$AR^{2/3} = \frac{nQ}{1.00S^{1/2}} = \frac{(0.013)(2.0)}{(0.0015)^{1/2}} = 0.671$$

$$A = 0.4W; \quad WP = W + 0.8$$

$$R = \frac{A}{WP} = \frac{0.4W}{W + 0.8} \quad \text{: Then } AR^{2/3} = 0.4W \left[ \frac{0.4W}{W + 0.8} \right]^{2/3} \quad \text{: By trial, } W = 3.55 \text{ m}$$



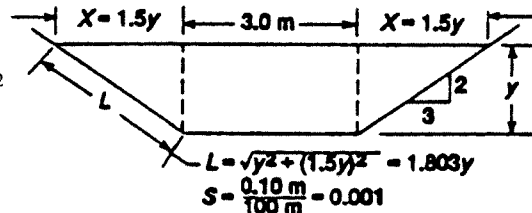
$$14.19 \quad \text{For } y = 1.50 \text{ m, } X = 2.25 \text{ m}$$

$$L = 1.803(1.5) = 2.704 \text{ m}$$

$$A = (3)(1.5) + 2 \left[ \frac{1}{2}(1.5)(2.25) \right] = 7.875 \text{ m}^2$$

$$WP = 3.0 + 2(2.704) = 8.408 \text{ m}$$

$$R = A/WP = 7.875/8.408 = 0.937 \text{ m}$$



$$Q = \frac{1.00}{0.015} (7.875)(0.937)^{2/3} (0.001)^{1/2} = 15.89 \text{ m}^3/\text{s}$$

$$v = \frac{Q}{A} = \frac{15.89 \text{ m}^3/\text{s}}{7.875 \text{ m}^2} = 2.018 \text{ m/s}; \quad \text{Top width} = T = 3.0 + 2X = 7.50 \text{ m}$$

$$\text{Hydraulic Depth} = y_h = \frac{A}{T} = \frac{7.875 \text{ m}^2}{7.50 \text{ m}} = 1.05 \text{ m}$$

$$\text{Froude No.} = N_F = \frac{v}{\sqrt{gy_h}} = \frac{2.018}{\sqrt{(9.81)(1.05)}} = 0.629$$

$$\text{Find critical depth for } Q = 15.89 \text{ m}^3/\text{s}: \quad \text{Let } N_F = 1.0 = \frac{Q/A}{\sqrt{gy_h}} \quad \text{①}$$

$$A = 3y + Xy = 3y + (1.5y)(y) = 3y + 1.5y^2$$

$$T = 3 + 2X = 3 + 2(1.5)y = 3 + 3y$$

$$\text{From Eq. ①, } \frac{Q}{A} = \frac{\sqrt{gA}}{T} \quad \text{or} \quad \frac{Q^2}{A^2} = \frac{gA}{T} \quad \text{or} \quad \frac{T}{A^3} = \frac{g}{Q^2} = \frac{9.81}{(15.89)^2} = 0.0388$$

$$\text{But } \frac{T}{A^3} = \frac{3 + 3y}{[3y + 1.5y^2]^3} \quad \text{: Find } y \text{ such that } \frac{T}{A^3} = 0.0388$$

$$\text{By trial, } y = 1.16 \text{ m} = y_c = \text{Critical depth}$$

14.20 Each trough:

$$Q = 250 \text{ gal/min} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 0.557 \text{ ft}^3/\text{s}$$

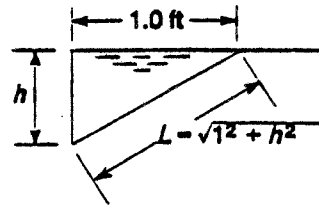
$$AR^{2/3} = \frac{nQ}{1.49S^{1/2}} = \frac{(0.017)(0.557)}{(1.49)(0.01)^{1/2}} = 0.0635$$

$$A = (1.0)(h) \frac{1}{2} = h/2$$

$$WP = h + L = h + \sqrt{1 + h^2}$$

$$R = \frac{A}{WP} = \frac{h/2}{h + \sqrt{1 + h^2}}$$

$$AR^{2/3} = \frac{h}{2} \left[ \frac{h/2}{h + \sqrt{1 + h^2}} \right]^{2/3}$$



Find  $h$  such that  $AR^{2/3} = 0.0635$

By trial,  $h = 0.458 \text{ ft}$

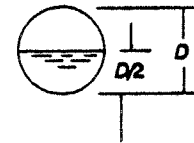
14.21  $Q = 500 \text{ gal/min} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 1.114 \text{ ft}^3/\text{s}$

$$AR^{2/3} = \frac{nQ}{1.49S^{1/2}} = \frac{(0.013)(1.114)}{(1.49)(0.001)^{1/2}} = 0.307$$

$$A = \pi D^2/8; WP = \pi D/2; R = \frac{A}{WP} = \frac{\pi D^2}{8} \frac{2}{\pi D} = \frac{D}{4}$$

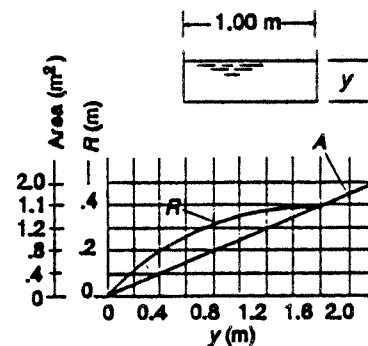
$$AR^{2/3} = \frac{\pi D^2}{8} \left[ \frac{D}{4} \right]^{2/3} = \frac{\pi D^2 (D)^{2/3}}{8(4)^{2/3}} = \frac{\pi (D)^{8/3}}{8(2.52)} = 0.156(D)^{8/3} = 0.307$$

$$\text{Then } D = \left[ \frac{0.307}{0.156} \right]^{3/8} = 1.29 \text{ ft}$$



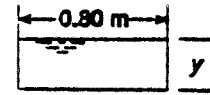
14.22  $A = 1.00(y)$ ;  $WP = 1.00 + 2y$ ;  $R = \frac{y}{1 + 2y}$

$y(\text{m})$	$A(\text{m}^2)$	$R(\text{m})$	$y$	$A$	$R$
0.10	0.10	0.0833	0.80	0.80	0.3077
0.20	0.20	0.1429	1.00	1.00	0.3333
0.30	0.30	0.1875	1.50	1.50	0.3750
0.40	0.40	0.2222	2.00	2.00	0.4000
0.50	0.50	0.250			
0.60	0.60	0.2727			



$$14.23 \quad Q = Av = (0.80 \text{ m})(y)(v)$$

$$y = \frac{Q}{0.8v} = \frac{2.00 \text{ m}^3/\text{s}}{(0.80 \text{ m})(3.0 \text{ m/s})} = 0.833 \text{ m}$$



$$WP = 0.8 + 2y = 0.8 + 2(0.833) = 2.467 \text{ m}; A = 0.8(y) = 0.8(0.833) = 0.666 \text{ m}^2$$

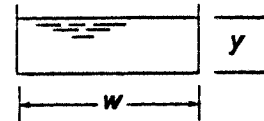
$$R = \frac{A}{WP} = \frac{0.666 \text{ m}^2}{2.467 \text{ m}} = 0.270 \text{ m}$$

$$14.24 \quad Q = \frac{1.00}{n} AR^{2/3} S^{1/2}; S = \left[ \frac{nQ}{AR^{2/3}} \right]^2 = \left[ \frac{(0.015)(2.00)}{(0.666)(0.270)^{2/3}} \right]^2 = 0.0116 \text{ m}^3$$

Data from Problem 14.23.

14.25 and 14.26

$$Q = Av = Wyv; y = \frac{Q}{Wv} = \frac{2.00}{W(3.0)}$$



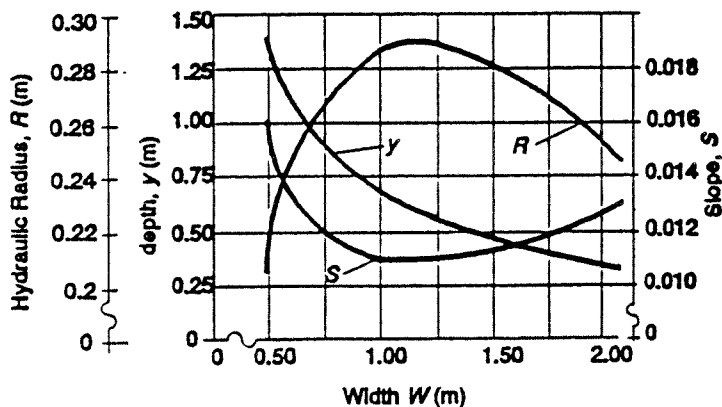
$$WP = W + 2y; R = \frac{A}{WP}$$

$$S = \left[ \frac{nQ}{AR^{2/3}} \right]^2 = \left[ \frac{(0.015)(2.00)}{AR^{2/3}} \right]^2$$

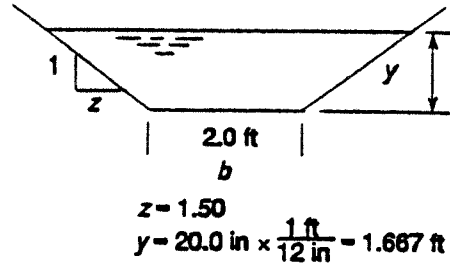
$W(\text{m})$	$y = 2/3W$	$WP = W + 2y$	$A = Wy$	$R = A/WP$	$S$
0.50	1.333 m	3.167 m	0.667 m <sup>2</sup>	0.2105 m	0.0162
0.75	0.889	2.528	0.667	0.2637	0.0120
1.00	0.667	2.333	0.667	0.2857	0.0108
1.25	0.533	2.317	0.667	0.2878	0.0107
1.50	0.444	2.389	0.667	0.2791	0.0111
1.75	0.381	2.512	0.667	0.2654	0.0119
2.00	0.333	2.667	0.667	0.2500	0.0129

Prob. 14.25

Prob. 14.26



14.27 From Table 14.2:  
 $A = (b + zy)y = [2.00 + 1.5(1.667)](1.667)$   
 $= 7.50 \text{ ft}^2$   
 $WP = b + 2y\sqrt{1 + z^2}$   
 $= 2.0 + 2(1.667)\sqrt{1 + 1.5^2} = 8.009 \text{ ft}$   
 $R = A/WP = 7.50/8.009 = 0.936 \text{ ft}$



14.28 **Data from Prob. 14.27**  $n = 0.017$  – formed unfinished concrete.

$$Q = \frac{1.49}{n} AR^{2/3}S^{1/2} = \frac{1.49}{0.017} (7.5)(0.936)^{2/3}(0.005)^{1/2} = 44.49 \text{ ft}^3/\text{s}$$

14.29 Same as 14.28 except  $n = 0.010$  – plastic:

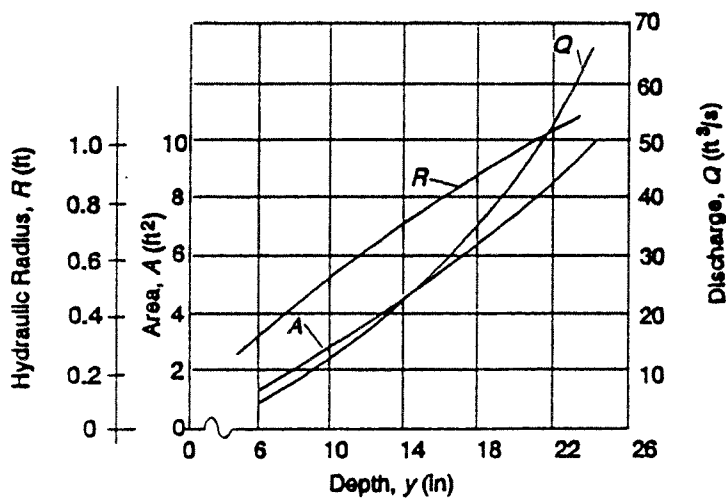
$$Q = \frac{1.49}{0.010} (7.5)(0.936)^{2/3}(0.005)^{1/2} = 75.63 \text{ ft}^3/\text{s}$$

14.30 and 14.31

$b = 2.00 \text{ ft}$ ;  $z = 1.50$ ;  $S = 0.005$ ;  $n = 0.017$

$$A = (b + zy)y; WP = b + 2y\sqrt{1 + z^2}; R = A/WP; Q = \frac{1.49}{n} AR^{2/3}S^{1/2}$$

$y(\text{in})$	$y(\text{ft})$	$A(\text{ft}^2)$	$WP(\text{ft})$	$R(\text{ft})$	$Q(\text{ft}^3/\text{s})$
6.00	0.500	1.375	3.803	0.3616	4.325
10.00	0.833	2.708	5.005	0.5412	11.147
14.00	1.167	4.375	6.206	0.7049	21.476
18.00	1.500	6.375	7.408	0.8605	35.745
22.00	1.833	8.708	8.610	1.0114	54.380
24.00	2.000	10.000	9.211	1.0856	65.466



14.32  $D = 0.375$  m;  $y = 0.225$  m  $> D/2 \rightarrow$  See Table 14.2.

$$\theta = \pi + 2 \sin^{-1}[(2y/D) - 1] = 3.544 \text{ rad}$$

$$A = \frac{(\theta - \sin \theta)D^2}{8} = \frac{(3.544 - \sin 3.544)(0.375)^2 \text{ m}^2}{8} = \mathbf{0.06919 \text{ m}^2}$$

$$WP = \theta D/2 = (3.544)(0.375 \text{ m})/2 = 0.665 \text{ m}$$

$$R = \left[ \frac{\theta - \sin \theta}{\theta} \right] \frac{D}{4} = \left[ \frac{3.544 - \sin 3.544}{3.544} \right] \frac{0.375 \text{ m}}{4} = \mathbf{0.104 \text{ m}}$$

14.33  $D = 0.375$  m;  $y = .135$  m  $< D/2 \rightarrow$  See Table 14.2.

$$\theta = \pi - 2 \sin^{-1}[1 - 2y/D] = \pi - 2 \sin^{-1} \left[ 1 - \frac{2(0.135)}{0.375} \right] = 2.574 \text{ rad}$$

$$A = \frac{(\theta - \sin \theta)D^2}{8} = \frac{(2.574 - \sin 2.574)(0.375)^2}{8} = \mathbf{0.0358 \text{ m}^2}$$

$$WP = \theta D/2 = (2.574)(0.375 \text{ m})/2 = 0.482 \text{ m}$$

$$R = \left[ \frac{\theta - \sin \theta}{\theta} \right] \frac{D}{4} = \left[ \frac{2.574 - \sin 2.574}{2.574} \right] \frac{0.375 \text{ m}}{4} = \mathbf{0.0742 \text{ m}}$$

14.34  $S = 0.0012$ ;  $n = 0.013$ ; Data from Prob. 14.32:

$$Q = \frac{1.00}{0.013} AR^{2/3} A^{1/2} = \frac{1.00}{0.013} (0.06919)(0.104)^{2/3}(0.0012)^{1/2} = \mathbf{4.08 \times 10^{-2} \text{ m}^3/\text{s}}$$

14.35  $S = 0.0012$ ;  $n = 0.013$ ; Data from Prob. 14.33:

$$Q = \frac{1.00}{0.013} AR^{2/3} S^{1/2} = \frac{1.00}{0.013} (0.0358)(0.0742)^{2/3}(0.0012)^{1/2} = \mathbf{1.68 \times 10^{-2} \text{ m}^3/\text{s}}$$

14.36, 14.37, 14.38

$$Q = 1.25 \text{ ft}^3/\text{s}; v = 2.75 \text{ ft/s}; A = Q/v = 0.4545 \text{ ft}^2 \text{ (All)}$$

$$\text{Rectangle: } y = \sqrt{\frac{A}{2.0}} = \sqrt{\frac{0.4545}{2}} = \mathbf{0.4767 \text{ ft}; b = 2y = \mathbf{0.9535 \text{ ft}}}$$

$$R = y/2 = 0.4767 \text{ ft}/2 = 0.2384 \text{ ft}$$

$$S = \left[ \frac{nQ}{1.49 AR^{2/3}} \right]^2 = \left[ \frac{(0.015)(1.25)}{(1.49)(0.4545)R^{2/3}} \right]^2 = \left[ \frac{0.02768}{R^{2/3}} \right]^2 = \left[ \frac{0.02768}{(0.2384)^{2/3}} \right]^2 = \mathbf{0.00519}$$

$$y_h = \frac{A}{T} = \frac{2y^2}{2y} = y = 0.4767 \text{ ft}; N_F = \frac{v}{\sqrt{gy_h}} = \frac{2.75}{\sqrt{(32.2)(0.4767)}} = \mathbf{0.702 < 1.0 \text{ Subcritical}}$$

$$\text{Triangle: } y = \sqrt{A} = \sqrt{0.4545} = \mathbf{0.674 \text{ ft}; R = 0.354y = 0.2387 \text{ ft}}$$

$$S = \left[ \frac{0.02768}{(0.2387)^{2/3}} \right]^2 = \mathbf{0.00518}$$

$$y_h = \frac{A}{T} = \frac{y^2}{2y} = \frac{y}{2} = 0.337 \text{ ft}; N_F = \frac{2.75}{\sqrt{(32.2)(0.337)}} = \mathbf{0.835 < 1.0 \text{ Subcritical}}$$

**Trapezoid:**  $y = \sqrt{\frac{A}{1.73}} = \sqrt{\frac{0.4545}{1.73}} = 0.5126 \text{ ft}; R = y/2 = 0.2563 \text{ ft}$

$$S = \left[ \frac{0.02768}{(0.2563)^{2/3}} \right]^2 = 0.00471;$$

$$y_h = \frac{A}{T} = \frac{A}{2.309y} = \frac{0.4545}{2.309(0.5126)} = 0.3841 \text{ ft}$$

$$N_F = \frac{2.75}{\sqrt{(32.2)(0.3841)}} = 0.782 < 1.0 \text{ Subcritical}$$

**Semicircle:**  $A = \frac{\pi y^2}{2}; y = \sqrt{\frac{2A}{\pi}} = \sqrt{\frac{2(0.4545)}{\pi}} = 0.5379 \text{ ft}$

$$R = y/2 = 0.269 \text{ ft}; S = \left[ \frac{0.02768}{(0.269)^{2/3}} \right]^2 = 0.00441$$

$$y_h = \frac{A}{T} = \frac{\pi y^2}{2(2y)} = \frac{\pi y}{4} = 0.4225 \text{ ft}$$

$$N_F = \frac{2.75}{\sqrt{(32.2)(0.4225)}} = 0.746 < 1.0 \text{ Subcritical}$$

14.39 a. When  $y = y_c, N_F = 1.0 = \frac{v}{\sqrt{gy_h}} = \frac{Q}{A\sqrt{gy}} = \frac{Q}{(by)\sqrt{gy}} = \frac{Q}{b\sqrt{g} y^{3/2}}$

$$\text{Then } y = \left[ \frac{Q}{b\sqrt{g}N_F} \right]^{2/3} = \left[ \frac{5.5}{2.0\sqrt{9.81}(1.0)} \right]^{2/3} = 0.917 \text{ m} = y_c$$

b. Minimum  $E$  occurs when  $y = y_c$ : From Eq. 14.18:

$$\begin{aligned} E_{\min} &= y_c + \frac{Q^2}{2gA^2} = y_c + \frac{Q^2}{2g(by_c)^2} = y_c + \frac{Q^2}{2gb^2y_c^2} \\ &= 0.917 + \frac{5.5^2}{2(9.81)(2.0)^2(0.917)^2} \end{aligned}$$

$$E_{\min} = 1.375 \text{ m}$$

c. See spreadsheet and graph for values of  $y$  versus  $E$ .

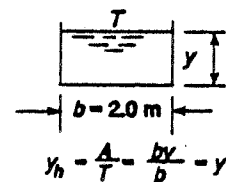
d. For  $y = 0.50 \text{ m}; E = 0.50 + \frac{5.5^2}{2(9.81)(2.0)^2(0.5)^2} = 2.042 \text{ m}$

From spreadsheet, alternate depth = 1.934 m

e.  $v = \frac{Q}{A} = \frac{Q}{by} = \frac{5.5}{2.0y}; N_F = \frac{v}{\sqrt{gy}}$

For  $y = 0.5 \text{ m}, v = 5.50 \text{ m/s}; N_F = 2.48$

For  $y = 1.934 \text{ m}, v = 1.418 \text{ m/s}; N_F = 1.325$



14.39 (continued)

**Rectangular channel**

$$b = 2$$

$$E = y + 0.3854/y^2$$

$$y = E_{\min} =$$

0.0917	1.375
--------	-------

$$Q = 5.5 \quad n = 0.017$$

Only for this problem

Critical depth—See Solution Manual

d), e), f)

Given $y =$	$E$	$A$	Velocity	$N_F$	$R$	$S$	
0.50	2.04160	1.000	5.500	2.483	0.333	0.0378	Given $y$
1.9391	2.04160	3.878	1.418	0.325	0.660	0.0010	Alternate depth for given depth by iteration on $y$ to make $E$ the same as for the given $y$

$y$	$E$
0.5	154.2
0.1	38.6
0.20	9.835
0.40	2.809
0.60	1.671
0.80	1.402
1.00	1.385
1.20	1.468
1.40	1.597
1.60	1.751
1.80	1.919
2.00	2.096
2.20	2.280
2.40	2.467
2.60	2.657
2.80	2.849
3.00	3.043
3.20	3.238
3.40	3.433
3.60	3.630
3.80	3.827
4.00	4.024
4.20	4.222
4.40	4.420
4.60	4.618

c) Equation for  $E$  (in m) as a function of  $y$ :  $A = by$ ;  $A^2 = b^2y^2$   
 Given:  $b = 2.0$  m;  $Q = 5.5$  m<sup>3</sup>/s;  $v = Q/A$

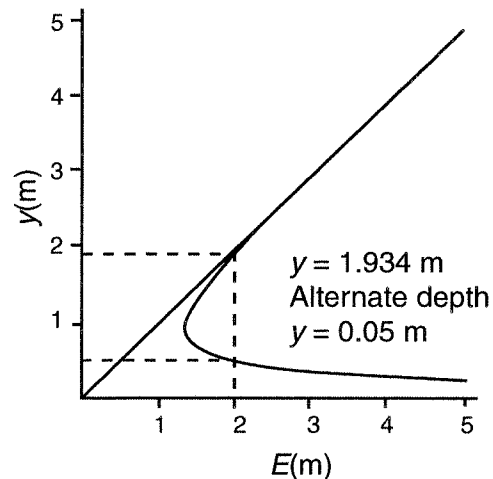
$$E = y + v^2/2g = y + Q^2/2gA^2 = Q^2/2gb^2y^2$$

$$E = y = (5.5)^2 / [3(9.81)(2.0)^2y^2] = y + 0.3854/y^2$$

f)  $S = \left[ \frac{nQ}{AR^{2/3}} \right]^2$ ;  $A = by = 2.0y$

$$WP = b + 2y = 2 + 2y$$

$$R = \frac{A}{WP} = \frac{2.0y}{2 + 2y} = \frac{y}{1 + y}$$



14.40 **Circular Channel**

$Q = 1.45 \text{ m}^3/\text{s}$   
 $D = 1.20 \text{ m}$

$n = 0.015$  Finished concrete

$y(\text{m})$	$\theta(\text{rad})$	$A(\text{m}^2)$	$T(\text{m})$	$y_h(\text{m})$	$N_F$	$E(\text{m})$	Velocity (m/s)	
<b><math>y</math> less than <math>D</math></b>								
0.10	1.171	0.0450	0.6633	0.068	39.478	52.982	32.211	
0.20	1.682	0.1239	0.8944	0.139	10.039	7.181	11.703	
0.25	1.896	0.1707	0.9747	0.175	6.481	3.928	8.494	
0.30	2.094	0.2211	1.0392	0.213	4.539	2.492	6.558	
0.40	2.462	0.3300	1.1314	0.292	2.597	1.384	4.394	
<b>0.50</b>	<b>2.807</b>	<b>0.4460</b>	<b>1.1832</b>	<b>0.377</b>	<b>1.690</b>	<b>1.039</b>	<b>3.251</b>	<b>Given <math>y</math></b>
0.60	3.142	0.5655	1.2000	0.471	1.193	0.935	2.564	
<b><math>y</math> greater than <math>D</math></b>								
0.658	3.335	0.6349	1.1944	0.532	1.000	0.924	2.284	<b>Critical depth</b>
0.70	3.476	0.6849	1.1832	0.579	0.888	0.928	2.117	
0.80	3.821	0.8010	1.1314	0.708	0.687	0.967	1.810	
0.90	4.189	0.9099	1.0392	0.876	0.544	1.029	1.594	
<b>0.913</b>	<b>4.238</b>	<b>0.9231</b>	<b>1.0240</b>	<b>0.901</b>	<b>0.528</b>	<b>1.039</b>	<b>1.571</b>	<b>Alt depth for given <math>y</math></b>
1.00	4.601	1.0071	0.8944	1.126	0.433	1.106	1.440	
1.199	6.168	1.1309	0.0693	16.330	0.101	1.283	1.282	<b>Nearly full pipe depth</b>
1.20	6.283	1.1310	0.0000	#DIV/0!	#DIV/0!	1.284	1.282	<b>Full pipe</b> ( $y_h$ and $N_F$ undefined)

**Part f of problem: Slopes for given  $y$  and alternate depth**

$y(\text{m})$	$R(\text{m})$	$S$	
0.50	0.2649	0.0140	$S$ for given $y$
0.913	0.3630	0.0021	$S$ for alternate depth

Problem 14.40 Procedure: Refer to Table 14.2 for geometry of a partially full circular pipe.

- a) For given  $Q$ ,  $D$ , and  $y$ : Compute  $\theta$ ,  $A$ ,  $T$  using equations in Table 14.2.

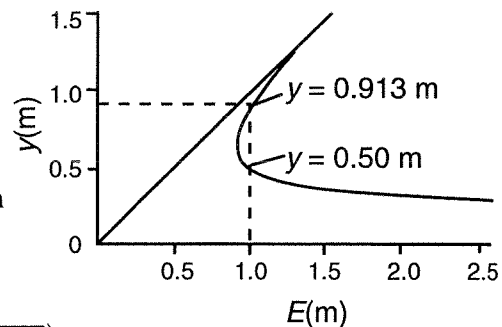
Compute  $N_F = v / \sqrt{gy_h} = Q / (A \sqrt{gy_h})$ .

Iterate values of  $y$  until  $N_F = 1.000$ . See spreadsheet:  $y_c = 0.658 \text{ m}$ .

- b) Minimum specific energy:  $E = y + v^2/2g = y + Q^2/(2gA^2)$   
 From spreadsheet, with  $y = y_c = 0.658 \text{ m}$ :  $E_{\min} = 0.924 \text{ m}$ .

- c) Specific energy versus  $y$ :  
 See spreadsheet using equation in b).

- d) Specific energy for  $y = 0.50 \text{ m}$ :  
 $E = 1.039 \text{ m}$  from spreadsheet.  
 Iterate on  $y$  to find alternate depth for which  
 $E = 1.039 \text{ m}$ .  
 See spreadsheet:  $y_{\text{alt}} = 0.913 \text{ m}$ .



- e) Velocity  $= v = Q/A$ ,  $N_F = v / \sqrt{gy_h} = Q / (A \sqrt{gy_h})$ . See spreadsheet

For  $y = 0.50 \text{ m}$ :  $v = 3.251 \text{ m/s}$ ,  $N_F = 1.690$ . **Supercritical**  
 For  $y = 0.913 \text{ m}$ :  $v = 1.571 \text{ m/s}$ ,  $N_F = 0.528$ . **Subcritical.**

f) Compute  $WP = \theta D/2$  (See Table 14.2). Compute  $R = A/WP$ .

Compute  $S: \left[ \frac{nQ}{AR^{2/3}} \right]^2$

See spreadsheet: For  $y = 0.50$  m,  $S = 0.0140$ . For  $y = 0.913$  m,  $S = 0.0021$ .

**14.41 Triangular channel**

$z = 1.5$                        $n = 0.022$   
 $Q = 0.68 \text{ ft}^3/\text{s}$

$y(\text{ft})$	$A(\text{ft}^2)$	$V(\text{ft}/\text{s})$	$T(\text{ft})$	$y_h(\text{ft})$	$N_F$	$E(\text{ft})$	
0.20	0.060		0.60	0.100	6.316	2.194	
<b>0.25</b>	<b>0.094</b>	<b>7.253</b>	<b>0.75</b>	<b>0.125</b>	<b>3.615</b>	<b>1.067</b>	<b>Given <math>y</math></b>
0.30	0.135		0.90	0.150	2.292	0.694	
0.40	0.240		1.20	0.200	1.116	0.525	
<b>0.418</b>	<b>0.262</b>	<b>2.594</b>	<b>1.254</b>	<b>0.209</b>	<b>1.000</b>	<b>0.523</b>	<b>Critical depth</b>
0.50	0.375		1.50	0.250	0.639	0.551	
0.60	0.540		1.80	0.300	0.405	0.625	
0.70	0.735		2.10	0.350	0.276	0.713	
0.80	0.960		2.40	0.400	0.197	0.808	
0.90	1.215		2.70	0.450	0.147	0.905	
1.00	1.500		3.00	0.500	0.113	1.003	
<b>1.065</b>	<b>1.701</b>	<b>0.400</b>	<b>3.20</b>	<b>0.533</b>	<b>0.097</b>	<b>1.067</b>	<b>Alternate depth</b>
1.10	1.815		3.30	0.550	0.089	1.102	
1.20	2.160		3.60	0.600	0.072	1.202	
1.30	2.535		3.90	0.650	0.059	1.301	
1.40	2.940		4.20	0.700	0.049	1.401	
1.50	3.375		4.50	0.750	0.041	1.501	

**Slopes at given depth and alternate depth**

$y(\text{ft})$	$R(\text{ft})$	$S$	
0.25	0.10401	0.521	Slope for given depth
1.065	0.44307	0.000229	Slope for alternate depth

**Problem 14.41 Procedure:** Refer to Table 14.2 for geometry of a triangular channel.

a) For given  $Q$ ,  $z$ , and  $y$ : Compute  $A$ ,  $T$  using equations in Table 14.2.

Compute  $N_F = v/\sqrt{gy_h} = Q/(A\sqrt{gy_h})$ .

Iterate values of  $y$  until  $N_F = 1.000$ .

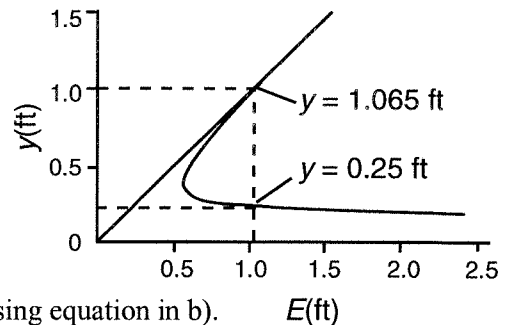
See spreadsheet:  $y_c = 0.418$  ft.

b) Minimum specific energy:

$E = y + v^2/2g = y + Q^2/(2gA^2)$

From spreadsheet, with  $y = y_c = 0.418$  ft:

$E_{\min} = 0.523$  ft.



c) Specific energy versus  $y$ : See spreadsheet using equation in b).

d) Specific energy for  $y = 0.25$  ft:  $E = 1.067$  ft from spreadsheet.

Iterate on  $y$  to find alternate depth for which  $E = 0.1067$  ft.

See spreadsheet:  $y_{\text{alt}} = 1.065$  ft.

e) Velocity =  $v = Q/A$ ,  $N_F = v/\sqrt{gy_h} = Q/(A\sqrt{gy_h})$ . See spreadsheet

For  $y = 0.25$  ft:  $v = 7.253$  ft/s,  $N_F = 3.615$ . **Supercritical**

For  $y = 1.065$  ft:  $v = 0.400$  ft/s,  $N_F = 0.097$ . **Subcritical.**

f) Compute  $WP = 2y\sqrt{1+z^2}$  (See Table 14.2). Compute  $R = A/WP$ .

Compute  $S: \left[ \frac{nQ}{AR^{2/3}} \right]^2$

See spreadsheet: For  $y = 0.25$  ft,  $S = 0.0521$ . For  $y = 1.065$  ft,  $S = 0.000229$ .

14.42 Trapezoidal channel

$z = 0.75$                        $n = 0.013$   
 $Q = 0.80$  ft<sup>3</sup>/s               $b = 3.000$  ft

$y(\text{ft})$	$A(\text{ft}^2)$	$V(\text{ft/s})$	$T(\text{ft})$	$Y_h(\text{ft})$	$N_F$	$E(\text{ft})$	
<b>0.05</b>	<b>0.152</b>	<b>5.267</b>	<b>3.08</b>	<b>0.049</b>	<b>4.177</b>	<b>0.481</b>	<b>Given y</b>
0.1	0.308	2.602	3.15	0.098	1.467	0.205	
<b>0.1288</b>	<b>0.399</b>	<b>2.006</b>	<b>3.19</b>	<b>0.125</b>	<b>1.000</b>	<b>0.191</b>	<b>Critical depth</b>
0.20	0.630	1.270	3.30	0.191	0.512	0.225	
0.25	0.797	1.004	3.38	0.236	0.364	0.266	
0.30	0.968	0.827	3.45	0.280	0.275	0.311	
0.40	1.320	0.606	3.60	0.367	0.176	0.406	
<b>0.4770</b>	<b>1.602</b>	<b>0.499</b>	<b>3.72</b>	<b>0.431</b>	<b>0.134</b>	<b>0.481</b>	<b>Alternate depth</b>
0.50	1.688	0.474	3.75	0.450	0.125	0.503	
0.60	2.070	0.386	3.90	0.531	0.093	0.602	
0.70	2.468	0.324	4.05	0.609	0.073	0.702	
0.80	2.880	0.278	4.20	0.686	0.059	0.801	
0.90	3.308	0.242	4.35	0.760	0.049	0.901	
1.00	3.750	0.213	4.50	0.833	0.041	1.001	
1.065	4.046	0.198	4.60	0.880	0.037	1.066	
1.10	4.208	0.190	4.65	0.905	0.035	1.101	
1.20	4.680	0.171	4.80	0.975	0.031	1.200	
1.30	5.168	0.155	4.95	1.044	0.027	1.300	
1.40	5.670	0.141	5.10	1.112	0.024	1.400	
1.50	6.188	0.129	5.25	1.179	0.021	1.500	

**Slopes at given depth and alternate depth**

$y(\text{ft})$	$R(\text{ft})$	$S$	
0.05	0.0486	0.264	Slope for given depth
0.477	0.3820	0.000152	Slope for alternate depth

**Problem 14.42 Procedure:** Refer to Table 14.2 for geometry of a trapezoidal channel.

a) For given  $Q$ ,  $b$ ,  $z$ , and  $y$ : Compute  $A$ ,  $T$  using equations in Table 14.2.

Compute  $N_F = v/\sqrt{gy_h} = Q/(A\sqrt{gy_h})$ .

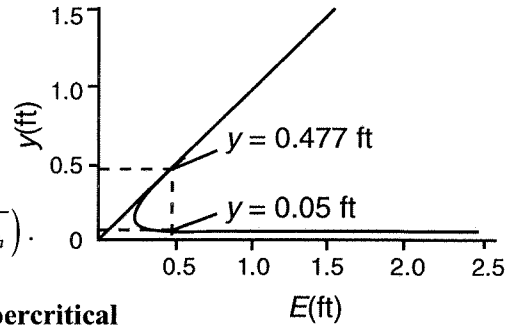
Iterate values of  $y$  until  $N_F = 1.000$ . See spreadsheet:  $y_c = 0.1288$  ft.

b) Minimum specific energy:  $E = y + v^2/2g = y + Q^2/(2gA^2)$

From spreadsheet, with  $y = y_c = 0.1288$  ft:  $E_{\min} = 0.191$  ft.

c) Specific energy versus  $y$ : See spreadsheet using equation in b).

- d) Specific energy for  $y = 0.05$  ft:  $E = 0.481$  ft from spreadsheet.  
Iterate on  $y$  to find alternate depth for which  $E = 0.481$  ft.  
See spreadsheet:  $y_{alt} = 0.4770$  ft.



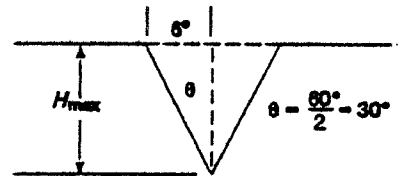
- e) Velocity  $= v = Q/A$ ,  $N_F = v/\sqrt{gy_h} = Q/(A\sqrt{gy_h})$ .  
See spreadsheet  
For  $y = 0.05$  ft:  $v = 5.267$  ft/s,  $N_F = 4.177$ . **Supercritical**  
For  $y = 0.4770$  ft:  $v = 0.499$  ft/s,  $N_F = 0.134$ . **Subcritical.**

- f) Compute  $WP = b + 2y\sqrt{1+z^2}$  (See Table 14.2). Compute  $R = A/WP$ .

$$\text{Compute } S: \left[ \frac{nQ}{AR^{2/3}} \right]^2$$

See spreadsheet: For  $y = 0.05$  ft,  $S = 0.264$ . For  $y = 0.4770$  ft,  $S = 0.000152$ .

- 14.43  $H_{max} = 6 \text{ in}/\tan 30^\circ = 10.4 \text{ in} \times \text{ft}/12 \text{ in} = 0.867$  ft  
 $Q_{max} = 1.43 H_{max}^{5/2} = (1.43)(0.867)^{5/2} = 1.00 \text{ ft}^3/\text{sec}$



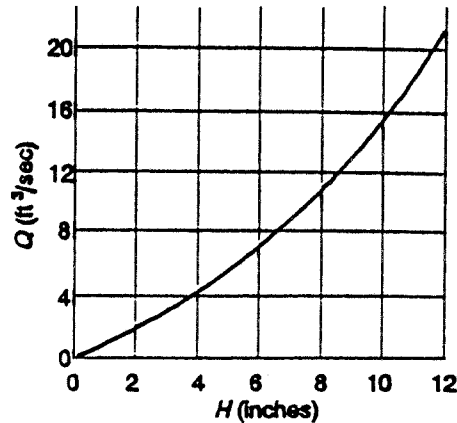
- 14.44  $H = 1.5$  ft;  $H_c = 3$  ft;  $Q = 15 \text{ ft}^3/\text{sec}$ ; use Eq. (14.15)  
 $Q = [3.27 + 0.40(1.5/3.0)][L - 0.2(1.5)](1.5)^{3/2}$   
 $= (3.47)(L - 0.3)(1.838)$

$$L - 0.3 = \frac{Q}{(3.47)(1.838)} = \frac{15}{(3.47)(1.838)} = 2.36 \text{ ft}$$

$$L = 2.36 \text{ ft} + 0.30 \text{ ft} = 2.66 \text{ ft}$$

- 14.45  $(Q = 3.27 + 0.40H/H_c)LH^{3/2}$   
 $H_c = 2$  ft;  $L = 6$  ft

		Prob. (15.10) (15.11)	
$H(\text{in})$	$H(\text{ft})$	$Q(\text{ft}^3/\text{sec})$	$Q$
0	0	0.00	0.00
2	.167	1.35	1.34
4	.333	3.84	3.80
6	.500	7.14	7.03
8	.667	11.10	10.90
10	.833	15.70	15.48
12	1.000	20.80	20.40

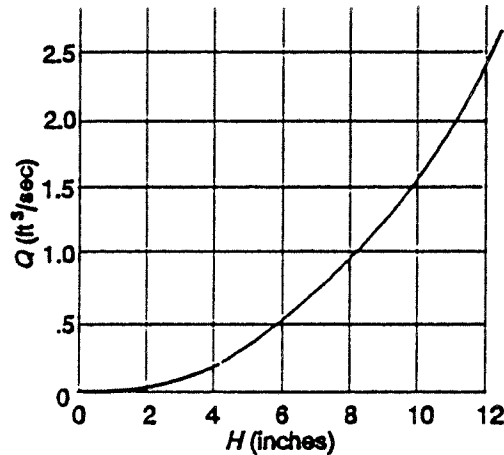


- 14.46  $Q = (3.27 + 0.40H/H_c)(L - 0.2H)H^{3/2}$   $\uparrow$   
Negligible difference on graph.

- 14.47 (a)  $Q = (3.27 + 0.4H/H_c)LH^{3/2} = [3.27 + 0.4(1.5/4)](3)(1.5)^{3/2} = 18.8 \text{ ft}^3/\text{sec}$   
(b)  $Q = (3.27 + 0.4H/H_c)(L - 0.2H)H^{3/2} = (3.42)(2.70)(1.5)^{3/2} = 16.95 \text{ ft}^3/\text{sec}$   
(c)  $Q = 2.48H^{5/2} = (2.48)(1.5)^{5/2} = 6.84 \text{ ft}^3/\text{sec}$

14.48  $Q = 2.48H^{5/2}$

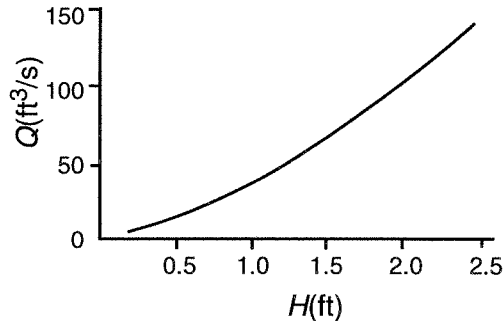
$H(\text{in})$	$H(\text{ft})$	$Q(\text{ft}^3/\text{sec})$
0	0	0
2	.167	.0283
4	.333	.159
6	.500	.439
8	.667	.900
10	.833	1.57
12	1.000	2.48



14.49  $Q = 3.07H^{1.53}$   
 $H^{1.53} = Q/3.07 \therefore H = (Q/3.07)^{1/1.53}$   
 Min  $Q = 0.09 \text{ ft}^3/\text{sec}$   
 $H = (0.09/3.07)^{1/1.53} = (0.0293)^{0.654}$   
 $= \mathbf{0.10 \text{ ft}}$   
 Max  $Q = 8.9 \text{ ft}^3/\text{sec}$   
 $H = (8.9/3.07)^{1/1.53} = (2.90)^{0.654}$   
 $= \mathbf{2.01 \text{ ft}}$

14.50  $L = 8.0 \text{ ft}$ ;  $Q_{\min} = 3.5 \text{ ft}^3/\text{s}$ ;  $Q_{\max} = 139.5 \text{ ft}^3/\text{s}$   
 $Q = 4.00 LH^n$ ;  $H = [Q/(4.00)L]^{1/n} = [Q/(4.00)(8.0)]^{1/1.61} = [Q/32]^{0.621}$   
 $Q_{\min} = 3.5 \text{ ft}^3/\text{s}$ ;  $H = [3.5/32]^{0.621} = \mathbf{0.253 \text{ ft}}$   
 $Q_{\max} = 139.5 \text{ ft}^3/\text{s}$ ;  $H = [139.5/32]^{0.621} = \mathbf{2.496 \text{ ft}}$

$H(\text{ft})$	$Q(\text{ft}^3/\text{sec})$
0.25	3.434
1.00	32.000
1.50	61.469
2.00	97.681
2.25	118.077
2.50	139.905



14.51 a)  $Q = 50 \text{ ft}^3/\text{s}$ ;  $L = 4.0 \text{ ft}$ ;  $Q = 4.00 LH^n$ ;  $n = 1.58$   
 $H = [Q/(4.00)L]^{1/n} = [50/(4.00)(4.0)]^{1/1.58} = [3.125]^{0.633} = \mathbf{2.06 \text{ ft}}$

b)  $L = 10.0 \text{ ft}$   
 $Q = (3.6875L + 2.5)H^{1.6} = 39.375H^{1.6}$   
 $H = \left(\frac{Q}{39.375}\right)^{1/1.6} = \left(\frac{50}{39.375}\right)^{0.625} = \mathbf{1.155 \text{ ft}}$

14.52 Trapezoidal channel—Long-throated flume – Design C:  $H = 0.84 \text{ ft}$ ;  $Q = K_1(H + K_2)^n$   
 $K_1 = 16.180$ ;  $K_2 = 0.035$ ;  $n = 1.784$   
 $Q = 16.180[0.84 + 0.035]^{1.784} = \mathbf{12.75 \text{ ft}^3/\text{s} = Q}$

- 14.53 Trapezoidal channel—Long-throated flume – Design B:  $H = 0.65$  ft;  $Q = K_1(H + K_2)^n$   
 $K_1 = 14.510$ ;  $K_2 = 0.053$ ;  $n = 1.855$   
 $Q = 14.510[0.65 + 0.053]^{1.855} = \mathbf{7.547 \text{ ft}^3/\text{s} = Q}$
- 14.54 Rectangular channel—Long-throated flume – Design A:  $H = 0.35$  ft;  $Q = b_c K_1(H + K_2)^n$   
 $b_c = 0.500$  ft;  $K_1 = 3.996$ ;  $K_2 = 0.000$ ;  $n = 1.612$   
 $Q = (0.500)(3.996)[0.35 + 0.000]^{1.612} = \mathbf{0.368 \text{ ft}^3/\text{s} = Q}$
- 14.55 Rectangular channel—Long-throated flume – Design C:  $H = 0.40$  ft;  $Q = b_c K_1(H + K_2)^n$   
 $b_c = 1.500$  ft;  $K_1 = 3.375$ ;  $K_2 = 0.011$ ;  $n = 1.625$   
 $Q = (1.500)(3.375)[0.40 + 0.011]^{1.625} = \mathbf{1.194 \text{ ft}^3/\text{s} = Q}$
- 14.56 Circular channel—Long-throated flume – Design B:  $H = 0.25$  ft;  $Q = D^{2.5} K_1 (H/D + K_2)^n$   
 $D = 2.00$  ft;  $K_1 = 3.780$ ;  $K_2 = 0.000$ ;  $n = 1.625$   
 $Q = (2.00)^{2.5}(3.780)[0.25/2.00 + 0.000]^{1.625} = \mathbf{0.729 \text{ ft}^3/\text{s} = Q}$
- 14.57 Circular channel—Long-throated flume – Design A:  $H = 0.09$  ft;  $Q = D^{2.5} K_1 (H/D + K_2)^n$   
 $b_c = 1.00$  ft;  $K_1 = 3.970$ ;  $K_2 = 0.004$ ;  $n = 1.689$   
 $Q = (1.00)^{2.5}(3.970)[0.09/1.00 + 0.004]^{1.689} = \mathbf{0.0732 \text{ ft}^3/\text{s} = Q}$
- 14.58 Rectangular channel—Long-throated flume – Design B:  $Q = 1.25$  ft<sup>3</sup>/s; Find  $H$ .  
 $Q = b_c K_1(H + K_2)^n$ ;  $b_c = 1.00$  ft;  $K_1 = 3.696$ ;  $K_2 = 0.004$ ;  $n = 1.617$   
Solving for  $H$ :  $H = [Q/(b_c K_1)]^{1/n} - K_2 = [1.25/(1.0)(3.696)]^{1/1.617} - 0.004 = \mathbf{0.507 \text{ ft} = H}$
- 14.59 Circular channel—Long-throated flume – Design C:  $Q = 6.80$  ft<sup>3</sup>/s; Find  $H$ .  
 $Q = D^{2.5} K_1(H/D + K_2)^n$ ;  $D = 3.000$  ft;  $K_1 = 3.507$ ;  $K_2 = 0.000$ ;  $n = 1.573$   
Solving for  $H$ :  $H = D\{[Q/D^{2.5}](K_1)^{1/n} - K_2\} = 3.0\{[6.80/(3.0^{2.5})(3.507)]^{1/1.573} - 0.000\}$   
 $= \mathbf{0.797 \text{ ft} = H}$
- 14.60 Select a long-throated flume for  $30 \text{ gpm} < Q < 500 \text{ gpm}$ . Using  $449 \text{ gpm} = 1.0 \text{ ft}^3/\text{s}$ ,  
 $0.0668 \text{ ft}^3/\text{s} < Q < 1.114 \text{ ft}^3/\text{s}$ ; Select Circular channel; Design A;  $Q = D^{2.5} K_1(H/D + K_2)^n$   
 $H = D\{[Q/D^{2.5}](K_1)^{1/n} - K_2\}$ ;  $D = 1.000$  ft;  $K_1 = 3.970$ ;  $K_2 = 0.004$ ;  $n = 1.689$   
For  $Q = 0.0668 \text{ ft}^3/\text{s}$ :  $H = -1.0\{[0.0668/(1.0^{2.5})(3.970)]^{1/1.689} - 0.004\} = \mathbf{0.0851 \text{ ft} = H}$   
For  $Q = 1.114 \text{ ft}^3/\text{s}$ :  $H = -1.0\{[1.114/(1.0^{2.5})(3.970)]^{1/1.689} - 0.004\} = \mathbf{0.467 \text{ ft} = H}$

$H$	$Q(\text{ft}^3/\text{s})$	$Q(\text{gpm})$
0.10	0.087	39.06
0.20	0.271	121.7
0.30	0.531	238.4
0.40	0.859	385.7

- 14.61 Given  $50 \text{ m}^3/\text{h} < Q < 180 \text{ m}^3/\text{h}$ ; Convert to  $\text{ft}^3/\text{s}$ ;  $0.4907 \text{ ft}^3/\text{h} < Q < 1.766 \text{ ft}^3/\text{h}$   
Specify Rectangular channel long-throated flume, Design B.

Find  $H$  for each limiting flow rate.

$$Q = b_c K_1 (H + K_2)^n; b_c = 1.00 \text{ ft}; K_1 = 3.696; K_2 = 0.004; n = 1.617$$

$$\text{Solving for } H: H_{\min} = [Q/(b_c K_1)]^{1/n} - K_2 = [0.4907/(1.0)(3.696)]^{1/1.617} - 0.004 \\ = \mathbf{0.2829 \text{ ft} = H_{\min}}$$

Converting to m:  $H_{\min} = \mathbf{0.0863 \text{ m for } Q = 50 \text{ m}^3/\text{h}}$

$$H_{\max} = [Q/b_c K_1]^{1/n} - K_2 = [1.766/(1.0)(3.696)]^{1/1.617} - 0.004 = 0.629 \text{ ft} = H_{\max}$$

Converting to m:  $H_{\max} = \mathbf{0.1917 \text{ m for } Q = 180 \text{ m}^3/\text{h}}$

$H(\text{m})$	$H(\text{ft})$	$Q(\text{ft}^3/\text{s})$	$Q(\text{m}^3/\text{h})$
0.100	0.328	0.622	63.38
0.125	0.410	0.888	90.49
0.150	0.492	1.190	121.3
0.175	0.524	1.524	155.3

# CHAPTER FIFTEEN

## FLOW MEASUREMENT

$$15.1 \quad Q = CA_1 \left[ \frac{2g(p_1 - p_2)/\gamma}{(A_1/A_2)^2 - 1} \right]^{1/2} = (0.984)(7.854 \times 10^{-3}) \left[ \frac{2(9.81)(55)/9.53}{[(7.854 \times 10^{-3})/(1.964 \times 10^{-3})]^2 - 1} \right]^{1/2}$$

$Q = 2.12 \times 10^{-2} \text{ m}^3/\text{s} = \mathbf{0.0212 \text{ m}^3/\text{s}}$       Now check  $N_R$  and re-evaluate  $C$ .

$$v_1 = \frac{Q}{A_1} = \frac{2.12 \times 10^{-2} \text{ m}^3/\text{s}}{7.854 \times 10^{-3} \text{ m}^2} = 2.70 \text{ m/s}$$

$$N_R = \frac{v_1 D_1}{\nu} = \frac{(2.70)(0.10)}{3.60 \times 10^{-7}} = 7.5 \times 10^5 \quad \text{Then } C = 0.984; \mathbf{OK}$$

$$15.2 \quad p_1 - p_2 = \gamma_w h_w = (9.81 \text{ kN/m}^3)(0.081 \text{ m}) = 0.795 \text{ kN/m}^2$$

$$\frac{p_1 - p_2}{\gamma_{air}} = \frac{0.795 \text{ kN/m}^2}{12.7 \text{ N/m}^3} \times \frac{10^3 \text{ N}}{1 \text{ kN}} = 62.57 \text{ m}$$

Assume  $C = 0.98$

$$Q = CA_1 \left[ \frac{2gh[\gamma_m/\gamma_w - 1]}{(A_1/A_2)^2 - 1} \right]^{1/2} = (0.98)(7.854 \times 10^{-3}) \left[ \frac{2(9.81)(0.81)/[9810/12.7 - 1]}{[(7.854 \times 10^{-3})/(1.964 \times 10^{-3})]^2 - 1} \right]^{1/2}$$

$Q = 6.96 \times 10^{-2} \text{ m}^3/\text{s}$

Check  $C$  from Fig. 15.5.

$$v = \frac{Q}{A_1} = \frac{6.96 \times 10^{-2} \text{ m}^3/\text{s}}{7.854 \times 10^{-3}} = 8.87 \text{ m/s}$$

$$N_R = \frac{v_1 D_1}{\nu} = \frac{(8.87)(0.100)}{1.3 \times 10^{-5}} = 6.82 \times 10^4 \quad \text{Then } C = 0.98, \mathbf{OK}$$

$$15.3 \quad A_1 = 0.02333 \text{ ft}^2; A_2 = 0.00545 \text{ ft}^2; A_2/A_1 = 0.234$$

$$D = 2.067 \text{ in}; d/D = 1.00/2.067 \text{ in} = 0.484; \text{ try } C = 0.605 \text{ (Fig. 15.7)}$$

$$Q = CA_1 \left[ \frac{2g(p_1 - p_2)/\gamma}{(A_1/A_2)^2 - 1} \right]^{1/2} = (0.605)(0.02333) \left[ \frac{2(32.2)(0.53)(144)/51.2}{[(0.02333)/(0.00545)]^2 - 1} \right]^{1/2}$$

$= 0.0332 \text{ ft}^3/\text{sec}$

$$v_1 = \frac{Q}{A_1} = \frac{0.0332 \text{ ft}^3/\text{sec}}{0.02333 \text{ ft}^2} = 1.42 \text{ ft/sec}$$

$$N_R = \frac{v_1 D_1 \rho}{\mu} = \frac{(1.42)(0.1723)(1.60)}{3.43 \times 10^{-5}} = 1.14 \times 10^4$$

Then  $C = 0.612$  (Fig. 15.7)—Recompute  $Q$

$$Q = 0.0332 \text{ ft}^3/\text{sec} \times 0.612/0.605 = \mathbf{0.0336 \text{ ft}^3/\text{sec}}$$

$$v = Q/A = 1.44 \text{ ft/sec}; N_R = 1.16 \times 10^4; \text{ No change in } C$$

- 15.4  $Q = 25 \text{ gal/min} \times 1 \text{ ft}^3/\text{sec}/449 \text{ gal/min} = 0.0557 \text{ ft}^3/\text{sec}$   
 $v = Q/A = 0.0557 \text{ ft}^3/\text{sec}/0.545 \text{ ft}^2 = 0.1022 \text{ ft/sec}$   
 pipe  $N_R = \frac{vD\rho}{\mu} = \frac{(0.1022)(0.833)(0.83)(1.94)}{2.5 \times 10^{-6}} = 5.5 \times 10^4$   
 (a)  $d/D = 1.0/10.0 = 0.10$ ;  $C = 0.595$  (Fig. 15.7)  
 (b)  $d/D = 7.0/10.0 = 0.70$ ;  $C = 0.620$

Solve for  $p_1 - p_2$  from Eq. (15.5)

$$Q = CA_1 \left[ \frac{2g(p_1 - p_2)/\gamma}{(A_1/A_2)^2 - 1} \right]^{1/2}; \text{ Then } Q^2 = C^2 A_1^2 \left[ \frac{2g(p_1 - p_2)/\gamma}{(A_1/A_2)^2 - 1} \right]$$

$$p_1 - p_2 = \frac{\gamma Q^2 [(A_1/A_2)^2 - 1]}{2g C^2 A_1^2}$$

- (a) For  $d = 1.0 \text{ in}$ ,  $A_2 = 0.00545 \text{ ft}^2$ ;  $A_1/A_2 = 0.545/0.00545 = 100$

$$p_1 - p_2 = \frac{\gamma Q^2 [(A_1/A_2)^2 - 1]}{2g C^2 A_1^2} = \frac{(0.83)(62.4)(0.0557)^2 [(100)^2 - 1]}{2(32.2)(0.595)^2 (0.545)^2} = 238 \text{ lb/ft}^2$$

For Manometer

$$p_1 + \gamma_A h - \gamma_w h = p_2$$

$$p_1 - p_2 = \gamma_w h - \gamma_A h = h(\gamma_w - \gamma_A)$$

$$h = \frac{p_1 - p_2}{\gamma_w - \gamma_A} \text{ But } \gamma_A = (0.83)(62.4 \text{ lb/ft}^3) = 51.8 \text{ lb/ft}^3$$

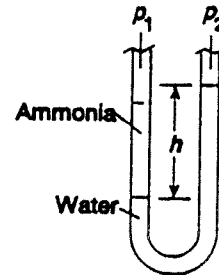
$$h = \frac{p_1 - p_2}{62.4 - 51.8} = \frac{p_1 - p_2}{10.6 \text{ lb/ft}^3} = \frac{238 \text{ lb/ft}^2}{10.6 \text{ lb/ft}^3} = 22.4 \text{ ft}$$

- (b) For  $d = 7.0 \text{ in}$ ,  $A_2 = \frac{\pi(7.0)^2 \text{ in}^2}{4} \times \frac{\text{ft}^2}{144 \text{ in}^2} = 0.267 \text{ ft}^2$

$$A_1/A_2 = 0.545/0.267 = 2.04$$

$$p_1 - p_2 = \frac{\gamma Q^2 [(A_1/A_2)^2 - 1]}{2g C^2 A_1^2} = \frac{(0.83)(62.4)(0.0557)^2 [(2.04)^2 - 1]}{2(32.2)(0.620)^2 (0.545)^2} = 0.0694 \text{ lb/ft}^2$$

$$h = \frac{p_1 - p_2}{10.6} = \frac{0.0694 \text{ lb/ft}^2}{10.6 \text{ lb/ft}^3} = 0.00655 \text{ ft}$$



An orifice size between 1.0 in and 7.0 in would be preferred to give a more convenient manometer deflection.

- 15.5 Find  $\Delta p$  across nozzle,  $Q = 1800 \text{ gal/min}(1 \text{ ft}^3/\text{s})(449 \text{ gal/min}) = 4.009 \text{ ft}^3/\text{s}$

$$v_1 = Q/A_1 = (4.009 \text{ ft}^3/\text{s})/(0.1810 \text{ ft}^2) = 22.15 \text{ ft/s}$$

$$\text{Water at } 120^\circ\text{F}; \gamma = 61.7 \text{ lb/ft}^3; \nu = 5.94 \times 10^{-6} \text{ ft}^2/\text{s}$$

$$N_R = v_1 D_1 / \nu = (22.15)(0.4801)/(5.94 \times 10^{-6}) = 1.79 \times 10^6; \text{ Then } C = 0.992$$

From Eq. (15-4), solving for  $p_1 - p_2 = \Delta p$

$$\Delta p = [v_1/C]^2 [(A_1/A_2)^2 - 1] [\gamma/2g] = [22.15/0.992]^2 [(0.18/0.0668)^2 - 1] [61.7/(2(32.2))]$$

$$\Delta p = 3029 \text{ lb/ft}^2 (1 \text{ ft}^2/144 \text{ in}^2) = 21.04 \text{ psi}$$

- 15.6 Find  $\Delta p$  across Venturi,  $Q = 600 \text{ gal/min}(1 \text{ ft}^3/\text{s})(449 \text{ gal/min}) = 1.336 \text{ ft}^3/\text{s}$   
 $v_1 = Q/A_1 = (1.336 \text{ ft}^3/\text{s})/(0.0844 \text{ ft}^2) = 15.12 \text{ ft/s}$   
 Kerosene at  $77^\circ\text{F}$ ;  $\gamma = 51.2 \text{ lb/ft}^3$ ;  $\nu = 2.14 \times 10^{-5} \text{ ft}^2/\text{s}$   
 $N_R = v_1 D_1 / \nu = (15.12)/(0.3355)/(2.14 \times 10^{-5}) = 2.37 \times 10^5$ ; Then  $C = 0.984$   
 From Eq. (15-4), solving for  $p_1 - p_2 = \Delta p$   
 $\Delta p = [v_1/C]^2 [(A_1/A_2)^2 - 1] [\gamma/2g] = [15.12/0.984]^2 [(0.0884/0.01227)^2 - 1][51.2/(2(32.2))]$   
 $\Delta p = 9551 \text{ lb/ft}^2 (1 \text{ ft}^2/144 \text{ in}^2) = \mathbf{66.3 \text{ psi}}$

- 15.7 Find  $Q$  through an orifice meter.  $D_1 = 97.2 \text{ mm}$ ;  $A_1 = 7.419 \times 10^{-3} \text{ m}^2$ ;  $d = 50 \text{ mm} = 0.050 \text{ m}$   
 $A_2 = 1.963 \times 10^{-3} \text{ m}^2$ ;  $A_1 A_2 = 3.778$ ;  $d/D = 0.05/0.0972 = 0.514$ ; Trial 1:  $C = 0.608$  for  
 $N_R = 1 \times 10^5$   
 Ethylene glycol at  $25^\circ\text{C}$ :  $\gamma = 10.79 \text{ kN/m}^3$ ;  $\nu = 1.47 \times 10^{-5} \text{ m}^2/\text{s}$

$$v_1 = C \left[ \frac{2gh[\gamma_m / \gamma_{eg} - 1]}{(A_1 / A_2)^2 - 1} \right]^{1/2} = (0.608) \left[ \frac{2(9.81)(0.095)/[132.8/10.79 - 1]}{[3.778]^2 - 1} \right]^{1/2}$$

- $\nu = 0.766 \text{ m/s}$ ; Iteration: New  $N_R = 5.07 \times 10^3$ ; New  $C = 0.623$   
 New  $v_1 = 0.785 \text{ m/s}$ ; New  $N_R = 5.19 \times 10^3$ ; New  $C = 0.623$  – Unchanged.  
 Final value of  $Q = A_1 v_1 = (7.419 \times 10^{-3} \text{ m}^2)(0.785 \text{ m/s}) = \mathbf{5.824 \times 10^{-3} \text{ m}^3/\text{s} = Q}$

- 15.8 Orifice meter. Propyl alcohol at  $25^\circ\text{C}$ ;  $\gamma = 7.87 \text{ kN/m}^3$ ;  $\nu = 2.39 \times 10^{-6} \text{ m}^2/\text{s}$   
 1 1/2 in  $\times$  0.065 in wall steel tube:  $D_1 = 34.8 \text{ mm} = 0.0348 \text{ m}$ ;  $A_1 = 9.51 \times 10^{-4} \text{ m}^2$   
 Let  $\beta = 0.40 = d/D$ ; Then  $d = 0.40 D = 0.40(34.8 \text{ mm}) = 13.92 \text{ mm} = 0.01392 \text{ m}$   
 $A_2 = \pi d^2/4 = \pi(0.01392 \text{ m})^2/4 = 1.52 \times 10^{-4} \text{ m}^2$ ;  $A_1/A_2 = 6.26$   
 From Eq. (15-6), solve for  $h$  in mercury manometer;  $\gamma_m = 132.8 \text{ kN/m}^3$

$$h = \frac{[(A_1 / A_2)^2 - 1]v_1^2}{2gC^2[(\gamma_m / \gamma_a) - 1]}$$

- $v_{1\text{min}} = Q_{\text{min}}/A_1 = (1.0 \text{ m}^3/\text{h})/(9.51 \times 10^{-4} \text{ m}^2)(1 \text{ h})/(3600 \text{ s}) = 0.292 \text{ m/s}$   
 $N_{R1} = v_1 D_1 / \nu = (0.292)(0.0348)/(9.51 \times 10^{-4} \text{ m}^2) = 4.25 \times 10^3$ ;  $C = 0.619$

$$h_{\text{min}} = \frac{[(A_1 / A_2)^2 - 1]v_{1\text{min}}^2}{2gC^2[(\gamma_m / \gamma_a) - 1]} = \frac{[(6.26)^2 - 1](0.292 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)(0.619)^2[(132.8/7.87) - 1]} = 0.0273 \text{ m} = \mathbf{27.3 \text{ mm}}$$

- Similarly,  $v_{1\text{max}} = 0.730 \text{ m/s}$ ;  $N_R = 1.06 \times 10^3$ ;  $C = 0.610$   
 $h_{\text{max}} = 0.1754 \text{ m} = \mathbf{175.4 \text{ mm}}$

- 15.9 Flow nozzle — Design: Install in 5 1/2 inch Type K copper tube;  $D_1 = 4.805 \text{ in}$ ;  $A_1 = 0.1259 \text{ ft}^2$   
 Specify the throat diameter  $d$ . **NOTE: Multiple solutions possible.**  
 Fluid: Linseed oil at  $77^\circ\text{F}$ ;  $\gamma = 58.0 \text{ lb/ft}^3$ ;  $\nu = 3.84 \times 10^{-4} \text{ ft}^2/\text{s}$   
 Use mercury manometer with scale range 0 – 8 inHg  
 Range of flow rate:  $Q_{\text{min}} = 700 \text{ gpm} = 1.559 \text{ ft}^3/\text{s}$ ;  $Q_{\text{max}} = 1000 \text{ gpm} = 2.227 \text{ ft}^3/\text{s}$   
 Velocity in pipe:  $v_{1\text{-min}} = Q_{\text{min}}/A_1 = 12.38 \text{ ft/s}$ ;  $v_{1\text{-max}} = Q_{\text{max}}/A_1 = 17.69 \text{ ft/s}$   
 Reynolds No.:  $N_{R\text{-min}} = v_{1\text{-min}} D_1 / \nu = 1.29 \times 10^4$ ;  $N_{R\text{-max}} = v_{1\text{-max}} D_1 / \nu = 1.84 \times 10^4$   
 From Figure 15-5:  $C_{\text{min}} = 0.955$ ;  $C_{\text{max}} = 0.961$

- a) Use Eq. (15-6) and solve for  $A_2$  from which we can obtain the throat diameter  $d$

$$A_2 = \frac{A_1}{\left[ \frac{BhC^2}{v_1^2} + 1 \right]^{1/2}}$$

$$\text{Where } B = 2g[(\gamma_m/\gamma_{Lo}) - 2(32.2)[844.9/58.0] - 1] = 873.7$$

$$\text{Let } h = 8.0 \text{ in} = 0.667 \text{ ft when } v = v_{1-\max} = 17.69 \text{ ft/s and } C = 0.961$$

$$A_2 = \frac{0.1259}{\left[ \frac{(873.7)(0.667)(0.961)^2}{(17.69)^2} + 1 \right]^{1/2}} = 0.07635 \text{ ft}^2 = \pi d^2/4$$

$$\text{Then } d = (4A_2/\pi)^{1/2} = [(4)(0.07635)/\pi]^{1/2} = 0.3118 \text{ ft} = \mathbf{3.741 \text{ in} = \text{Throat diameter}}$$

- b) Use Eq. (15-6) and solve for  $h$  to determine the manometer reading when  $Q = Q_{\min}$ .

$$h = \frac{(v_1/C)^2[(A_1/A_2)^2 - 1]}{B}$$

$$\text{For } v_1 = v_{1-\min} = 12.38 \text{ ft/s and } C = 0.955,$$

$$h = \frac{(v_1/C)^2[(A_1/A_2)^2 - 1]}{B} = \frac{[(12.38/0.955)^2[(0.1259/0.07635)^2 - 1]}{873.73} = 0.3306 \text{ ft} = \mathbf{3.97 \text{ in}}$$

**Summary:** Nozzle throat diameter =  $d = 3.741 \text{ in}$   
 When  $Q = 1000 \text{ gpm}$ ,  $h = 8.00 \text{ in}$  manometer deflection  
 When  $Q = 700 \text{ gpm}$ ,  $h = 3.97 \text{ in}$  manometer deflection

- 15.10 Orifice Meter — Design: Install in 12 inch ductile iron pipe;  $D_1 = 12.24 \text{ in} = 1.020 \text{ ft}$ ;  
 $A_1 = 0.8171 \text{ ft}^2$

Specify the orifice diameter  $d$ . **NOTE:** Multiple solutions possible.

Fluid: Water at 60°F;  $\gamma = 62.4 \text{ lb/ft}^3$ ;  $\nu = 1.21 \times 10^{-5} \text{ ft}^2/\text{s}$

Use mercury manometer with scale range 0 – 12 inHg

Range of flow rate:  $Q_{\min} = 1500 \text{ gpm} = 3.341 \text{ ft}^3/\text{s}$ ;  $Q_{\max} = 4000 \text{ gpm} = 8.909 \text{ ft}^3/\text{s}$

Velocity in pipe:  $v_{1-\min} = Q_{\min}/A_1 = 4.089 \text{ ft/s}$ ;  $v_{1-\max} = Q_{\max}/A_1 = 10.90 \text{ ft/s}$

Reynolds No.:  $N_{R-\min} = v_{1-\min} D_1/\nu = 3.45 \times 10^5$ ;  $N_{R-\max} = v_{1-\max} D_1/\nu = 9.19 \times 10^5$

From Figure 15-5:  $C_{\min} = 0.612$ ;  $C_{\max} = 0.610$  [Assumed  $\beta = d/D = 0.70$ ]

- a) Use Eq.(15-6) and solve for  $A_2$  from which we can obtain the throat diameter  $d$ .

$$A_2 = \frac{A_1}{\left[ \frac{BhC^2}{v_1^2} + 1 \right]^{1/2}}$$

$$\text{Where } B = 2g[(\gamma_m/\gamma_w) - 1] = 2(32.2)[(844.9/62.4) - 1] = 807.6$$

$$\text{Let } h = 10.0 \text{ in} = 0.833 \text{ ft when } v = v_{1-\max} = 10.90 \text{ ft/s and } C = 0.610$$

$$A_2 = \frac{0.8171}{\left[ \frac{(807.6)(0.833)(0.610)^2}{(10.90)^2} + 1 \right]^{1/2}} = 0.4636 \text{ ft}^2 = \pi d^2/4$$

Then  $d = (4A_2/\pi)^{1/2} = [(4)(0.4636)/\pi]^{1/2} = 0.7683 \text{ ft} = \mathbf{9.219 \text{ in}} = \mathbf{\text{Throat diameter}}$   
 Actual  $\beta = d/D = 9.219/12.24 = 0.753$ ; Assumed  $C$  values OK.

b) Use Eq. (15-6) and solve for  $h$  to determine the manometer reading when  $Q = Q_{\min}$ .

$$h = \frac{(v_1/C)^2[(A_1/A_2)^2 - 1]}{B}$$

For  $v_1 = v_{1-\min} = 4.089 \text{ ft/s}$  and  $C = 0.612$

$$h = \frac{(v_1/C)^2[(A_1/A_2)^2 - 1]}{B} = \frac{[(4.089/0.612)^2(0.8171/0.4636)^2 - 1]}{807.6} = 0.1164 \text{ ft} = \mathbf{1.40 \text{ in}}$$

Summary: Nozzle throat diameter =  $d = 9.219 \text{ in}$ .  
 When  $Q = 4000 \text{ gpm}$ ,  $h = 10.0 \text{ in}$  manometer deflection  
 When  $Q = 1500 \text{ gpm}$ ,  $h = 1.40 \text{ in}$  manometer deflection

15.11  $v = \sqrt{2gh(\gamma_g - \gamma)/\gamma}$ ;  $h = 225 \text{ mm} = 0.225 \text{ m}$

$\gamma_g = 132.8 \text{ kN/m}^3$  (mercury);  $\gamma = 7.74 \text{ kN/m}^3$  (methyl alcohol)

$v = \sqrt{2(9.81)(0.225)(132.8 - 7.74)/7.74} = \mathbf{8.45 \text{ m/s}}$

15.12  $v = \sqrt{2gh(\gamma_g - \gamma)/\gamma}$  Solve for  $h$  ( $\gamma_{\text{air}} = 11.05 \text{ N/m}^3$ )

$$h = \frac{\gamma v^2}{2g(\gamma_g - \gamma)}$$

( $\gamma_g = 9.73 \text{ kN/m}^3 = 9.73 \times 10^3 \text{ N/m}^3$ )

( $\gamma_g - \gamma = 9.719 \times 10^3 \text{ N/m}^3 = 9719 \text{ N/m}^3$ )

$$h = \frac{(11.05)(25)^2}{2(9.81)(9719)} \text{ m} = 0.036 \text{ m} \times 10^3 \text{ mm/m} = \mathbf{36 \text{ mm}}$$

15.13  $v = \sqrt{2gh(\gamma_g - \gamma)/\gamma} = \sqrt{2(9.81)(0.106)(132.8 - 9.81)/9.81} = \mathbf{5.11 \text{ m/s}}$

15.14 Pitot-static tube carrying air at atmospheric pressure and  $50^\circ\text{C}$ .  $\gamma_a = 10.71 \text{ N/m}^3$ .

$h = 4.80 \text{ mmH}_2\text{O}$ ;  $h = (4.80 \text{ mm})(1 \text{ m}/1000 \text{ mm}) = 0.0048 \text{ mH}_2\text{O}$ ;  $\gamma_g = \gamma_w = 9810 \text{ N/m}^3$

Find flow velocity  $v$ .

$$v = \sqrt{2gh(\gamma_w - \gamma_a)/\gamma_a} = \sqrt{2(9.81 \text{ m/s}^2)(0.0048 \text{ m})(9810 - 10.71)/10.71} = 9.28 \text{ m/s}$$

15.15 Pitot-static tube carrying air at atmospheric pressure and  $80^\circ\text{F}$ .  $\gamma_a = 0.0736 \text{ lb/ft}^3$ .

$h = 0.24 \text{ inH}_2\text{O}$ ;  $h = (0.24 \text{ in})(1.0 \text{ ft}/12 \text{ in}) = 0.02 \text{ ft}$ ;  $\gamma_g = \gamma_w = 62.4 \text{ lb/ft}^3$

Find flow velocity  $v$ .

$$v = \sqrt{2gh(\gamma_w - \gamma_a)/\gamma_a} = \sqrt{2(32.2 \text{ ft}^2/\text{s}^2)(0.02 \text{ ft})(62.4 - 0.0736)/0.0736} = 33.0 \text{ ft/s}$$

# CHAPTER SIXTEEN

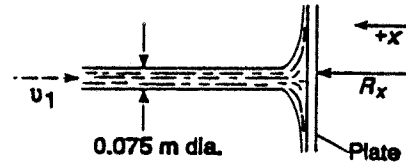
## FORCES DUE TO FLUIDS IN MOTION

$$16.1 \quad Q = Av = \frac{\pi(0.075 \text{ m})^2}{4} \times \frac{25 \text{ m}}{\text{s}} = \frac{0.1104 \text{ m}^3}{\text{s}}$$

$$R_x = \rho Q(v_{2_x} - v_{1_x}) = \rho Q(0 - (-v_1)) = \rho Q v_1$$

$$R_x = \frac{1000 \text{ kg}}{\text{m}^3} \times \frac{0.1104 \text{ m}^3}{\text{s}} \times \frac{25 \text{ m}}{\text{s}} = \frac{2761 \text{ kg} \cdot \text{m}}{\text{s}^2}$$

$$= 2761 \text{ N} = \mathbf{2.76 \text{ kN}}$$



$$16.2 \quad \text{See sketch for Problem 16.1: } R_x = \rho Q v_1 = \rho(A v_1) v_1 = \rho A v_1^2$$

$$v = \sqrt{\frac{R_x}{\rho A}} = \sqrt{\frac{300 \text{ lb} \cdot 144 \text{ in}^2/\text{ft}^2}{(1.94 \text{ lb} \cdot \text{s}^2/\text{ft}^4)(\pi(2.0 \text{ in})^2/4)}} = \mathbf{84.2 \text{ ft/s}}$$

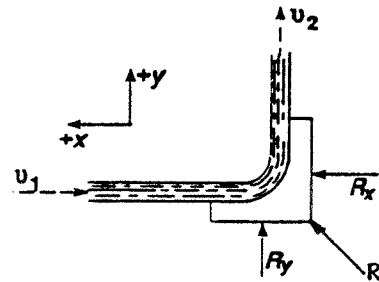
$$16.3 \quad Q = 150 \text{ gal/min} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 0.334 \text{ ft}^3/\text{s}$$

$$v_1 = v_2 = \frac{Q}{A} = \frac{0.324 \text{ ft}^3/\text{s}}{\pi(1/12 \text{ ft})^2/4} = 61.25 \text{ ft/s}$$

$$R_x = \rho Q(v_{2_x} - v_{1_x}) = \rho Q(0 - (-v_1)) = \rho Q v_1$$

$$R_x = \frac{1.94 \text{ lb} \cdot \text{s}^2}{\text{ft}^4} \times \frac{0.334 \text{ ft}^3}{\text{s}} \times \frac{61.25 \text{ ft}}{\text{s}} = \mathbf{39.7 \text{ lb}}$$

$$R_y = \rho Q(v_{2_y} - v_{1_y}) = \rho Q(v_2 - 0) = \rho Q v_2 = \rho Q v_1 = \mathbf{39.7 \text{ lb}}$$



$$16.4 \quad \text{Assume all air leaves parallel to the face of the sign.}$$

$$v_1 = 125 \text{ km/h} \times \frac{10^3 \text{ m}}{\text{km}} \times \frac{1 \text{ h}}{3600 \text{ s}} = 34.7 \text{ m/s}$$

$$R_x = \rho Q(v_{2_x} - v_{1_x}) = \rho Q(0 - (-v_1)) = \rho Q v_1 = \rho(A v_1)(v_1) = \rho A v_1^2$$

$$R_x = \frac{1.341 \text{ kg}}{\text{m}^3} \times (3 \text{ m})(4 \text{ m}) \times \frac{(34.7)^2 \text{ m}^2}{\text{s}^2} = \frac{19.4 \times 10^3 \text{ kg} \cdot \text{m}}{\text{s}^2} = \mathbf{19.4 \text{ kN}}$$

$$\text{Equivalent pressure} = p = \frac{R_x}{A} = \frac{19.4 \times 10^3 \text{ N}}{12 \text{ m}^2} = \frac{1617 \text{ N}}{\text{m}^2} = \mathbf{1617 \text{ Pa}}$$

$$16.5 \quad Q = Av = \frac{\pi(1.75 \text{ in})^2}{4} \times \frac{\text{ft}^2}{144 \text{ in}^2} \times \frac{25 \text{ ft}}{\text{s}}$$

$$= 0.418 \text{ ft}^3/\text{s}$$

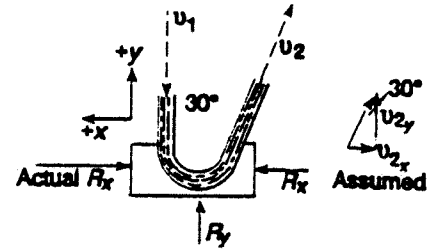
$$R_x = \rho Q(v_{2x} - v_{1x}) = \rho Q[-v_2 \sin 30^\circ - (0)]$$

$$R_x = -\rho Q v_2 \sin 30^\circ = -(1.94)(0.418)(25) \sin 30^\circ$$

$$R_x = -10.13 \text{ lb} = \mathbf{10.13 \text{ lb to right}}$$

$$R_y = \rho Q(v_{2y} - v_{1y}) = \rho Q[v_2 \cos 30^\circ - (-v_1)]$$

$$R_y = \rho Q[v_2 \cos 30^\circ + v_1] = (1.94)(0.418)[25 \cos 30^\circ + 25] = \mathbf{37.79 \text{ lb up}}$$



$$16.6 \quad Q = Av = (2.95 \text{ in}^2)(22.0 \text{ ft/s})(1 \text{ ft}^2/144 \text{ in}^2)$$

$$= 0.451 \text{ ft}^3/\text{s}$$

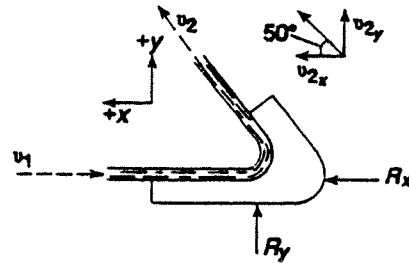
$$R_x = \rho Q(v_{2x} - v_{1x}) = \rho Q[v_2 \cos 50^\circ - (-v_1)]$$

$$R_x = \rho Q[v_2 \cos 50^\circ + v_1]; \text{ but } v_2 = v_1$$

$$R_x = \rho Q v_1 [\cos 50^\circ + 1]$$

$$R_x = \frac{1.88 \text{ lb} \cdot \text{s}^2}{\text{ft}^4} \times \frac{0.451 \text{ ft}^3}{\text{s}} \times \frac{22.0 \text{ ft}}{\text{s}} \times 1.643$$

$$= \mathbf{30.6 \text{ lb}}$$



$$R_y = \rho Q(v_{2y} - v_{1y}) = \rho Q[v_2 \sin 50^\circ - 0] = (1.88)(0.451)(22 \sin 50^\circ) = \mathbf{14.3 \text{ lb}}$$

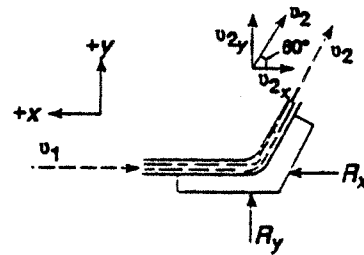
$$16.7 \quad Q = Av = \frac{\pi(0.10 \text{ m})^2}{4} \times \frac{15 \text{ m}}{\text{s}} = 0.118 \text{ m}^3/\text{s}$$

$$R_x = \rho Q[v_{2x} - v_{1x}] = \rho Q[-v_2 \cos 60^\circ - (-v_1)]$$

$$R_x = \rho Q v_1 [1 - \cos 60^\circ]$$

$$R_x = \frac{988 \text{ kg}}{\text{m}^3} \times \frac{0.118 \text{ m}^3}{\text{s}} \times \frac{15 \text{ m}}{\text{s}} \times [0.5]$$

$$= \frac{873 \text{ kg} \cdot \text{m}}{\text{s}^2} = \mathbf{873 \text{ N}}$$



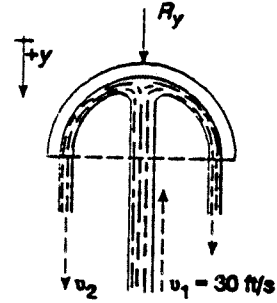
$$R_y = \rho Q[v_{2y} - v_{1y}] = \rho Q[v_2 \sin 60^\circ - 0] = (988)(0.118)(15)(\sin 60^\circ) = \mathbf{1512 \text{ N}}$$

$$16.8 \quad Q = A_1 v_1 = \frac{\pi(1.00 \text{ in})^2}{4} \times \frac{\text{ft}^2}{144 \text{ in}^2} \times \frac{30 \text{ ft}}{\text{s}} = \frac{0.1636 \text{ ft}^3}{\text{s}}$$

$$v_2 = \frac{Q}{A_2} = \frac{0.1636 \text{ ft}^3/\text{s}}{\pi(4.00^2 - 3.80^2) \text{ in}^2/4} = \frac{19.23 \text{ ft}}{\text{s}}$$

$$R_y = \rho Q (v_{2y} - v_{1y})$$

$$R_y = \frac{1.88 \text{ lb} \cdot \text{s}^2}{\text{ft}^4} \times \frac{0.1636 \text{ ft}^3}{\text{s}} [19.23 - (-30)] \frac{\text{ft}}{\text{s}} = 15.14 \text{ lb}$$

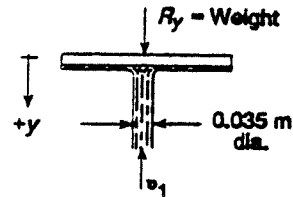


$$16.9 \quad R_y = 550 \text{ N} = 550 \text{ kg} \cdot \text{m/s}^2 = \rho Q (v_{2y} - v_{1y})$$

$$= \rho A_1 v_1 (0 - (-v_1)) = \rho A_1 v_1^2$$

$$v_1 = \sqrt{\frac{R_y}{\rho A_1}} = \sqrt{\frac{550 \text{ kg} \cdot \text{m/s}^2}{(900 \text{ kg/m}^3)(9.62 \times 10^{-4} \text{ m}^2)}} = 25.2 \text{ m/s}$$

$$A_1 = \frac{\pi(0.035 \text{ m})^2}{4} = 9.62 \times 10^{-4} \text{ m}^2$$



$$16.10 \quad R_{x_1} = \rho Q (v_{2x} - v_{1x}) = \rho A v_1 [0 - (-v_1)] = \rho A_1 v_1^2$$

$$A_1 = \frac{1}{2} \left[ \frac{\pi(2.0 \text{ in})^2}{4} \times \frac{\text{ft}^2}{144 \text{ in}^2} \right] = 0.0109 \text{ ft}^2$$

$$R_{x_1} = \frac{1.94 \text{ lb} \cdot \text{s}^2}{\text{ft}^4} \times 0.0109 \text{ ft}^2 \times \left( \frac{40.0 \text{ ft}}{\text{s}} \right)^2 = 33.9 \text{ lb}$$

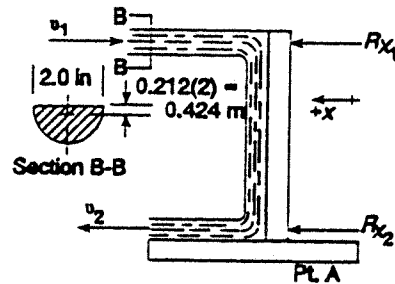
$$R_{x_2} = \rho Q (v_{2x} - v_{1x}) = \rho Q (v_2 - 0) = \rho Q v_2$$

Assume  $v_2 = v_1, A_2 = A_1$

$$R_{x_2} = \rho A v_1^2 = 33.9 \text{ lb}$$

$$M_{1A} = R_{x_1} (4.00 - 0.424) \text{ in} = (33.9 \text{ lb})(3.576 \text{ in}) = 121 \text{ lb} \cdot \text{in}$$

Moment due to  $R_{x_2}$  is small—depends on shape of leaving stream.



$$16.11 \quad Q = 100 \text{ gal/min} \times \frac{1 \text{ ft}^3/\text{s}}{449 \text{ gal/min}} = 0.223 \text{ ft}^3/\text{s}; \quad v_1 = \frac{Q}{A} = \frac{0.223 \text{ ft}^3/\text{s}}{0.0060 \text{ ft}^2} = 37.1 \text{ ft/s}$$

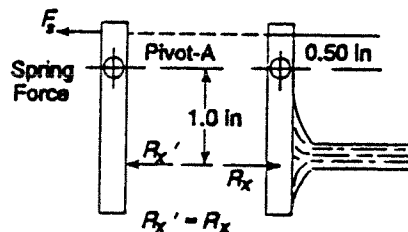
Assume all fluid strikes vane and is deflected perpendicular to incoming stream.

$$R_x = \rho Q (v_{2x} - v_{1x}) = \rho Q [0 - (-v_1)] = \rho Q v_1$$

$$R_x = \frac{1.94 \text{ lb} \cdot \text{s}^2}{\text{ft}^4} \times \frac{0.223 \text{ ft}^3}{\text{s}} \times \frac{37.1 \text{ ft}}{\text{s}} = 16.0 \text{ lb}$$

$R_x$  is force exerted by vane on water  
 $R_x'$  is force exerted by water on vane  
 $\Sigma M_A = 0 = F_s(0.5 \text{ in}) - R_x'(1.0 \text{ in})$

$$F_s = R_x' \frac{1.0}{0.5} = 2R_x' = 2(16.0 \text{ lb}) = 32.0 \text{ lb}$$



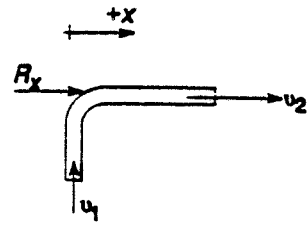
$$16.12 \quad R_x = \rho Q [v_{2x} - v_{1x}] = \rho A v_2 [v_2 - 0] = \rho A v_2^2$$

$$A = \frac{\pi(4.0 \text{ in})^2}{4} \times \frac{\text{ft}^2}{144 \text{ in}^2} = 0.0873 \text{ ft}^2$$

$$R_x = \frac{1.94 \text{ lb} \cdot \text{s}^2}{\text{ft}^4} \times 0.0873 \text{ ft}^2 \times (60 \text{ ft/s})^2$$

$$= 609 \text{ lb acting on water jet}$$

Force on boat is reaction to  $R_x$  acting toward left. ←



$$16.13 \quad \frac{p_1}{\gamma} + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma} + \frac{v_2^2}{2g}$$

$$v_1 = v_2 \cdot \frac{A_2}{A_1} = 80 \cdot \frac{0.0218}{0.0873}$$

$$= 20 \text{ ft/sec}$$

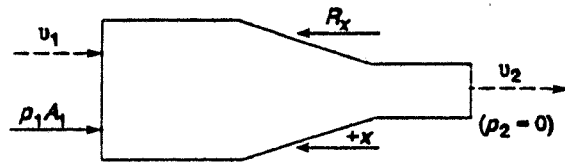
$$p_1 = \gamma \left[ \frac{v_2^2}{2g} - \frac{v_1^2}{2g} + h_L \right] = \gamma \left[ \frac{v_2^2}{2g} - \frac{v_1^2}{2g} + \frac{0.12v_2^2}{2g} \right] = \gamma \left[ \frac{1.12v_2^2 - v_1^2}{2g} \right]$$

$$p_1 = \frac{62.4 \text{ lb}}{\text{ft}^3} \left[ \frac{1.12(80)^2 - (20)^2}{64.4} \right] \text{ ft} = 6550 \text{ lb/ft}^2$$

$$R_x - p_1 A_1 = \rho Q (v_{2x} - v_{1x}) = \rho Q (-v_2 - (-v_1)) = \rho Q (v_1 - v_2)$$

$$R_x = \rho Q (v_1 - v_2) + p_1 A_1 = (1.94)(0.0218)(80)(20 - 80) + (6550)(0.0873) = -203 + 571$$

$$= 368 \text{ lb}$$



$$16.14 \quad v_1 = \frac{Q}{A_1} = \frac{0.025 \text{ m}^3/\text{s}}{7.538 \times 10^{-3} \text{ m}^2} = 3.32 \text{ m/s}$$

$$v_2 = \frac{Q}{A_2} = \frac{0.025 \text{ m}^3/\text{s}}{1.945 \times 10^{-3} \text{ m}^2} = 12.85 \text{ m/s}$$

$$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma} + \frac{v_2^2}{2g}$$

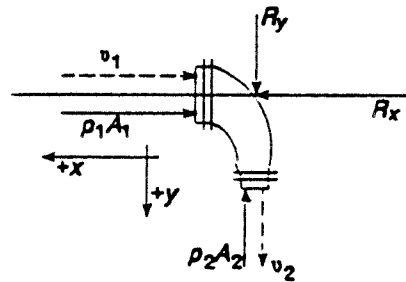
$$p_2 = p_1 + \gamma \left[ \frac{v_1^2 - v_2^2}{2g} - h_L \right] = p_1 + \gamma \left[ \frac{v_1^2}{2g} - \frac{v_2^2}{2g} - 3.5 \frac{v_1^2}{2g} \right] = p_1 + \gamma \left[ -\frac{v_2^2}{2g} - 2.5 \frac{v_1^2}{2g} \right]$$

$$p_2 = 825 \text{ kPa} + (1.03)(9.81 \text{ kN/m}^3) \left[ \frac{[-12.85^2 - 2.5(3.32)^2] \text{ m}^2/\text{s}^2}{2(9.81 \text{ m/s}^2)} \right]$$

$$= 825 \text{ kPa} - 99.2 \text{ kPa} = 726 \text{ kPa}$$

$$\rho Q v_1 = (1.03)(1000 \text{ kg/m}^3)(0.025 \text{ m}^3)(3.32 \text{ m/s}) = 85.5 \text{ kg} \cdot \text{m/s}^2 = 85.5 \text{ N}$$

$$\rho Q v_2 = (1.03)(1000)(0.025)(12.85) \text{ N} = 331 \text{ N}$$



$$p_1 A_1 = (825 \text{ kN/m}^2)(7.538 \times 10^{-3} \text{ m}^2) = 6.219 \text{ kN} = 6219 \text{ N}$$

$$p_2 A_2 = (726 \text{ kN/m}^2)(1.945 \times 10^{-3} \text{ m}^2) = 1.412 \text{ kN} = 1412 \text{ N}$$

**x-direction:**

$$R_x - p_1 A_1 = \rho Q (v_{2x} - v_{1x}) = \rho Q (0 - (-v_1)) = \rho Q v_1$$

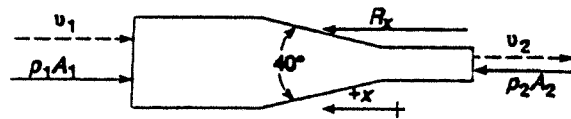
$$R_x = \rho Q v_1 + p_1 A_1 = 85.5 \text{ N} + 6219 \text{ N} = \mathbf{6305 \text{ N}}$$

**y-direction:**

$$R_y - p_2 A_2 = \rho Q (v_{2y} - v_{1y}) = \rho Q (v_2 - 0) = \rho Q v_2$$

$$R_y = \rho Q v_2 + p_2 A_2 = 331 \text{ N} + 1412 \text{ N} = \mathbf{1743 \text{ N}}$$

16.15  $Q = 500 \text{ gal/min} \times \frac{1 \text{ ft}^3/\text{sec}}{449 \text{ gal/min}}$   
 $= 1.114 \text{ ft}^3/\text{sec}$



$$v_1 = \frac{Q}{A_1} = \frac{1.114 \text{ ft}^3/\text{sec}}{0.2006 \text{ ft}^2} = 5.55 \text{ ft/sec} \quad A_1 = 0.2006 \text{ ft}^2 = 28.89 \text{ in}^2$$

$$A_2 = 0.05132 \text{ ft}^2 = 7.39 \text{ in}^2$$

$$v_2 = \frac{Q}{A_2} = \frac{1.114 \text{ ft}^3/\text{sec}}{0.05132 \text{ ft}^2} = 21.7 \text{ ft/sec} \quad D_1/D_2 = 0.5054/0.2557 = 1.98; K = 0.043$$

From Section 10.8,  $h_L = K \frac{v_2^2}{2g} = 0.043 \frac{(21.7)^2}{64.4} = 0.314 \text{ ft}$

$$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} \therefore p_2 = p_1 + \gamma \left[ \frac{v_1^2 - v_2^2}{2g} - 0.314 \right]$$

$$p_2 = 125 + \frac{62.4 \text{ lb}}{\text{ft}^3} \left[ \frac{(5.55)^2 - (21.7)^2}{64.4} - 0.314 \right] \text{ft} \frac{1 \text{ ft}^2}{144 \text{ in}^2} = 125 - 3.10 = 121.9 \text{ psig}$$

$$\Sigma F_x = R_x + p_2 A_2 - p_1 A_1 = \rho Q (v_{2x} - v_{1x}) = \rho Q (-v_2 - (-v_1)) = \rho Q (v_1 - v_2)$$

$$R_x = \rho Q (v_1 - v_2) - p_2 A_2 + p_1 A_1$$

$$= (1.94)(1.11)(5.55 - 21.7) - (121.9)(7.39) + (125)(28.89)$$

$$R_x = -34.9 - 900 + 3611 = \mathbf{2676 \text{ lb}}$$

16.16 Find  $p_1$  ( $p_2 = 0$ ,  $v_1 = v_2$ ,  $z_1 = z_2$ )

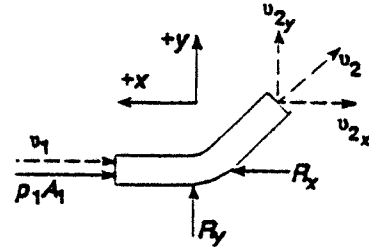
$$\frac{p_1}{\gamma} - h_L = 0; p_1 = \gamma h_L = \gamma f_T \frac{L_e v^2}{D 2g}$$

$$v = Q/A = 6.5/0.3174 = 20.45 \text{ ft/sec}$$

$$N_R = \frac{vD}{\gamma} = \frac{(20.45)(0.6354)}{9.15 \times 10^{-6}} = 1.42 \times 10^6$$

$$f_T = 0.014 \text{ (Table 10.5); } L_e/D = 16 \text{ (Table 10.4)}$$

$$p_1 = \gamma h_L = (62.2)(0.014)(16)(20.45)^2/64.4 = 90.5 \text{ lb/ft}^2$$



**x-direction:**

$$R_x - p_1 A_1 = \rho Q (v_{2x} - v_{1x}) = \rho Q (-v \sin 45^\circ - (-v_1)) = \rho Q v (1 - \sin 45^\circ)$$

$$R_x = \rho Q v (1 - \sin 45^\circ) + p_1 A_1 = (1.93)(6.5)(20.45)(0.293) + (90.5)(0.3174) = 103.9 \text{ lb}$$

**y-direction:**

$$R_y = \rho Q (v_{2y} - v_{1y}) = \rho Q (v_2 \cos 45^\circ - 0) = (1.93)(6.5)(20.45)(0.707) = 182 \text{ lb}$$

16.17  $v = \frac{Q}{A} = \frac{0.125 \text{ m}^3/\text{s}}{1.864 \times 10^{-2} \text{ m}^2} = 6.71 \text{ m/s}$

**x-direction:**

$$R_x - p_1 A_1 = \rho Q (v_{2x} - v_{1x}) = \rho Q (0 - (-v_1))$$

$$R_x = \rho Q v_1 + p_1 A_1$$

$$= \frac{1000 \text{ kg}}{\text{m}^3} \times \frac{0.125^3}{\text{s}} \times \frac{6.71 \text{ m/s}}{\text{s}} + \frac{1050 \text{ kN}}{\text{m}^2} \times 1.864 \times 10^{-2} \text{ m}^2$$

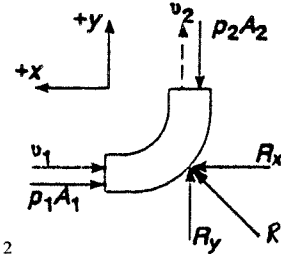
$$R_x = 838 \text{ kg}\cdot\text{m/s}^2 + 19.57 \text{ kN} = 838 \text{ N} \times \frac{1 \text{ kN}}{10^3 \text{ N}} + 19.57 \text{ kN} = 20.41 \text{ kN}$$

└ N ─┘

**y-direction:**

$$R_y - p_2 A_2 = \rho Q (v_{2y} - v_{1y}) = \rho Q (v_2 - 0)$$

$$R_y = \rho Q v_2 + p_2 A_2 = 0.838 \text{ kN} + 19.57 \text{ kN} = 20.41 \text{ kN}$$



$$R = \sqrt{R_x^2 + R_y^2}$$

$$R = 28.9 \text{ kN @ } 45^\circ$$

16.18  $Q = 2000 \text{ L/min} \times 16.67 \times 10^{-6} \text{ m}^3/\text{s}/1 \text{ L/min} = 0.0333 \text{ m}^3/\text{s}$

$$v = Q/A = 0.0333 \text{ m}^3/\text{s}/7.419 \times 10^{-3} \text{ m}^2 = 4.49 \text{ m/s}$$

$$\Sigma F_x = \rho Q (v_{2x} - v_{1x}) = \rho Q (v_2 - (-v_1)) = 2\rho Q v$$

$$\Sigma F_x = R_x - p_1 A_1 - p_2 A_2 = R_x - 2p_1 A_1$$

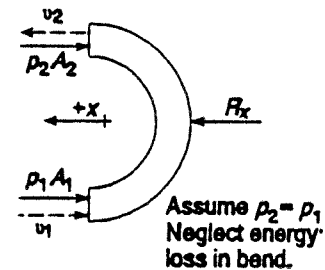
$$\text{Then } R_x - 2p_1 A_1 = 2\rho Q v$$

$$R_x = 2\rho Q v + 2p_1 A_1$$

$$= 2(0.89) \frac{(1000 \text{ kg})}{\text{m}^3} \times \frac{0.0333 \text{ m}^3}{\text{s}} \times \frac{4.49 \text{ m}}{\text{s}} + 2 \times \frac{2.0 \times 10^6 \text{ N}}{\text{m}^2} \times 7.419 \times 10^{-3} \text{ m}^2$$

$$= \frac{267 \text{ kg}\cdot\text{m}}{\text{s}^2} + 29.68 \times 10^3 \text{ N} = 267 \text{ N} + 29.68 \times 10^3 \text{ N} = 0.267 \text{ kN} + 29.68 \text{ kN}$$

$$R_x = 29.95 \text{ kN}$$



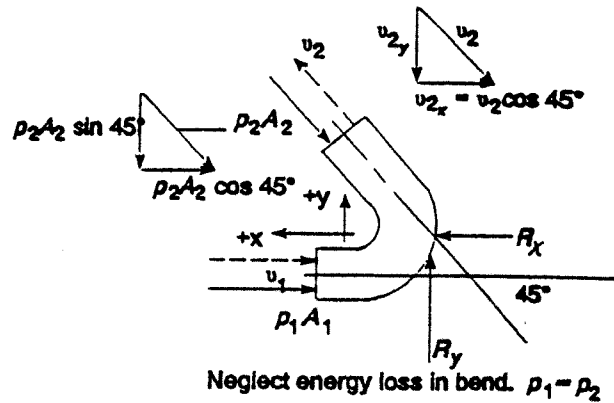
16.19  $v_1 = v_2 = v$

$$v = \frac{Q}{A} = \frac{0.12 \text{ m}^3/\text{s}}{1.670 \times 10^{-2} \text{ m}^2} = 7.19 \text{ m/s}$$

$$p_1 A_1 = p_2 A_2$$

$$= \frac{275 \text{ kN}}{\text{m}^2} \times 1.670 \times 10^{-2} \text{ m}^2$$

$$= 4.59 \text{ kN}$$



**x-direction:**

$$R_x - p_1 A_1 - p_2 A_2 \cos 45^\circ = \rho Q (v_{2x} - v_{1x})$$

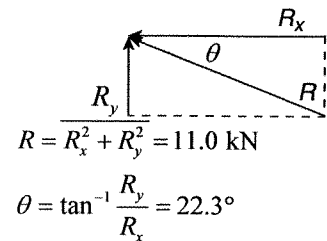
$$R_x - p_1 A_1 (1 + \cos 45^\circ) = \rho Q (v_2 \cos 45^\circ - (-v_1))$$

$$R_x - p_1 A_1 (1 + \cos 45^\circ) = \rho Q v (1 + \cos 45^\circ)$$

$$R_x = \rho Q v (1 + \cos 45^\circ) + p_1 A_1 (1 + \cos 45^\circ)$$

$$\rho Q v = \frac{1590 \text{ kg}}{\text{m}^3} \times \frac{0.12 \text{ m}^3}{\text{s}} \times \frac{7.19 \text{ m}}{\text{s}} = \frac{1.37 \times 10^3 \text{ kg} \cdot \text{m}}{\text{s}^2} = 1.37 \text{ kN}$$

$$R_x = 1.37 \text{ kN}(1.707) + 4.59 \text{ kN}(1.707) = \mathbf{10.17 \text{ kN}}$$



**y-direction:**

$$R_y - p_2 A_2 \sin 45^\circ = \rho Q (v_{2y} - v_{1y}) = \rho Q (v_2 \sin 45^\circ - 0) = \rho Q v \sin 45^\circ$$

$$R_y = (\rho Q v + p_2 A_2) \sin 45^\circ = (1.37 \text{ kN} + 4.59 \text{ kN})(0.707) = \mathbf{4.18 \text{ kN}}$$

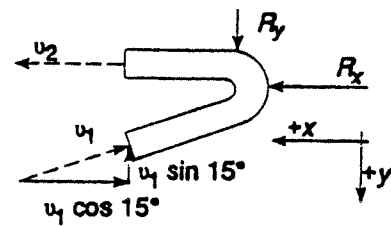
16.20  $Q = Av = (3.142 \times 10^{-2} \text{ m}^2)(30 \text{ m/s}) = 0.943 \text{ m}^3/\text{s}$

a. **x-direction:**

$$R_x = \rho Q (v_{2x} - v_{1x}) = \rho Q (v_2 - (-v_1 \cos 15^\circ))$$

$$R_x = \rho Q v (1 + \cos 15^\circ) = 1.966 \rho Q v$$

$$R_x = (1.966) \left( \frac{1000 \text{ kg}}{\text{m}^3} \right) \left( \frac{0.943 \text{ m}^3}{\text{s}} \right) \left( \frac{30 \text{ m}}{\text{s}} \right)$$



$$R_x = 55.6 \times 10^3 \text{ kg} \cdot \text{m/s}^2 = 55.6 \text{ kN} = \text{Force of car on water. } \leftarrow$$

$$\text{Force on car} = 55.6 \text{ kN } \rightarrow$$

**y-direction:**

$$R_y = \rho Q (v_{2y} - v_{1y}) = \rho Q (0 - (-v_1 \sin 15^\circ)) = \rho Q v \sin 15^\circ$$

$$R_y = (1000)(0.943)(30)(0.259) = 7.32 \times 10^3 \text{ kg} \cdot \text{m/s}^2 = 7.32 \text{ kN} = \text{Force on water } \downarrow$$

$$\text{Force on car} = 7.32 \text{ kN } \uparrow$$

- b. Because the inlet jet acts at an angle to the  $x$ - $y$  directions, we compute its components:  
 $v_{1x} = v_1 \cos(15^\circ) = (30 \text{ m/s})(0.966) = 28.98 \text{ m/s}$ ;  $v_{1y} = v_1 \sin(15^\circ) = 30 \text{ m/s}(0.259) = 7.76 \text{ m/s}$

Only  $v_{1x}$  is affected by the moving vane. Then  $v_{e1x} = v_{1x} - 12 \text{ m/s} = 16.98 \text{ m/s}$ .

$v_{e1y} = v_{1y} = 7.76 \text{ m/s}$ . The magnitude of the resultant effective velocity is:

$$|v_{e1y}| = \sqrt{(16.98)^2 + (7.76)^2} = 18.67 \text{ m/s}$$

The total effective mass flow rate into the vane,  $M_e$ , is,

$$M_e = \rho Q_e = \rho A v_{e1} = (1000 \text{ kg/m}^3)(3.142 \times 10^{-2} \text{ m}^2)(18.67 \text{ m/s}) = 586.6 \text{ kg/s}$$

The velocity,  $v_{e1}$ , acts at an angle  $\alpha$ , with respect to the horizontal, where

$$\alpha = \tan^{-1}(7.76/16.98) = 24.58^\circ$$

Only the component of  $v_{e1}$  acting parallel to the vane is maintained as the jet travels around the vane.

This component is computed using  $\beta$ , the difference between  $\alpha$  and the angle of the vane inlet.

$$\beta = 24.58^\circ - 15^\circ = 9.58^\circ$$

$$\text{Then, } v_{e1(\text{par})} = (v_{e1})\cos(9.58^\circ) = (18.67 \text{ m/s})(0.986) = 18.41 \text{ m/s}$$

This velocity remains undiminished as the jet travels around the vane. Then  $v_{e2} = 18.41 \text{ m/s}$  to the left.

$$\text{Force in } x\text{-direction: } R_x = M_e(\Delta v_{ex}) = M_e(v_{e2x} - v_{e1x}) = (586.6 \text{ kg/s})[18.41 - (-16.98)]\text{m/s} = \mathbf{20.86 \text{ kN}}$$

$$\text{Force in } y\text{-direction: } R_y = M_e(\Delta v_{ey}) = M_e(v_{e2y} - v_{e1y}) = (586.6 \text{ kg/s})[0 - (-7.76)]\text{m/s} = \mathbf{4.55 \text{ kN}}$$

$$16.21 \quad R_x = \rho Q(v_{2x} - v_{1x}) = \rho A v_1(0 - (-v_1)) = \rho A v_1^2 \quad \textcircled{1}$$

$$\text{Weight of carton} = w_c = mg = \frac{0.10 \text{ kg} \cdot 9.81 \text{ m}}{\text{s}^2} = 0.981 \text{ N}$$

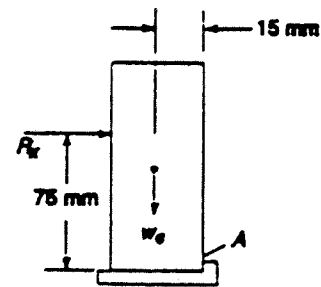
$$\Sigma M_A = R_x(75 \text{ mm}) - w_c(15 \text{ mm}) = 0 \quad \text{Impending tipping}$$

$$R_x = w_c \frac{15}{75} = 0.981 \text{ N} \frac{15}{75} = 0.196 \text{ N}$$

$$\text{From } \textcircled{1}, v_1 = \sqrt{\frac{R_x}{\rho A}}$$

$$A = \pi(0.010 \text{ m})^2/4 = 7.85 \times 10^{-5} \text{ m}^2$$

$$v_1 = \sqrt{\frac{0.196 \text{ kg} \cdot \text{m/s}^2}{(1.20 \text{ kg/m}^3)(7.85 \times 10^{-5} \text{ m}^2)}} = \mathbf{45.6 \text{ m/s}}$$

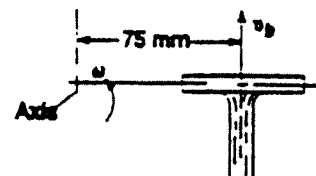


$$16.22 \quad R_x = \rho Q(v_{2x} - v_{1x}) = \rho A v_1(0 - (-v_1)) = \rho A v_1^2$$

$$R_x = \frac{1.20 \text{ kg}}{\text{m}^3} \times \frac{\pi(0.015 \text{ m})^2}{4} \times \frac{(0.35 \text{ m/s})^2}{1} = \frac{2.60 \times 10^{-5} \text{ kg} \cdot \text{m}}{\text{s}^2} = \mathbf{2.6 \times 10^{-5} \text{ N}}$$

$$16.23 \quad \text{Let } v_{1e} = v_1 - v_b$$

$\left\{ \begin{array}{l} \text{L Velocity of Blade} \\ \text{L Velocity of Air} \end{array} \right.$



$$v_b = R\omega = (0.075 \text{ m}) \times \frac{40 \text{ rev}}{\text{min}} \times \frac{2\pi \text{ rad}}{\text{rev}} \times \frac{1 \text{ min}}{60 \text{ s}}$$

$$= 0.314 \text{ m/s}$$

$$v_e = 0.35 \text{ m/s} - 0.314 \text{ m/s} = 0.0358 \text{ m/s}$$

$$R_x = \rho A v_e^2 = (1.20) \frac{\pi(0.015)^2}{4} (0.0358)^2 = 2.72 \times 10^{-7} \text{ N}$$

16.24  $R_x = \rho Q(v_{2x} - v_{1x})$

$$R_x = \rho Q(0 - (-v_1 \sin 45^\circ))$$

$$R_x = \rho Q v_1 \sin 45^\circ$$

$$= \rho(A v_1) v_1 \sin 45^\circ$$

$$R_x = \rho A v_1^2 \sin 45^\circ$$

Compute  $R_x$  for a 20.0 in length of louver, as shown in Fig. 16.19.

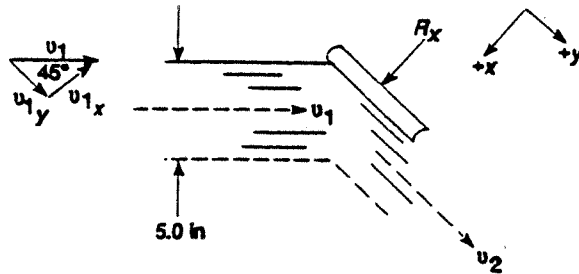
$$A = (5 \text{ in})(20.0 \text{ in})(1 \text{ ft}^2/144 \text{ in}^2)$$

$$= 0.694 \text{ ft}^2$$

$$R_x = \frac{2.06 \times 10^{-3} \text{ lb} \cdot \text{s}^2}{\text{ft}^4} \times 0.694 \text{ ft}^2 \times (10.0 \text{ ft/s})^2 \times \sin 45^\circ = 0.101 \text{ lb}$$

Assume  $R_x$  acts at middle of louver, 2.50 in from pivot

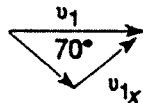
$$\text{Moment} = R_x(2.5) = 0.101 \text{ lb}(2.5 \text{ in}) = \mathbf{0.253 \text{ lb-in}}$$



16.25 See Problem 16.24:

$$R_x = \rho A v_1^2 \sin 70^\circ = (2.06 \times 10^{-3})(0.694)(10.0)^2 \sin 70^\circ = 0.1345 \text{ lb}$$

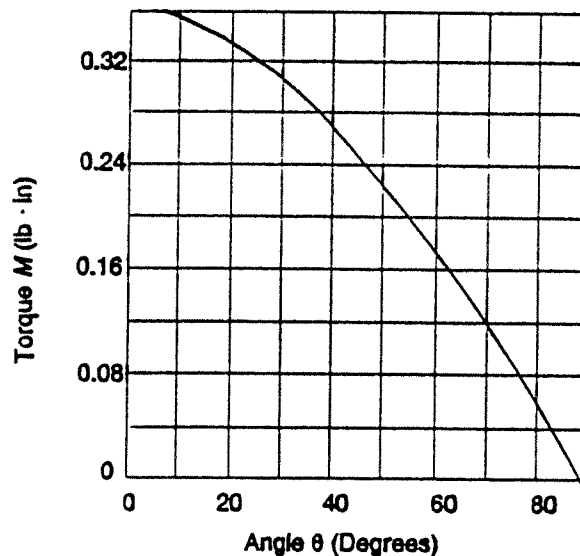
$$\text{Moment} = R_x(2.5) = (0.1345 \text{ lb})(2.5 \text{ in}) = \mathbf{0.336 \text{ lb-in}}$$



16.26 See analysis—Problem 16.24:  $R_x = \rho A v_1^2 \sin(90 - \theta) = \rho A v_1^2 \cos \theta$

$$R_x = (2.06 \times 10^{-3})(0.417)(10.0)^2 \cos \theta = 0.143 \cos \theta; \text{Moment} = R_x(2.5 \text{ in})$$

$\theta$	$R_x(\text{lb})$	$M(\text{lb-in})$
10	0.141	0.352
20	0.134	0.336
30	0.124	0.310
40	0.110	0.274
50	0.0920	0.230
60	0.0715	0.179
70	0.0489	0.122
80	0.0248	0.062
90	0.0	0.0

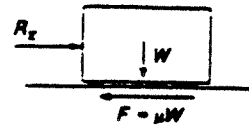


- 16.27 Maximum  $F_f = \mu W = 0.60W$   
Sliding is impending when  $R_x = F_f$

$$R_x = \rho Q(v_{2x} - v_{1x}) = \rho A v_1(0 - (-v_1)) = \rho A v_1^2$$

$$\text{Then } W = \frac{R_x}{0.6} = \frac{\rho A v_1^2}{0.6}$$

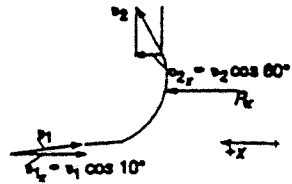
$$W = \frac{2.40 \times 10^{-3} \text{ lb} \cdot \text{s}^2}{\text{ft}^4} \times \frac{\pi(1.5 \text{ in})^2}{4} \times \frac{\text{ft}^2}{144 \text{ in}^2} \times \frac{(25.0 \text{ ft/s})^2}{0.6} = 0.0307 \text{ lb}$$



- 16.28 See Prob. 16.27:

$$W = \frac{\rho A v_1^2}{0.6} = \frac{1.94 \text{ lb} \cdot \text{s}^2}{\text{ft}^4} \times \frac{\pi(0.75 \text{ in})^2}{4} \times \frac{(25.0 \text{ ft/s})^2}{144 \text{ in}^2 / \text{ft}^2} \times \frac{1}{0.6} = 6.20 \text{ lb}$$

- 16.29  $R_x = M(\Delta v_x) = M(v_{2x} - v_{1x})$ : Where  $M = \rho A v$   
 $A = \pi D^2/4 = \pi(0.0075 \text{ m})^2/4 = 4.418 \times 10^{-5} \text{ m}^2$   
 $M = \rho A v = (1000 \text{ kg/m}^3)(4.418 \times 10^{-5} \text{ m}^2)(25 \text{ m/s}) = 1.105 \text{ kg/s}$   
 $v_{1x} = v_1 \cos(10^\circ) = (25 \text{ m/s})(0.985) = 24.62 \text{ m/s}$   
 $v_{1y} = v_1 \sin(10^\circ) = (25 \text{ m/s})(0.174) = 4.34 \text{ m/s}$   
 $v_2 = v = 25 \text{ m/s}$   
 $v_{2x} = v_2 \cos(60^\circ) = (25 \text{ m/s})(0.5) = 12.5 \text{ m/s}$ ;  $v_{2y} = v_2 \sin(60^\circ)$   
 $= (25 \text{ m/s})(0.866) = 21.65 \text{ m/s}$



$$\text{Force in the } x\text{-direction: } R_x = M(\Delta v_x) = M(v_{2x} - v_{1x})$$

$$= (1.105 \text{ kg/s})[12.5 - (-24.62)]\text{m/s} = \mathbf{41.0 \text{ N}}$$

$$\text{Force in the } y\text{-direction: } R_y = M(\Delta v_y) = M(v_{2y} - v_{1y})$$

$$= (1.105 \text{ kg/s})[21.65 - 4.34]\text{m/s} = \mathbf{19.1 \text{ N}}$$

- 16.30 Compute the force on one blade when the turbine wheel is rotating and has a tangential velocity of 10 m/s.

*Method:* See vector diagram on next page. Law of sines and law of cosines used.

1. Compute the velocity relative to the blade  $v_{R1}$  for the inlet.
2. The magnitude of this velocity remains undiminished as the jet traverses the blade.
3. The relative velocity rotates  $110^\circ$  as it traverses the blade.
4. Resolve  $v_{R1}$  and  $v_{R2}$  into  $x$  and  $y$  components.
5. Compute the effective mass flow rate  $M_e = \rho Q_e = \rho A_j v_R$ .
6. Compute reaction forces:  $R_x = M_e(v_{R2x} - v_{R1x})$  and  $R_y = M_e(v_{R2y} - v_{R1y})$

**Results:**

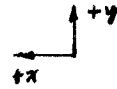
$$v_{R1} = 15.25 \text{ m/s } \swarrow \mathbf{16.54^\circ} ; v_{R2} = 15.25 \text{ m/s } \searrow \mathbf{53.46^\circ}$$

$$v_{R1x} = 14.62 \text{ m/s } \rightarrow ; v_{R1y} = 4.34 \text{ m/s } \uparrow ; v_{R2x} = 9.077 \text{ m/s } \leftarrow ; v_{R2y} = 12.25 \text{ m/s } \uparrow$$

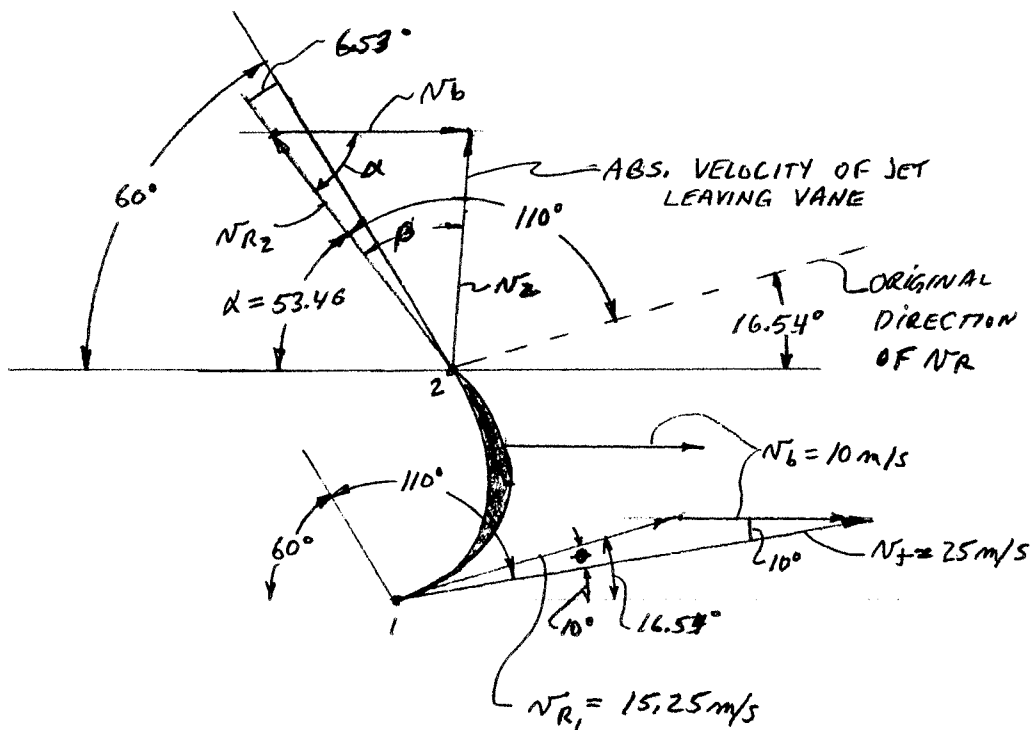
$$M_e = \rho Q_e = \rho A_j v_R = (1000 \text{ kg/m}^3)[\pi(0.0075 \text{ m})^2/4](15.25 \text{ m/s}) = 0.674 \text{ kg/s}$$

$$R_x = M_e(v_{R2x} - v_{R1x}) = (0.674 \text{ kg/s})(9.077 - (-14.62)) \text{ m/s} = 15.97 \text{ kg m/s}^2 = 15.97 \text{ N } \leftarrow$$

$$R_y = M_e(v_{R2y} - v_{R1y}) = (0.674)(12.25 - 4.34) = 5.33 \text{ N } \uparrow$$



$$\text{Rotational speed} = \omega = \frac{v_t}{r} = \frac{10.0 \text{ m}}{s(0.20 \text{ m})} \times \frac{\text{rev}}{2\pi \text{ rad}} \times \frac{60 \text{ s}}{\text{min}} = 477 \text{ rpm}$$



**Vector diagram for Problem 16.30**

$V_j$  = Velocity of water jet

$v_R$  = Velocity relative to blade

$v_b$  = Velocity of blade

Assume  $|v_{R1}| = |v_{R2}|$  and  $v_R$  vector is rotated  $110^\circ$  from inlet to outlet

Problem 16.31		Forces on rotating turbine wheel					
$v$ Blade (m/s)	$v_{R1}$ (m/s)	$\phi$ ( $^\circ$ )	$v_{R2}$ (m/s)	$\alpha$ ( $^\circ$ )	$M_e$ (kg/s)	$R_x$ (N)	$R_y$ (N)
0	25.00	10.00	25.00	60.00	1.105	41.00	19.12
5	20.09	12.48	20.09	57.52	0.888	27.00	11.20
10	15.25	16.54	15.25	53.46	0.674	15.97	5.33
15	10.55	24.29	10.55	45.71	0.466	7.92	1.50
20	6.34	43.22	6.34	26.78	0.280	2.88	-0.42
25	4.36	95.00	4.36	-25.00	0.193	0.69	-1.19

$R_x$  is the reaction force exerted by the blade on the water; positive  $R_x$  acts to the left

Then the force exerted by the water on the blade acts to the right, accelerating the blade

Positive  $R_y$  acts radially outward

Then the force exerted by the water on the blade acts radially inward toward the center of rotation

When  $R_y$  is negative, the net radial force on the blade is outward.

# CHAPTER SEVENTEEN

## DRAG AND LIFT

$$17.1 \quad F_D = C_D \left( \frac{1}{2} \rho v^2 \right) A; A = D \times L = (0.025 \text{ m})(1 \text{ m}) = 0.025 \text{ m}^2$$

a. Water at 15°C:  $\rho = 1000 \text{ kg/m}^3$ ;  $\nu = 1.15 \times 10^{-6} \text{ m}^2/\text{s}$

$$N_R = \frac{vD}{\nu} = \frac{(0.15)(0.025)}{1.15 \times 10^{-6}} = 3.26 \times 10^3; \text{ Then } C_D = 0.90 \text{ (Fig. 17.3)}$$

$$F_D = (0.90)(0.50)(1000 \text{ kg/m}^3)(0.15 \text{ m/s})^2(0.025 \text{ m}^2) = 0.253 \text{ kg}\cdot\text{m/s}^2 = \mathbf{0.253 \text{ N}}$$

b. Air at 10°C:  $\rho = 1.247 \text{ kg/m}^3$ ;  $\nu = 1.42 \times 10^{-5} \text{ m}^2/\text{s}$

$$N_R = \frac{vD}{\nu} = \frac{(0.15)(0.025)}{1.42 \times 10^{-5}} = 2.64 \times 10^2; \text{ Then } C_D = 1.30$$

$$F_D = (1.30)(0.5)(1.247 \text{ kg/m}^3)(0.15 \text{ m/s})^2(0.025 \text{ m}^2) = \mathbf{4.56 \times 10^{-4} \text{ N}}$$

17.2 Assume a smooth sphere

a.  $v = \frac{15 \text{ km}}{\text{h}} \times \frac{10^3 \text{ m}}{\text{km}} \times \frac{1 \text{ h}}{3600 \text{ s}} = 4.17 \text{ m/s}$  |  $A = \frac{\pi D^2}{4} = \frac{\pi(2.0)^2}{4} = 3.142 \text{ m}^2$

$$N_R = \frac{vD}{\nu} = \frac{(4.17)(2.0)}{1.33 \times 10^{-5}} = 6.27 \times 10^5; \text{ Then } C_D = 0.20 \text{ (Fig. 17.3)}$$

$$F_D = C_D \left( \frac{1}{2} \rho v^2 \right) A = (0.20)(0.5)(1.292 \text{ kg/m}^3)(4.17 \text{ m/s})^2(3.142 \text{ m}^2) = 7.06 \text{ N}$$

Similarly for (b), (c), and (d):

	$v(\text{km/h})$	$v(\text{m/s})$	$N_R$	$C_D$	$F_D(\text{N})$
(a)	15	4.17	$6.27 \times 10^5$	0.20	<b>7.06</b>
(b)	30	8.33	$1.25 \times 10^6$	0.20	<b>28.16</b>
(c)	60	16.67	$2.50 \times 10^6$	0.20	<b>112.7</b>
(d)	120	33.33	$5.01 \times 10^6$	0.20	<b>450.7</b>
(e)	160	44.44	$6.68 \times 10^6$	0.20	<b>801.9</b>

- 17.3 For equilibrium  $F_D = w - F_b$  at terminal velocity  
 $w = \gamma V = \gamma \pi D^3 / 6 = (26.6 \text{ kN/m}^3)(\pi(0.075 \text{ m})^3 / 6) = 5.88 \text{ N}$   
 $F_b = \gamma_f V = (9.42 \text{ kN/m}^3)(\pi(0.075 \text{ m})^3 / 6) = 2.08 \text{ N}$

$$F_D = w - F_b = 5.88 \text{ N} - 2.08 \text{ N} = 3.80 \text{ N} = C_D \left( \frac{1}{2} \rho v^2 \right) A$$

$$F_D = C_D(0.5)(960)(v^2)(4.418 \times 10^{-3}) = 2.12 C_D v^2$$

Then  $v = \sqrt{F_D / 2.12 C_D} = \sqrt{3.80 / 2.12 C_D} = \sqrt{1.79 / C_D}$ ; Assume  $C_D = 1.0$ ;  $v = 1.34 \text{ m/s}$

Check  $N_R = vD\rho/\mu = (1.34)(0.075)(960)/6.51 \times 10^{-1} = 1.48 \times 10^2$ ; Then  $C_D = 0.8$

Recompute  $v = 1.50 \text{ m/s}$ ;  $N_R = 1.65 \times 10^2$

Summary of results

	$w$	$F_b$	$F_D$	$C_D$	$v$	$N_R$
a) Cast. oil	5.88 N	2.08 N	3.80 N	0.8	<b>1.50 m/s</b>	$1.65 \times 10^2$
b) Water	5.88 N	2.16 N	3.72 N	0.4	<b>2.05 m/s</b>	$1.72 \times 10^5$
c) Air	5.88 N	5.88 N	5.88 N	0.2	<b>105 m/s</b>	$5.22 \times 10^5$

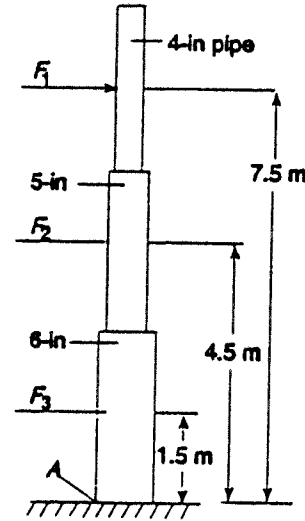
- 17.4  $M_A = F_1(7.5 \text{ m}) + F_2(4.5 \text{ m}) + F_3(1.5 \text{ m})$   
 $F_1, F_2, F_3, =$  Drag forces on pipes  
 $v = 150 \text{ km/h} \times 10^3 \text{ m/km} \times 1 \text{ h}/3600 \text{ s} = 41.67 \text{ m/s}$   
 $\rho = 1.292 \text{ kg/m}^3$

$$\frac{1}{2} \rho v^2 = (0.5)(1.292 \text{ kg/m}^3)(41.67 \text{ m/s})^2$$

$$= \frac{1122 \text{ kg} \cdot \text{m}}{\text{s}^2 (\text{m}^2)} = \frac{1112 \text{ N}}{\text{m}^2}$$

$$F_D = C_D \left( \frac{1}{2} \rho v^2 \right) A \quad (C_D \text{ from Fig. 17.3}) \quad (A = LD)$$

$$N_R = \frac{vD}{\nu} = \frac{(41.67)(D)}{1.33 \times 10^{-5}} = 3.13 \times 10^6 (D)$$



Pipe	$D(\text{m})$	$A(\text{m}^2)$	$N_R$	$C_D$	$F(\text{N})$	$M(\text{N} \cdot \text{m})$
1	0.1143	0.343	$3.58 \times 10^5$	0.70	267	2002
2	0.1413	0.424	$4.43 \times 10^5$	0.40	189	849
3	0.1683	0.505	$5.27 \times 10^5$	0.25	140	<u>211</u>
						<b>3062 N·m</b>

- 17.5 Circum. =  $\pi D = 225 \text{ mm}$ ;  $D = 225 \text{ mm}/\pi = 71.6 \text{ mm}$

$$A = \pi D^2 / 4 = \pi(0.0716 \text{ m})^2 / 4 = 4.03 \times 10^{-3} \text{ m}^2$$

$$N_R = \frac{vD}{\nu} = \frac{(20)(0.0716)}{1.60 \times 10^{-5}} = 8.95 \times 10^4$$
; then  $C_D = 0.45$

$$F_D = C_D \left( \frac{1}{2} \rho v^2 \right) A = (0.45)(0.5)(1.164)(20)^2(4.03 \times 10^{-3} \text{ m}^2) = 0.42 \text{ kg} \cdot \text{m/s} = \mathbf{0.42 \text{ N}}$$

17.6  $F_D = \text{Drag force} = F_R = \text{Force on car}$

$$F_D = C_D \left( \frac{1}{2} \rho v^2 \right) A$$



$C_D = 1.35$  for hemisphere cup (Table 17.1)

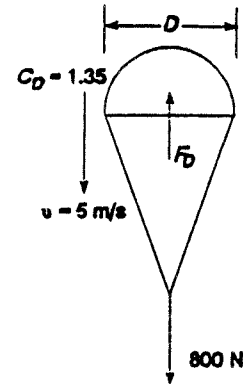
$$v = 1100 \text{ km/h} \times 10^3 \text{ m/km} \times 1 \text{ h}/3600 \text{ s} = 305.6 \text{ m/s}$$

$$F_D = (1.35)(0.5)(1.204)(305.6)^2(\pi(1.5)^2/4) = 134 \times 10^3 \text{ kg}\cdot\text{m/s}^2 = 134 \text{ kN}$$

17.7  $F_D = 800 \text{ N} = C_D \left( \frac{1}{2} \rho v^2 \right) A$  at terminal vel.

$$A = \frac{2F_D}{C_D \rho v^2} = \frac{(2)(800 \text{ N}) \frac{1 \text{ kg}\cdot\text{m/s}^2}{\text{N}}}{(1.35)(1.127 \text{ kg/m}^3)(5 \text{ m/s})^2} = 42.1 \text{ m}^2 = \pi D^2/4$$

$$D = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4(42.1 \text{ m}^2)}{\pi}} = 7.32 \text{ m}$$



17.8  $F_D = F_C = \text{Force in cable}$

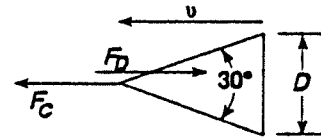
$$D = 2.20 \text{ m}$$

$$A = \pi D^2/4 = \pi(2.20 \text{ m})^2/4 = 3.80 \text{ m}^2$$

$$\rho = 1030 \text{ kg/m}^3 \text{ (Appendix B)}$$

$$F_D = C_D \left( \frac{1}{2} \rho v^2 \right) A = (0.34)(0.5)(1030)(7.5)^2(3.80 \text{ m}^2)$$

$$= 37.4 \times 10^3 \text{ kg}\cdot\text{m/s}^2 = 37.4 \text{ kN}$$



17.9 Rectangular plate:  $a/b = 4 \text{ m}/3 \text{ m} = 1.33$

$C_D = 1.16$  (Table 17.1)

$$v = 125 \text{ km/h} \times 10^3 \text{ m/km} \times 1 \text{ h}/3600 \text{ s} = 34.7 \text{ m/s}$$

$$F_D = C_D \left( \frac{1}{2} \rho v^2 \right) A = (1.16)(0.5)(1.341)(34.7)^2(12) = 11.2 \times 10^3 \text{ kg}\cdot\text{m/s}^2 = 11.2 \text{ kN}$$

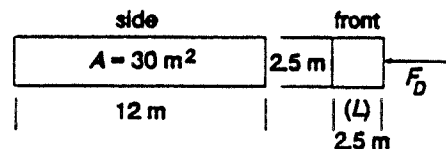
17.10  $v = 20 \text{ km/h} \times 10^3 \text{ m/km} \times 1 \text{ h}/3600 \text{ s} = 5.56 \text{ m/s}$

$$N_R = \frac{vL}{\nu} = \frac{(5.56)(2.5)}{1.33 \times 10^{-5}} = 1.04 \times 10^6$$

$C_D = 2.05$  (Estimated from Fig. 17.3)

$$F_D = C_D \left( \frac{1}{2} \rho v^2 \right) A = (2.05)(0.5)(1.292)(5.56)^2(30)$$

$$= 1.23 \times 10^3 \text{ kg}\cdot\text{m/s}^2 = 1.23 \text{ kN}$$



$$A = (12 \text{ m})(2.5 \text{ m}) = 30 \text{ m}^2$$

17.11  $v$  = Linear velocity of each cup

$$v = r\omega = (0.075 \text{ m}) \left( \frac{20 \text{ rev}}{\text{min}} \right) \left( \frac{2\pi \text{ rad}}{\text{rev}} \right) \left( \frac{1 \text{ min}}{60 \text{ s}} \right) = 0.157 \text{ m/s}$$

$$A = \frac{\pi D^2}{4} = \pi(0.025 \text{ m})^2/4 = 4.91 \times 10^{-4} \text{ m}^2$$

$$C_D = 1.35 \text{ (Table 17.1)}$$

a. Air at 30°C

$$\rho = 1.164 \text{ kg/m}^3$$

$$F_D = C_D \left( \frac{1}{2} \rho v^2 \right) A = (1.35)(0.5)(1.164)(0.157)^2(4.91 \times 10^{-4})$$

$$= 9.5 \times 10^{-6} \text{ kg}\cdot\text{m/s}^2 = 9.56 \text{ }\mu\text{N}$$

$$\text{Torque} = 4F_D r = (4)(9.56 \times 10^{-6} \text{ N})(0.075 \text{ m})$$

$$= 2.85 \times 10^{-6} \text{ N}\cdot\text{m} = \mathbf{2.85 \text{ }\mu\text{N}\cdot\text{m}}$$

b. Gasoline

$$\rho = 680 \text{ kg/m}^3$$

$$F_D = (1.35)(0.5)(680)(0.157)^2(4.91 \times 10^{-4}) = 5.56 \times 10^{-3} \text{ kg}\cdot\text{m/s}^2 = 5.56 \text{ mN}$$

$$\text{Torque} = 4F_D r = (4)(5.56 \times 10^{-3} \text{ N})(0.075 \text{ m}) = 1.67 \times 10^{-3} \text{ N}\cdot\text{m} = \mathbf{1.67 \text{ mN}\cdot\text{m}}$$

$$\text{Ratio } \frac{T_G}{T_A} = \frac{1.67 \times 10^{-3} \text{ N}\cdot\text{m}}{2.85 \times 10^{-6} \text{ N}\cdot\text{m}} = 586$$

Motor circuit senses change in torque to indicate fluid level.

17.12 Assume center of gravity is at center of home. When overturning is imminent, no weight is on right wheel.

$$\text{Then, } \sum M_A = 0 = w(1 \text{ m}) - F_D(1.75 \text{ m})$$

$$F_D = w/1.75$$

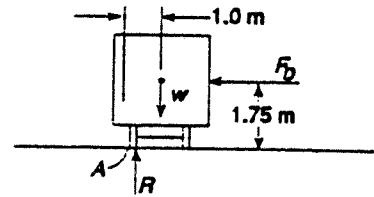
$$\text{But } F_D = C_D \left( \frac{1}{2} \rho v^2 \right) A; \text{ Assume } C_D = 2.05 \text{ square cylinder}$$

(Fig. 17.3)

$$A = (2.5 \text{ m})(10 \text{ m}) = 25 \text{ m}^2$$

$$v = \sqrt{\frac{2F_D}{C_D \rho A}} = \sqrt{\frac{2(w/1.75)}{(2.05)(1.292)(25)}} = 0.131\sqrt{w} \text{ m/s} \quad \text{If } w \text{ is weight in Newtons}$$

$$\text{Example: Assume } w = 5 \times 10^4 \text{ N; } v = 0.131\sqrt{5 \times 10^4} = 29.3 \text{ m/s}$$



$$17.13 \quad v = \frac{100 \text{ km}}{\text{h}} \times \frac{10^3 \text{ m}}{\text{km}} \times \frac{1 \text{ h}}{3600 \text{ s}} = 27.8 \text{ m/s}$$

$$\rho = 1.292 \text{ kg/m}^3; \quad \nu = 1.33 \times 10^{-5} \text{ m}^2/\text{s}$$

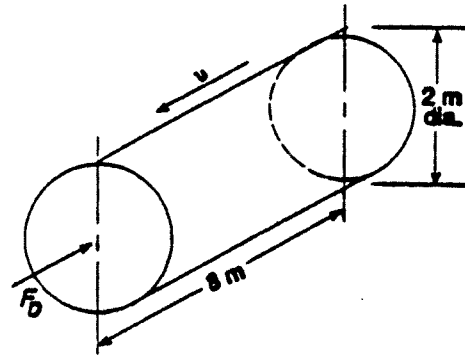
$$\text{Pressure drag: } F_{D_p} = C_{D_p} \left( \frac{1}{2} \rho v^2 \right) A$$

$$L/D = 8 \text{ m}/2 \text{ m} = 4.0; \quad C_D = 0.87 \text{ (Table 17.1)}$$

$$A = \pi D^2/4 = \pi(2 \text{ m})^2/4 = 3.14 \text{ m}^2$$

$$F_{D_p} = (0.87)(0.5)(1.292)(27.8)^2(3.14)$$

$$F_D = 1364 \text{ kg}\cdot\text{m/s}^2 = \mathbf{1364 \text{ N}}$$



$$17.14 \quad F_D = C_D \left( \frac{1}{2} \rho v^2 \right) A; \quad N_R = \frac{vD}{\nu} = \frac{(220)(0.167)}{1.16 \times 10^{-4}} = 3.15 \times 10^5 \rightarrow C_D = 0.8 \text{ Fig. 17.3}$$

↑

$$v = \frac{150 \text{ mi}}{\text{h}} \times \frac{5280 \text{ ft}}{1 \text{ mi}} \times \frac{1 \text{ h}}{3600 \text{ s}} = 220 \text{ ft/s}; \quad D = 2.0 \text{ in} (1 \text{ ft}/12 \text{ in}) = 0.167 \text{ ft}$$

$$\text{From Appendix E.2, } \nu = 1.17 \times 10^{-4} \text{ ft}^2/\text{s}$$

$$\rho = 2.80 \times 10^{-3} \text{ slugs/ft}^3$$

$$A = DL = (0.167 \text{ ft})(64 \text{ in})(1 \text{ ft}/12 \text{ in}) = 0.889 \text{ ft}^2$$

$$F_D = 0.8(0.5)(2.80 \times 10^{-3} \text{ lb}\cdot\text{s}^2/\text{ft}^4)(220 \text{ ft/s})^2(0.889 \text{ ft}^2) = \mathbf{48.2 \text{ lb}}$$

$$17.15 \quad \text{Elliptical cylinder — Table 17.1. } N_R = \frac{vL}{\nu} = \frac{(220)(1.33)}{1.17 \times 10^{-4}} = 2.50 \times 10^6$$

Assume breadth = Dia. of cyl. rods = 2.0 in; Then  $L = 8D = 8(2) = 16 \text{ in} = 1.33 \text{ ft}$

Use  $C_D \approx 0.20$ : Area is same as in Problem 17.14.

$$F_D = (0.20)(0.5)(2.8 \times 10^{-3})(220)^2(0.889) = \mathbf{12.05 \text{ lb } 75\% \text{ reduction}}$$

Navy strut: Fig. 17.5;  $C_D = 0.08$ ; Then  $F_D = 4.82 \text{ lb}$ ; 90% reduction from cylindrical rods.

$$17.16 \quad F_D = C_D \left( \frac{1}{2} \rho v^2 \right) A = C_D(0.5)(2.80 \times 10^{-3})(147)^2(A)$$

$$= (30.12)(C_D)(A)$$

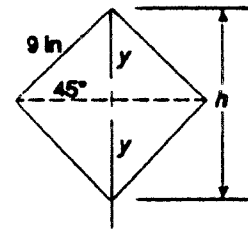
$$v = \frac{100 \text{ mi}}{\text{h}} \times \frac{5280 \text{ ft}}{1 \text{ mi}} \times \frac{1 \text{ h}}{3600 \text{ s}} = 147 \text{ ft/s}$$

$$A = (9 \text{ in})(60 \text{ in}) \frac{1 \text{ ft}^2}{144 \text{ in}^2} = 3.75 \text{ ft}^2 \text{ for designs a, c, d.}$$

$$\text{For design b: } y = (9 \text{ in}) \sin 45^\circ = 6.36 \text{ in}$$

$$h = 2y = (12.73 \text{ in}) \frac{1 \text{ ft}}{12 \text{ in}} = 1.06 \text{ ft}$$

$$A = h \times l = (1.06 \text{ ft})(5.0 \text{ ft}) = 5.303 \text{ ft}^2$$



a. **Square cylinder:**  $L = 9 \text{ in} \times 1 \text{ ft}/12 \text{ in} = 0.75 \text{ ft}$

$$N_R = \frac{\nu L}{\nu} = \frac{(147)(0.75)}{(1.17 \times 10^{-4})} = 9.42 \times 10^5 \rightarrow \text{Use } C_D \approx 2.10 \text{ Fig. 17.3 Extrapolated}$$

$$F_D = (30.12)(2.10)(3.75) = \mathbf{237 \text{ lb}}$$

NOTE: Extrapolated values should be verified.

b. Assume  $C_D = 1.60$  — Square cylinder — Point first orientation

$$F_D = (30.12)(1.60)(5.303) = \mathbf{256 \text{ lb Highest}}$$

c. **Circular cylinder:**  $D = 9.0 \text{ in} = 0.75 \text{ ft}$

$$N_R = \frac{\nu D}{\nu} = \frac{(147)(0.75)}{(1.17 \times 10^{-4})} = 9.42 \times 10^5 \rightarrow C_D = 0.30 \text{ (Fig. 17.3)}$$

$F_D = (30.12)(0.30)(3.75) = \mathbf{33.9 \text{ lb}}$  Note that  $C_D$  would rise to approximately 1.30 at lower speed. But, because  $F_D$  is proportional to  $\nu^2$ , drag force would likely be lower.

d. **Elliptical cylinder:**  $L = 18 \text{ in} = 1.50 \text{ ft}; h = 9.00 \text{ in} = 0.75 \text{ ft}; L/h = 2.0$

$$N_R = \frac{\nu L}{\nu} = \frac{(147)(1.50)}{1.16 \times 10^{-4}} = 1.88 \times 10^6 \rightarrow \text{Use } C_D \approx 0.25 \text{ Fig. 17.5 Extrapolated}$$

$$F_D = (30.12)(0.25)(3.75) = \mathbf{28.2 \text{ lb Lowest}}$$

$$17.17 \quad F_D = C_D \left( \frac{1}{2} \rho \nu^2 \right) A; \quad \nu = \frac{65 \text{ mi}}{\text{h}} \times \frac{5280 \text{ ft}}{\text{mi}} \times \frac{1 \text{ h}}{3600 \text{ s}} = 95.3 \text{ ft/s}$$

$$A = DL = (3.50 \text{ in})(92 \text{ in})/144 \text{ in}^2 = 2.236 \text{ ft}^2$$

$$N_R = \frac{\nu D}{\nu} = \frac{(95.3)(3.50/12)}{1.17 \times 10^{-4}} = 2.38 \times 10^5 \rightarrow C_D = 1.10 \text{ Fig. 17.3}$$

⌊ [See Problem 17.14 for  $\nu$ ]

$$F_D = (1.10)(0.5)(2.80 \times 10^{-3})(95.3)^2(2.236) = \mathbf{31.3 \text{ lb}}$$

$$17.18 \quad F_{D_{\text{tot}}} = F_{D_{\text{disks}}} + F_{D_{\text{tubes}}}; \quad \nu = 100 \text{ mi/hr} = 147 \text{ ft/s (See Prob. 17.16):}$$

$$C_{D_{\text{disks}}} = 1.11 \text{ (Table 17.1)}$$

$$N_{R_{\text{tubes}}} = \frac{\nu D}{\nu} = \frac{(147)(4.5/12)}{1.17 \times 10^{-4}} = 4.71 \times 10^5 \rightarrow \text{Use } C_{D_r} = 0.33 \text{ Fig. 17.3}$$

⌊ [See Prob. 17.14]

$$A_{\text{disks}} = 3 \frac{\pi D^2}{4} = 3 \frac{\pi (56/12)^2}{4} = 51.31 \text{ ft}^2; \quad A_{\text{tubes}} = DL = \left( \frac{4.5}{12} \right) \left( \frac{90}{12} \right) = 2.813 \text{ ft}^2$$

$$F_{D_{\text{tot}}} = C_{D_{\text{disks}}} \left( \frac{1}{2} \rho \nu^2 \right) A_d + C_D \left( \frac{1}{2} \rho \nu^2 \right) A_t = (1.11)(0.5)(2.80 \times 10^{-3})(147)^2(51.31)$$

$$+ (0.33)(0.5)(2.80 \times 10^{-3})(147)^2(2.813) = \begin{matrix} 1723 \text{ lb} & + & 28.1 \text{ lb} & = & \mathbf{1751 \text{ lb}} \\ \text{Disks} & & \text{Tubes} & & \text{Total} \end{matrix}$$

$$17.19 \quad F_D = C_D \left( \frac{1}{2} \rho v^2 \right) (A): \quad v = (160 \text{ mi/h})(5280 \text{ ft/mi})(1 \text{ h} / 3600 \text{ s}) = 235 \text{ ft/s}$$

$$A = DL = (0.20 \text{ in})(42 \text{ in})(1 \text{ ft}^2/144 \text{ in}^2) = 0.0583 \text{ ft}^2$$

$$N_R = \frac{vD}{\nu} = \frac{(235)(0.2/12)}{1.17 \times 10^{-4}} = 3.35 \times 10^4 \rightarrow C_D = 1.30 \text{ Fig. 17.3}$$

⌊ [See Prob. 17.14]

$$F_D = (1.30)(0.5)(2.80 \times 10^{-3})(235)^2(0.0583) = \mathbf{5.86 \text{ lb}}$$

$$17.20 \quad F_D = C_D \left( \frac{1}{2} \rho v^2 \right) (A) = (0.41)(0.50)(2.00 \text{ slugs/ft}^3)(25.0 \text{ ft/s})^2 \left[ \frac{\pi(7.25 \text{ ft})^2}{4} \right] = \mathbf{10580 \text{ lb}}$$

$$17.21 \quad F_D = C_D \left( \frac{1}{2} \rho v^2 \right) (A): \text{ For plate, } \frac{a}{b} = \frac{11.0 \text{ in}}{8.5 \text{ in}} = 1.29 \rightarrow C_D = 1.16 \text{ Table 17.1}$$

$$A = (8.5 \text{ in})(11.0 \text{ in})(1 \text{ ft}^2/144 \text{ in}^2) = 0.649 \text{ ft}^2$$

$$F_D = (1.16)(0.50)(1.94)(44.0)^2(0.649) = \mathbf{1414 \text{ lb}}$$

$$v = (30 \text{ mi/h})(5280 \text{ ft/mi})(1 \text{ h}/3600 \text{ s}) = 44.0 \text{ ft/s}$$

$$17.22 \quad F_D = C_D \left( \frac{1}{2} \rho v^2 \right) (A) = (1.11)(0.5)(2.47 \times 10^{-3})(88.0)^2 \left[ \frac{\pi(28/12)^2}{4} \right] = \mathbf{45.4 \text{ lb}}$$

$$v = 60 \text{ mi/h} = 88 \text{ ft/s}$$

$$17.23 \quad \text{Golf ball - curve 2, } C_D = 0.17; \text{ Smooth sphere - curve 1, } C_{D_s} = 0.44$$

$$A = \pi(1.25/12)^2/4 = 0.00852 \text{ ft}^2$$

$$F_{D_{gb}} = (0.17)(0.5)(2.47 \times 10^{-3})(212)^2(0.00852) = \mathbf{0.080 \text{ lb}} \text{ on golf ball}$$

$$\text{Where } N_R = \frac{vD}{\nu}; \quad v = \frac{N_R \nu}{D} = \frac{(1.5 \times 10^5)(1.47 \times 10^{-4})}{(1.25/12)} = 212 \text{ ft/s}$$

$$F_{D_s} = F_{D_{gb}} \times \frac{C_{D_s}}{C_{D_{gb}}} = (0.080 \text{ lb}) \frac{0.44}{0.17} = \mathbf{0.207 \text{ lb}} \text{ Smooth surface}$$

$$17.24 \quad v = \frac{18 \text{ in}}{20.4 \text{ s}} \times \frac{\text{ft}}{12 \text{ in}} = 0.0735 \text{ ft/s}; \quad D = (1.20 \text{ in})(1.0 \text{ ft}/12 \text{ in}) = 0.10 \text{ ft}$$

$$\sum F_y = 0 = w - F_b - F_D: \quad F_D = w - F_b$$

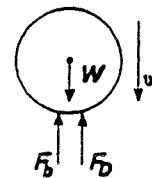
$$w = \gamma_{st} V_{st} = (s g_{st}) \gamma_w V_{st} = (7.83)(62.4 \text{ lb/ft}^3)(5.24 \times 10^{-4} \text{ ft}^3) = 0.256 \text{ lb}$$

$$V_{st} = \pi D^3/6 = \pi(0.10 \text{ ft})^3/6 = 5.24 \times 10^{-4} \text{ ft}^3$$

$$F_b = \gamma_{\text{syrup}} V_{st} = (s g_s)(\gamma_w) V_{st} = (1.18)(62.4)(5.24 \times 10^{-4}) = 0.0386 \text{ lb}$$

$$F_D = w - F_b = 0.256 \text{ lb} - 0.0386 \text{ lb} = 0.217 \text{ lb} = 3\pi\mu v D \text{ [Eq. 17.8]}$$

$$\mu = \frac{F_D}{3\pi v D} = \frac{0.217 \text{ lb}}{3\pi(0.0735 \text{ ft/s})(0.10 \text{ ft})} = \mathbf{3.14 \text{ lb}\cdot\text{s/ft}^2}$$



$$17.25 \quad P_D = F_D v = C_D \left( \frac{1}{2} \rho v^2 \right) A \times v$$

$$= (0.75)(0.5)(2.47 \times 10^{-3} \text{ lb}\cdot\text{s}^2/\text{ft}^4)(95.3 \text{ ft/s})^2(96 \text{ ft}^2)(95.3 \text{ ft/s})$$

$\underbrace{\hspace{10em}}_{F_D = 808 \text{ lb}} \quad \downarrow$   
 $v$

$$v = (65 \text{ mi/h})(5280 \text{ ft/mi})(1 \text{ h}/3600 \text{ s}) = 95.3 \text{ ft/s}$$

$$A = (8 \text{ ft})(12 \text{ ft}) = 96 \text{ ft}^2$$

$$P_D = 7.70 \times 10^4 \frac{\text{lb}\cdot\text{ft}}{\text{s}} \times \frac{\text{hp}}{550 \text{ lb}\cdot\text{ft/s}} = \mathbf{140 \text{ hp}}$$

$$17.26 \quad R_{ts}/\Delta = 0.06; R_{ts} = 0.06(\Delta) = (0.06)(125 \text{ tons})(2240 \text{ lb/ton}) = \mathbf{16800 \text{ lb}}$$

$$P_E = R_{ts} v = (16800 \text{ lb})(50 \text{ ft/s}) = \frac{840000 \text{ lb}\cdot\text{ft/s}}{550 \text{ lb}\cdot\text{ft/s}\langle\text{hp}\rangle} = \mathbf{1527 \text{ hp}}$$

$$17.27 \quad R_{ts}/\Delta = 0.004; R_{ts} = (0.004)(8700 \text{ T})(2240 \text{ lb/T}) = \mathbf{77952 \text{ lb}}$$

$$P_E = R_{ts} v = (77952 \text{ lb})(30 \text{ ft/s}) \frac{1 \text{ hp}}{550 \text{ lb}\cdot\text{ft/s}} = \mathbf{4252 \text{ hp}}$$

$$17.28 \quad F_L = C_L \left( \frac{1}{2} \rho v^2 \right) (A) = (1.25)(0.5)(1.204)(v^2)[(0.78)(1.46)\text{m}^2] = 0.857 v^2$$

$$\text{Use air at } 20^\circ\text{C at std. atm. pressure, } \rho = 1.204 \text{ kg/m}^3 = \frac{1.204 \text{ N}\cdot\text{s}^2}{\text{m}^4}$$

$$\text{For } v = 25 \text{ m/s, } F_L = (0.857)(25)^2 = \mathbf{536 \text{ N}}$$

$$17.29 \quad F_D = C_D \left( \frac{1}{2} \rho v^2 \right) (A) = (0.105)(0.5) \left( \frac{0.9093 \text{ N}\cdot\text{s}^2}{\text{m}^4} \right) (v^2)[(2 \text{ m})(10 \text{ m})] = 0.955(v^2)$$

$$\text{a. } v = \frac{600 \times 10^3 \text{ m}}{\text{h}} \times \frac{1 \text{ h}}{3600 \text{ s}} = 166.7 \text{ m/s; } F_D = 0.955(166.7)^2 = \mathbf{26.5 \text{ kN}}$$

$$\text{b. } v = (150 \times 10^3)/3600 = 41.67 \text{ m/s; } F_D = 0.955(41.67)^2 = \mathbf{1.66 \text{ kN}}$$

$$17.30 \quad F_L = C_L \left( \frac{1}{2} \rho v^2 \right) A; F_D = C_D \left( \frac{1}{2} \rho v^2 \right) A$$

$$C_L = 0.90; C_D = 0.05 \text{ (Fig. 17.10); } A = bc = (6.8 \text{ m})(1.4 \text{ m}) = 9.52 \text{ m}^2$$

$$v = \frac{200 \text{ km}}{\text{h}} \times \frac{10^3 \text{ m}}{\text{km}} \times \frac{1 \text{ h}}{3600 \text{ s}} = 55.56 \text{ m/s}$$

$$\text{a. At } 200 \text{ m, } \rho = 1.202 \text{ kg/m}^3 \text{ (Appendix E)}$$

$$F_L = (0.90)(0.5)(1.202)(55.56)^2(9.52) = 1.59 \times 10^4 \text{ kg}\cdot\text{m/s}^2$$

$$= 1.59 \times 10^4 \text{ N} = \mathbf{15.9 \text{ kN}}$$

$$F_D = \frac{0.05}{0.90} \times 1.59 \times 10^4 \text{ N} = \mathbf{883 \text{ N}}$$

b. At 10000 m;  $\rho = 0.4135 \text{ kg/m}^3$   
 $F_L = (0.9)(0.5)(0.4135)(55.56)^2(9.52) = 5.47 \times 10^3 \text{ N} = \mathbf{5.47 \text{ kN}}$   
 $F_D = \frac{0.05}{0.90} \times 5.47 \times 10^3 \text{ N} = \mathbf{304 \text{ N}}$

17.31 For  $\alpha = 19.6^\circ$ ;  $C_L = 1.52$ ;  $C_D = 0.16$  (Other data same as Prob. 17.30)

a.  $\left(\frac{1}{2}\rho v^2\right)A = (0.5)(1.202)(55.56)^2(9.52) = 1.766 \times 10^4 \text{ N}$

$$F_L = 1.52(1.766 \times 10^4) = 2.68 \times 10^4 \text{ N} = \mathbf{26.8 \text{ kN}}$$

$$F_D = 0.16(1.766 \times 10^4) = 2.83 \times 10^3 \text{ N} = \mathbf{2.83 \text{ kN}}$$

b.  $\left(\frac{1}{2}\rho v^2\right)A = (0.5)(0.4135)(55.56)^2(9.52) = 6.076 \times 10^3 \text{ N}$

$$F_L = 1.52(6.076 \times 10^3) = 9.24 \times 10^3 \text{ N} = \mathbf{9.24 \text{ kN}}$$

$$F_D = 0.16(6.076 \times 10^3) = \mathbf{972 \text{ N}}$$

17.32  $v = \frac{125 \text{ km}}{\text{h}} \times \frac{10^3 \text{ m}}{\text{km}} \times \frac{1 \text{ h}}{3600 \text{ s}} = 34.72 \text{ m/s}$

For  $\alpha = 15^\circ$ ,  $C_L = 1.25$  (Fig. 17.10)

$$\rho = 1.164 \text{ kg/m}^3; A = 9.52 \text{ m}^2 \text{ (Prob. 17.30)}$$

$$F_L = C_L \left(\frac{1}{2}\rho v^2\right)A = (1.25)(0.5)(1.164)(34.72)^2(9.52) = 8.35 \times 10^3 \text{ kg}\cdot\text{m/s}^2$$

$F_L = \mathbf{8.35 \text{ kN}}$  = Load which could be lifted

17.33  $F_L = C_L \left(\frac{1}{2}\rho v^2\right)A$

$$\text{Let } F_L = \text{Wt. of plane} = \text{mass} \times g = 1350 \text{ kg} \cdot 9.81 \text{ m/s}^2 = 13.24 \times 10^3 \text{ kg}\cdot\text{m/s}^2$$

$$F_L = 13.24 \text{ kN}$$

At  $\alpha = 2.5^\circ$ ;  $C_L = 0.33$  (Fig. 17.10)

At 5000 m;  $\rho = 0.7364 \text{ kg/m}^3$

Solve for  $A$

$$v = 125 \text{ km/h} = 34.72 \text{ m/s} \\ \text{(Prob. 17.32)}$$

$$A = \frac{2F_L}{C_L \rho v^2} = \frac{(2)(13.24 \times 10^3 \text{ kg}\cdot\text{m/s}^2)}{(0.33)(0.7364 \text{ kg/m}^3)(34.72 \text{ m/s})^2} = \mathbf{90.4 \text{ m}^2}$$

## CHAPTER EIGHTEEN

# FANS, BLOWERS, COMPRESSORS, AND THE FLOW OF GASES

### Units and conversion factors

$$18.1 \quad Q = 2650 \text{ cfm} \times \frac{1 \text{ ft}^3/\text{s}}{60 \text{ cfm}} = 44.17 \text{ ft}^3/\text{s}$$

$$18.2 \quad Q = 8320 \text{ cfm} \times \frac{1 \text{ ft}^3/\text{s}}{60 \text{ cfm}} = 138.7 \text{ ft}^3/\text{s}$$

$$18.3 \quad Q = 2650 \text{ cfm} \times \frac{1 \text{ m}^3/\text{s}}{2120 \text{ cfm}} = 1.25 \text{ m}^3/\text{s}$$

$$18.4 \quad Q = 8320 \text{ cfm} \times \frac{1 \text{ m}^3/\text{s}}{2120 \text{ cfm}} = 3.92 \text{ m}^3/\text{s}$$

$$18.5 \quad v = 1140 \text{ ft}/\text{min} \times \frac{1.0 \text{ m}/\text{s}}{197 \text{ ft}/\text{min}} = 5.79 \text{ m}/\text{s}$$

$$18.6 \quad v = 5.62 \text{ m}/\text{s} \times \frac{3.28 \text{ ft}/\text{s}}{\text{m}/\text{s}} = 18.43 \text{ ft}/\text{s}$$

$$18.7 \quad p = 4.38 \text{ in H}_2\text{O} \times \frac{1.0 \text{ psi}}{27.7 \text{ in H}_2\text{O}} = 0.158 \text{ psi}$$

$$18.8 \quad Q = 4760 \text{ cfm} \times \frac{1.0 \text{ m}^3/\text{s}}{2120 \text{ cfm}} = 2.25 \text{ m}^3/\text{s}$$
$$p = 0.75 \text{ in H}_2\text{O} \times \frac{248.8 \text{ Pa}}{1.0 \text{ in H}_2\text{O}} = 186.6 \text{ Pa}$$

$$18.9 \quad p = 925 \text{ Pa} \times \frac{1.0 \text{ in H}_2\text{O}}{248.8 \text{ Pa}} = 3.72 \text{ in H}_2\text{O}$$

$$18.10 \quad p = 925 \text{ Pa} \times \frac{1.0 \text{ psi}}{6895 \text{ Pa}} = 0.134 \text{ psi}$$

### Specific weight of air

$$18.17 \quad p = p_{\text{atm}} + p_{\text{gage}} = 14.7 \text{ psia} + 80 \text{ psig} = 94.7 \text{ psia}$$
$$T = t + 460 = 75^\circ\text{F} + 460 = 535^\circ\text{R}$$
$$\gamma = \frac{p}{RT} = \frac{94.7 \text{ lb}}{\text{in}^2} \times \frac{\text{lb} \cdot ^\circ\text{R}}{53.3 \text{ ft} \cdot \text{lb}} \times \frac{1}{535^\circ\text{R}} \times \frac{144 \text{ in}^2}{\text{ft}^2} = \mathbf{0.478 \text{ lb/ft}^3} \quad (\text{Eq. 18.2})$$
$$\text{or } \gamma = \frac{2.70p}{T} = \frac{2.70(94.7)}{535} = 0.478 \text{ lb/ft}^3 \quad (\text{Eq. 18.3})$$

$$18.18 \quad \gamma = \frac{2.70p}{T} = \frac{(2.70)(14.7 + 25)}{(105 + 460)} = \mathbf{0.190 \text{ lb/ft}^3} \quad (\text{Eq. 18.3}) \quad \text{Air}$$

$$18.19 \quad p = 4.50 \text{ in H}_2\text{O} \times \frac{1.0 \text{ psi}}{27.7 \text{ in H}_2\text{O}} = 0.162 \text{ psig} \quad \text{Natural gas}$$
$$p_{\text{abs}} = p_{\text{atm}} + p_{\text{gage}} = 14.7 \text{ psia} + 0.162 \text{ psig} = 14.86 \text{ psia}$$
$$T = 55^\circ\text{F} + 460 = 515^\circ\text{R}$$
$$\gamma = \frac{p}{RT} = \frac{14.86 \text{ lb}}{\text{in}^2} \times \frac{\text{lb} \cdot ^\circ\text{R}}{79.1 \text{ ft} \cdot \text{lb}} \times \frac{1}{515^\circ\text{R}} \times \frac{144 \text{ in}^2}{\text{ft}^2} = \mathbf{0.0525 \text{ lb/ft}^3}$$

$$18.20 \quad p = p_{\text{atm}} + p_{\text{gage}} = 14.7 \text{ psia} + 32 \text{ psig} = 46.7 \text{ psia} \quad \text{Nitrogen}$$
$$T = 120^\circ\text{F} + 460 = 580^\circ\text{R}$$
$$\gamma = \frac{p}{RT} = \frac{46.7 \text{ lb}}{\text{in}^2} \times \frac{\text{lb} \cdot ^\circ\text{R}}{55.2 \text{ ft} \cdot \text{lb}} \times \frac{1}{580^\circ\text{R}} \times \frac{144 \text{ in}^2}{\text{ft}^2} = \mathbf{0.210 \text{ lb/ft}^3}$$

$$18.21 \quad p = p_{\text{atm}} + p_{\text{gage}} = 101.3 \text{ kPa(air)} + 1260 \text{ Pa(gage)} \times \frac{\text{kPa}}{10^3 \text{ Pa}} = 102.56 \text{ kPa(abs)} \quad \text{Air}$$
$$T = t + 273 = 25^\circ\text{C} + 273 = 298 \text{ K}$$
$$\gamma = \frac{p}{RT} = \frac{102.56 \times 10^3 \text{ N}}{\text{m}^2} \times \frac{\text{N} \cdot \text{K}}{29.2 \text{ N} \cdot \text{m}} \times \frac{1}{298 \text{ K}} = \mathbf{11.79 \text{ N/m}^3}$$

$$18.22 \quad p = p_{\text{atm}} + p_{\text{gage}} = 14.7 \text{ psia} + 12.6 \text{ psig} = 27.3 \text{ psia}$$
$$T = 85^\circ\text{F} + 460 = 545^\circ\text{R}$$
$$\gamma = \frac{p}{RT} = \frac{27.3 \text{ lb}}{\text{in}^2} \times \frac{\text{lb} \cdot ^\circ\text{R}}{35.0 \text{ ft} \cdot \text{lb}} \times \frac{1}{545^\circ\text{R}} \times \frac{144 \text{ in}^2}{\text{ft}^2} = \mathbf{0.207 \text{ lb/ft}^3}$$

### Flow of compressed air in pipes

$$18.23 \quad Q_a = 820 \text{ cfm} \times \frac{14.7 \text{ psia}}{(14.7 + 80) \text{ psia}} \times \frac{(75 + 460)^\circ\text{R}}{520^\circ\text{R}} = \mathbf{131.0 \text{ cfm}} \quad (\text{Eq. 18.4a})$$

$$18.24 \quad Q_a = 2880 \text{ cfm} \times \frac{14.7}{(14.7 + 65)} \times \frac{(95 + 460)}{520} = \mathbf{566.9 \text{ cfm}}$$

18.25 From Table 18.1; **2 in Sch. 40 pipe**

18.26 1-1/4 in Sch. 40 pipe

18.27  $Q = 800$  cfm (Free air);  $p_2 = 100$  psig @  $70^\circ\text{F}$   
 Try a **2-1/2 in Sch. 40 pipe**:  $D = 0.2058$  ft;  $A = 0.3326$  ft<sup>2</sup>

$$\frac{p_1}{\gamma_1} = z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_2} + z_2 + \frac{v_2^2}{2g}; \quad z_1 = z_2, \quad v_1 = v_2; \quad \text{then } p_1 = p_2 + \gamma h_L$$

$$\gamma = \frac{2.70p}{T} = \frac{2.70(14.7+100)\text{psia}}{(70^\circ\text{F}+460)^\circ\text{R}} = 0.584 \text{ lb/ft}^3$$

$$h_L = f\left(\frac{L}{D}\right)\frac{v^2}{2g} + f_T\left(\frac{L_e}{D}\right)\frac{v^2}{2g}; \quad \frac{L}{D} = \frac{350 \text{ ft}}{0.2058 \text{ ft}} = 1700$$

$$\left(\frac{L_e}{D}\right)_{\text{tot}} = 8(30) + 2(8) + 100 = 356; \quad f_T = 0.018$$

Elbows Gate V. Check valve

$$Q_a = 800 \text{ cfm} \times \frac{14.7 \text{ psia}}{(14.7+100)\text{psia}} \times \frac{(70+460)^\circ\text{R}}{520^\circ\text{R}} = 104.5 \text{ cfm}$$

$$v = \frac{Q}{A} = \frac{104.5 \text{ ft}^3}{\text{min}} \times \frac{1}{0.3326 \text{ ft}^2} \times \frac{1 \text{ min}}{60 \text{ s}} = 52.4 \text{ ft/s}$$

$$\frac{v^2}{2g} = \frac{(52.4)^2 \text{ ft}^2/\text{s}^2}{2(32.2 \text{ ft/s}^2)} = 42.58 \text{ ft}$$

$$\text{Density} = \rho = \frac{\gamma}{g} = \frac{0.584 \text{ lb}}{\text{ft}^3} \frac{\text{s}^2}{32.2 \text{ ft}} = 0.0181 \text{ slugs/ft}^3$$

$t = (70^\circ\text{F} - 32)(5/9) = 21.1^\circ\text{C}$ ;  $\mu = 1.815 \times 10^{-5}$  Pa·s (App. E by interpolation)

$$\mu = (1.815 \times 10^{-5} \text{ Pa}\cdot\text{s})(2.089 \times 10^{-2}) = 3.792 \times 10^{-7} \text{ lb}\cdot\text{s/ft}^2$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(52.4)(0.2058)(0.0181)}{3.792 \times 10^{-7}} = 5.15 \times 10^5$$

$$\frac{D}{\varepsilon} = \frac{0.2058}{1.5 \times 10^{-4}} = 1372; \quad f = 0.0195$$

$$h_L = \left[ f\left(\frac{L}{D}\right) + f_T\left(\frac{L_e}{D}\right) \right] \frac{v^2}{2g} = [(0.0195)(1700) + 0.018(356)](42.58 \text{ ft}) = 1684 \text{ ft}$$

$$p_1 = p_2 + \gamma h_L = 100 \text{ psig} + \frac{0.584 \text{ lb}}{\text{ft}^3} \times 1684 \text{ ft} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} = \mathbf{106.8 \text{ psig}}$$

$$p_1 - p_2 = 6.7 \text{ psi} < 0.1p_2 \quad \mathbf{OK}$$

18.28  $Q = 3000$  cfm (Free air);  $p_2 = 80$  psig @  $120^\circ\text{F}$

Try a 3-1/2 in Sch. 40 pipe:  $D = 0.2957$  ft;  $A = 0.06868$  ft<sup>2</sup>

$$\frac{p_1}{\gamma_1} = z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_2} + z_2 + \frac{v_2^2}{2g}; \quad z_1 = z_2, \quad v_1 = v_2; \quad \text{then } p_1 = p_2 + \gamma h_L$$

$$\gamma = \frac{2.70p}{T} = \frac{2.70(14.7 + 80) \text{ psia}}{(120 + 460)^\circ\text{R}} = 0.4408 \text{ lb/ft}^3$$

$$\textcircled{1} \quad h_L = f \left( \frac{L}{D} \right) \frac{v^2}{2g} + f_T \left( \frac{L_e}{D} \right) \frac{v^2}{2g}; \quad \frac{L}{D} = \frac{180 \text{ ft}}{0.2957 \text{ ft}} = 609$$

$$\left( \frac{L_e}{D} \right)_{\text{tot}} = 45 + 12(30) + 4(20) + 150 = 635; \quad f_T = 0.017$$

Valve Elbows Tees Ch. valve

$$Q_a = 3000 \text{ cfm} \times \frac{14.7 \text{ psia}}{(14.7 + 80) \text{ psia}} \times \frac{(120 + 460)^\circ\text{R}}{520^\circ\text{R}} = 519.4 \text{ cfm}$$

$$v = \frac{Q_a}{A} = \frac{519.4 \text{ ft}^3}{\text{min}} \times \frac{1}{0.06868 \text{ ft}^2} \times \frac{1 \text{ min}}{60 \text{ s}} = 126.0 \text{ ft/s}$$

$$v^2/2g = (126.0)^2/2(32.2) = 246.7 \text{ ft}$$

$$\text{Density} = \rho = \gamma/g = \frac{0.4408 \text{ lb}}{\text{ft}^3} \frac{\text{s}^2}{32.2 \text{ ft}} = 0.01369 \text{ slugs/ft}^3$$

$$t = (120^\circ\text{F} - 32)5/9 = 48.89^\circ\text{C}; \quad \mu = 1.946 \times 10^{-5} \text{ Pa}\cdot\text{s} \text{ (App. E by interpolation)}$$

$$\mu = (1.946 \times 10^{-5} \text{ Pa}\cdot\text{s})(2.089 \times 10^{-2}) = 4.065 \times 10^{-7} \text{ lb}\cdot\text{s/ft}^2$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(126)(0.2957)(0.01369)}{4.065 \times 10^{-7}} = 1.25 \times 10^6$$

$$D/\varepsilon = 0.2957 \text{ ft}/1.5 \times 10^{-4} \text{ ft} = 1971; \quad f = 0.0175$$

$$\text{In Eq. } \textcircled{1}: \quad h_L = [(0.0175)(609) + (0.017)(635)](246.7 \text{ ft}) = 5292 \text{ ft}$$

$$p_1 = p_2 + \gamma h_L = 80 \text{ psig} + \frac{0.4408 \text{ lb}}{\text{ft}^3} \times 5292 \text{ ft} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} = 80 + 16.20 = 96.20 \text{ psig}$$

$\Delta p = 16.20$  psi is  $> 0.10p_2$  — Use larger pipe size

For 4-in Sch. 40 pipe:  $D = 0.3355$  ft;  $A = 0.0884$  ft<sup>2</sup>;  $f_T = 0.017$

$$v = \frac{Q_a}{A} = \frac{519.4}{(0.0884)(60)} = \frac{97.9 \text{ ft}}{\text{s}}; \quad \frac{v^2}{2g} = 148.9 \text{ ft}$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(97.9)(0.3355)(0.01369)}{4.065 \times 10^{-7}} = 1.11 \times 10^6$$

$$D/\varepsilon = 0.3355/1.5 \times 10^{-4} = 2237; \quad f = 0.0170$$

$$\text{In Eq. } \textcircled{1}: \quad h_L = [(0.017)(609) + (0.017)(635)](148.9 \text{ ft}) = 3149 \text{ ft}$$

$$p_1 = p_2 + \gamma h_L = 80 \text{ psig} + (0.4408)(3149)/144 = 80 + 9.64 = 89.6 \text{ psig}$$

$\Delta p$  is slightly  $> 0.1p_2$

Try 5-in Sch. 40 pipe:  $D = 0.4206$  ft;  $A = 0.1390$  ft<sup>2</sup>;  $f_T = 0.016$

$$v = \frac{Q_a}{A} = \frac{519.4}{(0.139)(60)} = \frac{62.28 \text{ ft}}{\text{s}}; \frac{v^2}{2g} = 60.23 \text{ ft}$$

$$N_R = \frac{vD\rho}{\mu} = \frac{(62.28)(0.4206)(0.01369)}{4.065 \times 10^{-7}} = 8.82 \times 10^5$$

$$D/\varepsilon = 0.4206/1.5 \times 10^{-4} = 2804; f = 0.017$$

In Eq. (I):  $h_L = [(0.017)(609) + (0.016)(635)](60.23 \text{ ft}) = 1235 \text{ ft}$

$$p_1 = p_2 + \gamma h_L = 80 + (0.4408)(1235)/144 = 80 + 3.78 = \mathbf{83.78 \text{ psig}}$$

$\Delta p < 0.1p_2$  — **OK**

### Gas flow through nozzles

18.29  $p_1 = 40.0$  psig + 14.7 psia = 54.7 psia;  $T_1 = 80^\circ\text{F} + 460 = 540^\circ\text{R}$

$p_2 = 20.0$  psig + 14.7 psia = 34.7 psia **Air**

$$\gamma_1 = \frac{2.70 p_1}{T_1} = \frac{2.70(54.7 \text{ psia})}{540^\circ\text{R}} = 0.2735 \text{ lb/ft}^3 \quad (\text{Eq. 18.3})$$

$$\gamma_2 = \gamma_1 \left[ \frac{p_2}{p_1} \right]^{1/k} = \frac{0.2735 \text{ lb}}{\text{ft}^3} \left[ \frac{34.7}{54.7} \right]^{1/1.4} = \mathbf{0.198 \text{ lb/ft}^3} \quad (\text{Eq. 18.8})$$

18.30  $p_1 = 275$  kPa(gage) + 101.3 kPa(abs) = 376.3 kPa(abs) **Air**

$T_1 = 25^\circ\text{C} + 273 = 298 \text{ K}$

$p_2 = 140$  kPa(gage) + 101.3 kPa(abs) = 241.3 kPa(abs)

$$\gamma_1 = \frac{p_1}{RT_1} = \frac{376.3 \times 10^3 \text{ N}}{\text{m}^2} \times \frac{\text{N} \cdot \text{K}}{29.2 \text{ N} \cdot \text{m}} \times \frac{1}{298 \text{ K}} = \mathbf{43.2 \text{ N/m}^3}$$

$$\gamma_2 = \gamma_1 \left[ \frac{p_2}{p_1} \right]^{1/k} = \frac{43.2 \text{ N}}{\text{m}^3} \left[ \frac{241.3}{376.3} \right]^{1/1.4} = \mathbf{31.5 \text{ N/m}^3}$$

18.31  $p_1 = 35.0$  psig + 14.7 psia = 49.7 psia: **R-12**

$T_1 = 60^\circ\text{F} + 460 = 520^\circ\text{R}$

$p_2 = 3.6$  psig + 14.7 psia = 18.3 psia

$$\gamma_1 = \frac{P_1}{RT_1} = \frac{49.7 \text{ lb}}{\text{in}^2} \times \frac{\text{lb} \cdot ^\circ\text{R}}{12.6 \text{ ft} \cdot \text{lb}} \times \frac{1}{520^\circ\text{R}} \times \frac{144 \text{ in}^2}{\text{ft}^2} = \mathbf{1.092 \text{ lb/ft}^3}$$

$$\gamma_2 = \gamma_1 \left[ \frac{p_2}{p_1} \right]^{1/k} = \frac{1.092 \text{ lb}}{\text{ft}^3} \left[ \frac{18.3}{49.7} \right]^{1/1.13} = \mathbf{0.506 \text{ lb/ft}^3}$$

18.32  $p_1 = 125$  psig + 14.4 psia = 139.4 psia **Oxygen**,  $k = 1.40$

$T_1 = 75^\circ\text{F} + 460 = 535^\circ\text{R}$

$$p_2 = 14.40 \text{ psia} = p_{\text{atm}}; p_1 = \frac{139.4 \text{ lb}}{\text{in}^2} \times \frac{144 \text{ in}^2}{\text{ft}^2} = 20074 \text{ lb/ft}^2$$

$$\frac{p_2}{p_1} = \frac{14.40}{139.4} = 0.103; \text{Critical ratio} = 0.528 \text{ from App. N.}$$

Then use **Eq. 18.15**:

$$A_2 = \frac{\pi D_2^2}{4} = \frac{\pi(0.120 \text{ in})^2}{4} \times \frac{\text{ft}^2}{144 \text{ in}^2} = 7.854 \times 10^{-5} \text{ ft}^2$$

$$\gamma_1 = \frac{p_1}{RT_1} = \frac{139.4 \text{ lb}}{\text{in}^2} \times \frac{\text{lb} \cdot ^\circ\text{R}}{48.3 \text{ ft} \cdot \text{lb}} \times \frac{1}{535^\circ\text{R}} \times \frac{144 \text{ in}^2}{\text{ft}^2} = 0.777 \text{ lb/ft}^3$$

$$W_{\max} = 7.854 \times 10^{-5} \text{ ft}^2 \left[ \frac{2(32.2 \text{ ft/s}^2)(1.40)}{1.40+1} \frac{20074 \text{ lb}}{\text{ft}^2} \frac{0.777 \text{ lb}}{\text{ft}^3} \left[ \frac{2}{1.40+1} \right]^{2/0.4} \right]^{1/2}$$

$$W_{\max} = \mathbf{0.0381 \text{ lb/s}}$$

$$v = c = \sqrt{\frac{\text{kg } p_2}{\gamma_2}} = \left[ \frac{(1.40)(32.2 \text{ ft/s}^2)(10605 \text{ lb/ft}^2)}{0.493 \text{ lb/ft}^3} \right]^{1/2} = \mathbf{985 \text{ ft/s}}$$

$$p_2 = p_{2c} = p_1 \left[ \frac{2}{k+1} \right]^{k/k-1} = 20074 \left[ \frac{2}{2.40} \right]^{1.4/1.4} = 10605 \text{ lb/ft}^2$$

$$\gamma_2 = \gamma_1 \left( \frac{p_2}{p_1} \right)^{1/k} = 0.777(0.528)^{1/1.4} = 0.493 \text{ lb/ft}^3$$

18.33  $p_1 = 7.50 \text{ psig} + 14.40 \text{ psia} = 21.9 \text{ psia} (144 \text{ in}^2/\text{ft}^2) = 3154 \text{ lb/ft}^2$

$$\frac{p_2}{p_1} = \frac{14.40}{21.90} = 0.658 > \text{critical}; \text{ Use Eq. 18.11}$$

$$\gamma_1 = \frac{p_1}{RT_1} = \frac{3154 \text{ lb}}{\text{ft}^2} \times \frac{\text{lb} \cdot ^\circ\text{R}}{48.3 \text{ ft} \cdot \text{lb}} \times \frac{1}{535^\circ\text{R}} = 0.122 \text{ lb/ft}^3$$

$$W = 7.854 \times 10^{-5} \left[ \frac{2(32.2)(1.40)(3154)(0.122)}{1.40-1} \left[ (0.658)^{2/1.4} - (0.658)^{2.4/1.4} \right] \right]^{1/2}$$

$$W = \mathbf{5.76 \times 10^{-3} \text{ lb/s}}$$

Use Eq. 18.10 for velocity

$$v_2 = \left[ \frac{2(32.2)(3154)}{0.122} \times \frac{1.40}{0.4} \times \left[ 1 - (0.658)^{0.4/1.4} \right] \right]^{1/2} = \mathbf{811 \text{ ft/s}}$$

18.34  $p_1 = 50 \text{ psig} + 14.60 \text{ psia} = \frac{64.60 \text{ lb}}{\text{in}^2} \times \frac{144 \text{ in}^2}{\text{ft}^2} = 9302 \text{ lb/ft}^2$  **Nitrogen**

$$T_1 = 70^\circ\text{F} + 460 = 530^\circ\text{R}$$

$$\frac{p_2}{p_1} = \frac{14.60}{64.60} = 0.226 < \text{critical ratio} = 0.527 \text{ (App. N)}$$

Use Eq. 18.15

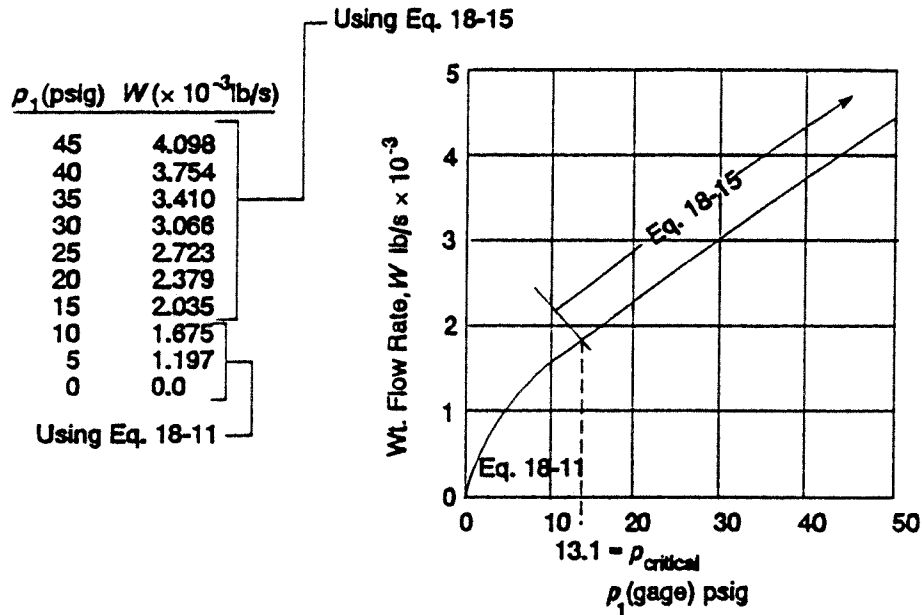
$$A_2 = \frac{\pi(0.062 \text{ in})^2}{4} \times \frac{\text{ft}^2}{144 \text{ in}^2} = 2.097 \times 10^{-5} \text{ ft}^2$$

$$\gamma_1 = \frac{p_1}{RT_1} = \frac{9302 \text{ lb}}{\text{ft}^2} \times \frac{\text{lb} \cdot ^\circ\text{R}}{55.2 \text{ ft} \cdot \text{lb}} \times \frac{1}{530^\circ\text{R}} = 0.318 \text{ lb/ft}^3$$

$$W_{\max} = 2.097 \times 10^{-5} \text{ ft}^2 \left[ \frac{2(32.2 \text{ ft/s}^2)(1.41)}{1.41+1} \times \frac{9302 \text{ lb}}{\text{ft}^2} \times \frac{0.318 \text{ lb}}{\text{ft}^3} \left[ \frac{2}{2.41} \right]^{2/0.41} \right]^{1/2}$$

$$W_{\max} = \mathbf{4.44 \times 10^{-3} \text{ lb/s}}$$

18.35 Use data from Problem 18.34.



18.36 Nozzle dia. = 0.50 in

$$p_1 = 25.0 \text{ psig} + 14.28 \text{ psia} = \frac{39.28 \text{ lb}}{\text{in}^2} \times \frac{144 \text{ in}^2}{1 \text{ ft}^2} = 5656 \text{ lb/ft}^2$$

$$\text{Propane: } \left( \frac{p_2}{p_1} \right)_c = 0.574; A_2 = \frac{\pi D_2^2}{4} = \frac{\pi (0.5 \text{ in})^2}{4} \text{ ft}^2 = 1.364 \times 10^{-3} \text{ ft}^2$$

$$\gamma_1 = \frac{p_1}{RT_1} = \frac{5656 \text{ lb}}{\text{ft}^2 (35.0 \text{ ft} \cdot \text{lb/lb} \cdot ^\circ\text{R})(65^\circ\text{F} + 460)^\circ\text{R}} = 0.308 \text{ lb/ft}^3$$

For  $p_2 = p_1 = 25.0$  psig,  $p_2/p_1 = 1$  and  $W = 0$

$$\text{For } p_2 = 20.0 \text{ psig} + 14.28 \text{ psi} = (34.28 \text{ psia})(144 \text{ in}^2/\text{ft}^2) = 4936 \text{ lb/ft}^2$$

$$p_2/p_1 = \frac{4936}{5656} = 0.8727 > \text{critical} \text{ — Use Eq. 18.11}$$

$$W = (1.364 \times 10^{-3} \text{ ft}^2) \sqrt{\frac{2(32.2 \text{ ft/s}^2)(1.15)(5656 \text{ lb})(0.308 \text{ lb})}{(1.15-1) \text{ ft}^2 \text{ ft}^3} \left[ (0.8727)^{2/1.15} - (0.8727)^{2.15/1.15} \right]}$$

$\underbrace{\hspace{10em}}_{8.597 \times 10^5}$

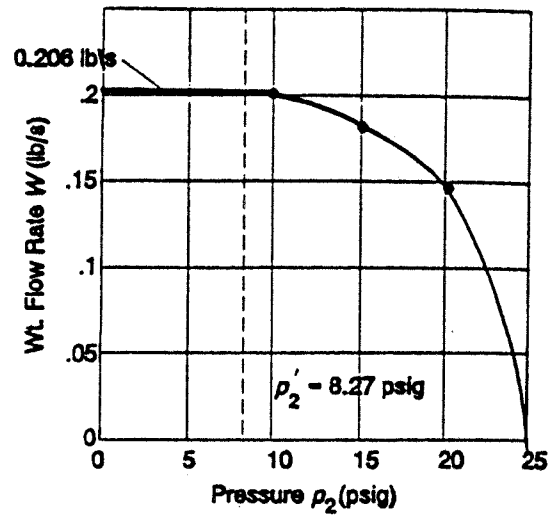
$$W = 0.149 \text{ lb/s}$$

$$p_{2c} = p_1(0.574) = 39.28 \text{ psia}(0.574) = 22.55 \text{ psia} - 14.28 \text{ psia} = 8.27 \text{ psig}$$

For  $p_2 \leq 8.27$  psig, Use Eq. 18.15.

$$W_{\text{max}} = (1.364 \times 10^{-3}) \sqrt{\frac{2(32.2)(1.15)(5656)(0.308)}{2.15} \left( \frac{2}{2.15} \right)^{2/0.15}} = 0.206 \text{ lb/s}$$

	$p_2$ (psig)	$p_2/p_1$	$W$ (lb/s)
	25.0	1.0	0.0
	20.0	0.8727	0.149
	15.0	0.7454	0.190
	10.0	0.6181	0.205
critical	8.27	0.574	0.206
	5.0	0.491	0.206



$$18.37 \quad \left(\frac{p_2}{p_1}\right)_c = 0.528; p_1 = \frac{p_2}{0.528} = \frac{98.5 \text{ kPa}}{0.528} = 186.6 \text{ kPa}$$

$$18.38 \quad c = \sqrt{\frac{\text{kg } p_2}{\gamma_2}} = \sqrt{\frac{(1.40)(9.81 \text{ m/s}^2)(186.6 \times 10^3 \text{ N/m}^2)}{11.00 \text{ N/m}^3}} = 483 \text{ m/s}$$

$$\gamma_1 = \frac{p_1}{RT_1} = \frac{186.6 \times 10^3 \text{ N/m}^2}{\frac{29.2 \text{ N}\cdot\text{m}}{\text{N}\cdot\text{K}} \times (95 + 273) \text{ K}} = 17.36 \text{ N/m}^3$$

$$\gamma_2 = \gamma_1(p_2/p_1)^{1/k} = (17.36)(0.528)^{1/1.4} = 11.00 \text{ N/m}^3$$

$$18.39 \quad \text{Use Eq. 18.15: } A_2 = \pi(0.010 \text{ m})^2/4 = 7.85 \times 10^{-5} \text{ m}^2$$

$$W_{\max} = (7.85 \times 10^{-5} \text{ m}^2) \sqrt{\frac{2(9.81)(1.40)(186.6 \times 10^3)(17.36) \left(\frac{2}{2.40}\right)^{2/0.4}}{2.40}} = 9.58 \times 10^{-3} \text{ N/s}$$

$$18.40 \quad p_1 = 150 \text{ kPa(gage)} + 100 \text{ kPa(atm)} = 250 \text{ kPa(abs): } \frac{p_2}{p_1} = \frac{100}{250} = 0.40: \left(\frac{p_2}{p_1}\right)_c = 0.578$$

$$\text{Use Eq. 18.15: } A_2 = \pi(0.008 \text{ m})^2/4 = 5.027 \times 10^{-5} \text{ m}^2$$

$$\gamma_1 = \frac{p_1}{RT_1} = \frac{250 \times 10^3 \text{ N/m}^2}{\frac{6.91 \text{ N}\cdot\text{m}}{\text{N}\cdot\text{K}} \times (20^\circ\text{C} + 273) \text{ K}} = 123.5 \text{ N/m}^3$$

$$W_{\max} = (5.027 \times 10^{-5} \text{ m}^2) \sqrt{\frac{2(9.81)(1.13)}{2.13} (250 \times 10^3)(123.5) \left(\frac{2}{2.13}\right)^{2/0.13}} = 0.555 \text{ N/s}$$

18.41 When  $p_2/p_1 < 0.578$ , use method of Prob. 18.40, Eq. 18.15.

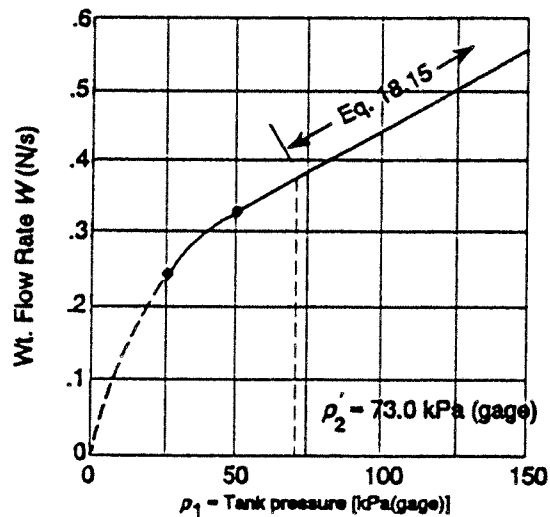
When  $p_2/p_1 = 0.578$ ;  $p_{1c} = \frac{p_2}{0.578} = \frac{100 \text{ kPa}}{0.578} = 173.0 \text{ kPa(abs)}$

$p_{1c} = 173.0 - 100 = 73.0 \text{ kPa(gage)}$ : Then for  $p_1 < 73.0 \text{ kPa(gage)}$ , use Eq. 18.11.

$p_1$ (gage)	$p_1$ (abs)	$(p_{atm}/p_1)$	$\gamma_1$ (N/m <sup>3</sup> )	$W$ (N/s)	
150 kPa	250 kPa	0.40	123.5	0.555	} $\frac{p_2}{p_1} > \text{critical}$ $p_1$
125	225	0.444	111.1	0.500	
100	200	0.500	98.8	0.444	
75	175	0.571	86.4	0.389	
-----	-----	-----	-----	-----	Use Eq. 18.15
73.0	173	0.578	85.4	0.384	} critical
-----	-----	-----	-----	-----	-----
50.0	150	0.667	74.1	0.326	} $\frac{p_2}{p_1} > \text{critical}$ $p_1$
25	125	0.800	61.7	0.238	
					Use Eq. 18.1

Eq. 18.11

$$W = (5.027 \times 10^{-5}) \sqrt{\frac{2(9.81)(1.13)}{0.13} (p_1 \gamma_1) \left[ \left( \frac{p_2}{p_1} \right)^{2/1.13} - \left( \frac{p_2}{p_1} \right)^{2.13/1.13} \right]}$$



# CHAPTER NINETEEN

## FLOW OF AIR IN DUCTS

### Energy losses in straight duct sections

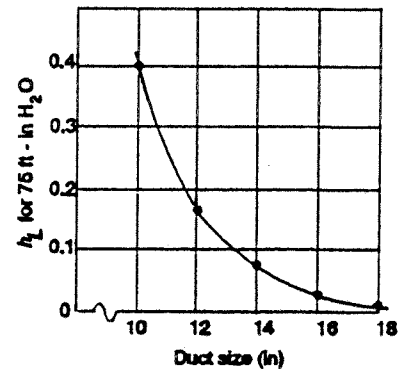
19.1 From Fig. 19.2:  $v = 570$  ft/min; 0.027 in H<sub>2</sub>O/100 ft

$$h_L = 0.027 \text{ in H}_2\text{O} \times 75 \text{ ft}/100 \text{ ft} = 0.0203 \text{ in H}_2\text{O} \text{ For 18 in Duct}$$

$$Q = 1000 \text{ cfm}$$

19.2

Duct size	$v$ (ft/min)	$h_L/100$ ft (in H <sub>2</sub> O)	$h_L$ for 75 ft
16 in	720	0.049	0.037 in H <sub>2</sub> O
14 in	960	0.100	0.075
12 in	1275	0.220	0.165
10 in	1850	0.530	0.400

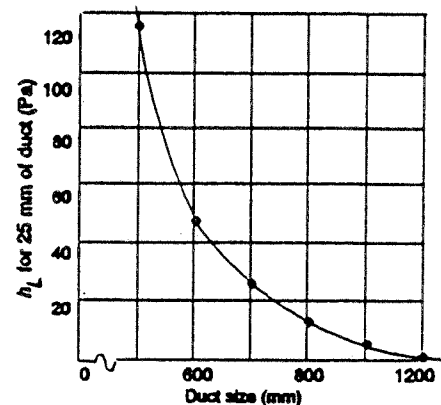


19.3  $D = 17.0$  in req'd  
 $h_L = 0.078$  in H<sub>2</sub>O/100 ft

19.4 From Fig. 19.3:  $v = 15.3$  m/s  
Loss = 4.70 Pa/m  $\times$  25 m = 118 Pa  
For 500 mm dia. duct

19.5 25 m of duct  
3.0 m<sup>3</sup>/s flow

Duct size (mm)	$v$ (m/s)	$h_L$ Pa/m	$h_L$ for 25 m
600	10.6	1.90	47.5 Pa
700	8.00	0.90	22.5
800	6.00	0.44	11.0
900	4.80	0.26	6.50
1000	3.80	0.14	3.50



19.6  $Q = 0.40$  m<sup>3</sup>/s: 350 mm duct size req'd:  $h_L = 0.58$  Pa/m

19.7 10  $\times$  30 in duct:

$$D_e = \frac{1.3(ab)^{5/8}}{(a+b)^{1/4}} = \frac{1.3[(10)(30)]^{0.625}}{(10+30)^{0.250}} = 18.3 \text{ in}$$

$$Q_{\max} = 2100 \text{ ft}^3/\text{min} \text{ for } h_L = 0.10 \text{ in H}_2\text{O}/100 \text{ ft}$$

19.8 3 × 10 in duct:

$$D_e = \frac{1.3(ab)^{0.625}}{(a+b)^{0.250}} = \frac{1.3[(3)(10)]^{0.625}}{(3+10)^{0.250}} = \mathbf{5.74 \text{ in}}; Q_{\max} = \mathbf{95 \text{ cfm}}$$

For  $h_L = 0.10$  in H<sub>2</sub>O

19.9 42 × 60 in duct:

$$D_e = \frac{1.30[(42)(60)]^{0.625}}{(42+60)^{0.250}} = \mathbf{54.7 \text{ in}}; Q_{\max} = \mathbf{37000 \text{ cfm}}$$

for  $h_L = 0.10$  in H<sub>2</sub>O

19.10 250 × 500 mm duct:

$$D_e = \frac{1.30[(250)(500)]^{0.625}}{(250+500)^{0.250}} = \mathbf{381 \text{ mm}}; Q_{\max} = \mathbf{0.60 \text{ m}^3/\text{s}}$$

for  $h_L = 0.80$  Pa/m

19.11 75 × 250 mm duct:

$$D_e = \frac{1.30[(75)(250)]^{0.625}}{(75+250)^{0.250}} = \mathbf{125 \text{ mm}}; Q_{\max} = \mathbf{0.0295 \text{ m}^3/\text{s}}$$

19.12  $Q = 1500$  cfm;  $h_{L_{\max}} = 0.10$  in H<sub>2</sub>O per 100 ft →  $D_e = \mathbf{16.2 \text{ in}}$

Duct:  $\mathbf{10 \times 24, 12 \times 20}$  Possible sizes from Table 19.2

19.13  $Q = 300$  cfm;  $h_{L_{\max}} = 0.10$  in H<sub>2</sub>O per 100 ft →  $D_e = \mathbf{8.8 \text{ in}}$

Duct:  $\mathbf{6 \times 12}$  ( $D_e = 9.1$  in)

### Energy losses in ducts with fittings

19.14  $Q = 650$  cfm;  $D = 12$  in round;  $v = 830$  ft/min (Fig. 19.2)

$$H_v = \left(\frac{v}{4005}\right)^2 = \left(\frac{830}{4005}\right)^2 = 0.0429 \text{ in H}_2\text{O}; C = 0.42 \text{ 3-pc elbow}$$

$$H_L = CH_v = 0.42(0.0429) = \mathbf{0.0180 \text{ in H}_2\text{O}}$$

19.15  $C = 0.33$  5-pc elbow;  $H_L = CH_v = 0.33(0.0429) = \mathbf{0.0142 \text{ in H}_2\text{O}}$

19.16  $Q = 1500$  cfm;  $D = 16$  in;  $v = 1080$  ft/min (Fig. 19.2)

$$H_v = \left(\frac{v}{4005}\right)^2 = \left(\frac{1080}{4005}\right)^2 = 0.0727 \text{ in H}_2\text{O}; C = 0.20$$

$$H_L = CH_v = 0.20(0.0727) = \mathbf{0.0145 \text{ in H}_2\text{O}}$$

19.17  $H_v = 0.0727$  in  $H_2O$  (Prob. 19.16),  $h_L = CH_v$

Position	$C$	$h_L$ (in $H_2O$ )
$10^\circ$	0.52	<b>0.378</b>
$20^\circ$	1.50	<b>0.109</b>
$30^\circ$	4.5	<b>0.327</b>

19.18  $10 \times 22 \rightarrow 15.9$  in circ. equiv.

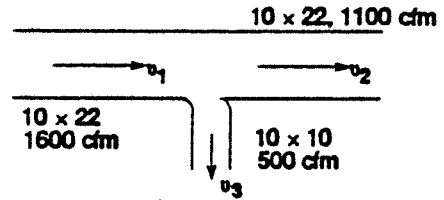
$10 \times 10 \rightarrow 10.9$  in circ. equiv.

$v_1 = 1160$  ft/min,  $H_v = 0.0839$  in  $H_2O$

$v_2 = 800$  ft/min,  $H_v = 0.0399$  in  $H_2O$

$v_3 = 720$  ft/min,  $H_v = 0.0323$  in  $H_2O = \left(\frac{720}{4005}\right)^2$

└Fig. 19.2┐



19.19 Tee, flow in branch;  $C = 1.00$ :  $H_L = 1.00(0.0839) = 0.0839$  in  $H_2O$

19.20 Tee, flow through main,  $C = 0.10$ :  $H_L = 0.10(0.0839) = 0.00839$  in  $H_2O$

19.21  $Q = 0.20$  m<sup>3</sup>/s;  $D = 200$  mm dia.;  $v = 6.40$  m/s

$$H_v = \left(\frac{v}{1.289}\right)^2 Pa = \left(\frac{6.40}{1.289}\right)^2 = 24.7 \text{ Pa}; C = 0.42 \text{ 3-pc elbow}$$

$$H_L = 0.42(24.7 \text{ Pa}) = 10.4 \text{ Pa}$$

19.22 Mitered elbow,  $C = 1.20$ :  $H_L = 1.20(24.7) = 29.6$  Pa

19.23  $Q = 0.85$  m<sup>3</sup>/s;  $D = 400$  mm;  $v = 6.8$  m/s

$$H_v = \left(\frac{v}{1.289}\right)^2 = \left(\frac{6.8}{1.289}\right)^2 = 27.8 \text{ Pa}; C = 4.5 \text{ damper at } 30^\circ$$

$$H_L = CH_v = 4.5(27.8 \text{ Pa}) = 125 \text{ Pa}$$

19.24 Use  $Q = 700$  cfm;  $D = 12$  in dia.;  $v = 900$  ft/min;  $h_L = 0.12$  in  $H_2O$  per 100 ft

$$H_v = \left(\frac{v}{4005}\right)^2 = \left(\frac{900}{4005}\right)^2 = 0.0505 \text{ in } H_2O$$

$$\text{Duct: } H_L = 0.12 \text{ in } H_2O \left(\frac{42}{100}\right) = 0.0504 \text{ in } H_2O$$

Damper:  $H_L = CH_v = 0.20(0.0505) = 0.0101$  in  $H_2O$   
 2, 3-pc elbows:  $H_L = 2(0.42)(0.0505) = 0.0424$  in  $H_2O$   
 Outlet grille:  $H_L = 0.06$  in  $H_2O$  (Table 19.3)

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$$H_{L_{total}} = 0.1629 \text{ in } H_2O$$

19.25  $12 \times 20$  rect  $\rightarrow$  16.8 in Circ. Eq.; use  $Q = 1500$  cfm;  $v = 980$  ft/min

$$h_L = 0.08 \text{ in } H_2O \text{ per } 100 \text{ ft}; H_v = \left(\frac{980}{4005}\right)^2 = 0.060 \text{ in } H_2O$$

---


$$\text{Duct: } H_L = 0.08 \text{ in } H_2O \left(\frac{38}{100}\right) = 0.0304 \text{ in } H_2O$$

Damper:  $H_L = CH_v = 0.20(0.060) = 0.0120$  in  $H_2O$   
 3 elbows:  $H_L = 3(0.22)(0.060) = 0.0396$  in  $H_2O$   
 Outlet grille:  $H_L = 0.060$  in  $H_2O$  (Table 19.3)

---


$$H_{L_{total}} = 0.1420 \text{ in } H_2O$$

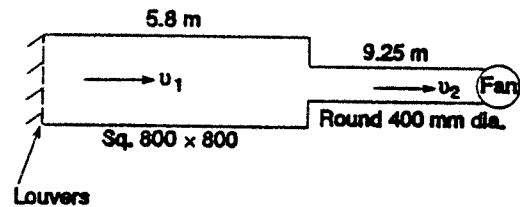
19.26  $Q = 0.80 \text{ m}^3/\text{s}$

For square duct:

$$D_{e1} = \frac{1.3[(800)(800)]^{5/8}}{(800 + 800)^{1/4}} = 875 \text{ mm Circ. Eq.}$$

$$v_1 = \frac{Q}{A} = \frac{0.80 \text{ m}^3/\text{s}}{\pi(0.875 \text{ m})^2/4} = 1.33 \text{ m/s}$$

$$H_v = \left(\frac{v}{1.289}\right)^2 = \left(\frac{1.33}{1.289}\right)^2 = 1.065 \text{ Pa}$$



$D_{e1}/D_2 = 875/400 = 2.19 \rightarrow K = 0.40$  (Fig. 10.7) Sudden contraction

$$H_{L1} = 0.40(1.065 \text{ Pa}) = 0.426 \text{ Pa}$$

---


$$H_{L2} = 17 \text{ Pa (Table 19.3) louvers}$$

Duct 1,  $H_L$  too low for chart in Fig. 19.3 — Neglect

---


$$\text{Duct 2, } v_2 = 6.30 \text{ m/s}; H_L = (1.10 \text{ Pa/m})(9.25 \text{ m}) = 10.2 \text{ Pa}$$

---


$$H_{L_{tot}} = 0.426 + 17 + 0 + 11.1 = 27.6 \text{ Pa Pressure drop from } p_{atm}$$

$$\text{Then } p_{fan} = -27.6 \text{ Pa}$$

# SPREADSHEETS

APPLIED FLUID MECHANICS	<i>I Power SI:</i> CLASS I SERIES SYSTEMS	
<b>Objective: Pump power</b>	Reference points for the energy equation:	
Example Problem 11.1	Point 1: At surface of lower reservoir	
Fig. 11.2	Point 2: At surface of upper reservoir	
<b>System Data:</b>	<b>SI Metric Units</b>	
Volume flow rate: $Q = 0.015 \text{ m}^3/\text{s}$	Elevation at point 1 = 2.00 m	
Pressure at point 1 = 0 kPa	Elevation at point 2 = 12.00 m	
Pressure at point 2 = 0 kPa	If Ref. pt. is in pipe: Set $v_1 = B20$ OR Set $v_2 = E20$	
Velocity at point 1 = 0 m/s -->	Vel head at point 1 = 0 m	
Velocity at point 2 = 0 m/s -->	Vel head at point 2 = 0 m	
<b>Fluid Properties:</b>	May need to compute: $v = \eta/\rho$	
Specific weight = $7.74 \text{ kN/m}^3$	Kinematic viscosity = $7.10\text{E-}07 \text{ m}^2/\text{s}$	
<b>Pipe 1: 4-in Schedule 40 steel pipe</b>	<b>Pipe 2: 2-in Schedule 40 steel pipe</b>	
Diameter: $D = 0.1023 \text{ m}$	Diameter: $D = 0.0525 \text{ m}$	
Wall roughness: $\epsilon = 4.60\text{E-}05 \text{ m}$	Wall roughness: $\epsilon = 4.60\text{E-}05 \text{ m}$	[See Table 8.2]
Length: $L = 15 \text{ m}$	Length: $L = 200 \text{ m}$	
Area: $A = 8.22\text{E-}03 \text{ m}^2$	Area: $A = 2.16\text{E-}03 \text{ m}^2$	[ $A = \pi D^2/4$ ]
$D/\epsilon = 2224$	$D/\epsilon = 1141$	Relative roughness
$L/D = 147$	$L/D = 3810$	
Flow Velocity = 1.82 m/s	Flow Velocity = 6.93 m/s	[ $v = Q/A$ ]
Velocity head = 0.170 m	Velocity head = 2.447 m	[ $v^2/2g$ ]
Reynolds No. = $2.63\text{E}+05$	Reynolds No. = $5.13\text{E}+05$	[ $N_R = vD/\nu$ ]
Friction factor: $f = 0.0182$	Friction factor: $f = 0.0198$	Using Eq. 8-7
<b>Energy losses-Pipe 1:</b>	K	Qty.
Pipe: $K_1 = f(L/D) = 2.67$	1	Energy loss $h_{L1} = 0.453 \text{ m}$ Friction
Entrance loss: $K_2 = 0.50$	1	Energy loss $h_{L2} = 0.085 \text{ m}$
Element 3: $K_3 = 0.00$	1	Energy loss $h_{L3} = 0.000 \text{ m}$
Element 4: $K_4 = 0.00$	1	Energy loss $h_{L4} = 0.000 \text{ m}$
Element 5: $K_5 = 0.00$	1	Energy loss $h_{L5} = 0.000 \text{ m}$
Element 6: $K_6 = 0.00$	1	Energy loss $h_{L6} = 0.000 \text{ m}$
Element 7: $K_7 = 0.00$	1	Energy loss $h_{L7} = 0.000 \text{ m}$
Element 8: $K_8 = 0.00$	1	Energy loss $h_{L8} = 0.000 \text{ m}$
<b>Energy losses-Pipe 2:</b>	K	Qty.
Pipe: $K_1 = f(L/D) = 75.35$	1	Energy loss $h_{L1} = 184.40 \text{ m}$ Friction
Globe valve: $K_2 = 6.46$	1	Energy loss $h_{L2} = 15.81 \text{ m}$
2 std elbows: $K_3 = 0.57$	2	Energy loss $h_{L3} = 2.79 \text{ m}$
Exit loss: $K_4 = 1.00$	1	Energy loss $h_{L4} = 2.45 \text{ m}$
Element 5: $K_5 = 0.00$	1	Energy loss $h_{L5} = 0.00 \text{ m}$
Element 6: $K_6 = 0.00$	1	Energy loss $h_{L6} = 0.00 \text{ m}$
Element 7: $K_7 = 0.00$	1	Energy loss $h_{L7} = 0.00 \text{ m}$
Element 8: $K_8 = 0.00$	1	Energy loss $h_{L8} = 0.00 \text{ m}$
<b>Results:</b>	Total energy loss $h_{L\text{Tot}} = 205.98 \text{ m}$	
	Total head on pump: $h_A = 216.0 \text{ m}$	
	Power added to fluid: $P_A = 25.08 \text{ kW}$	
	Pump efficiency = 76.00%	
		Power input to pump: $P_I = 32.99 \text{ kW}$

APPLIED FLUID MECHANICS		I Power US: CLASS I SERIES SYSTEMS	
<b>Objective: Pump power</b>		Reference points for the energy equation:	
Problem 11.29		Pt. 1: At pump inlet - Point A in Figure 11.23	
Fig. 11.26		Pt. 2: In free stream of fluid outside nozzle	
<b>System Data:</b>		<b>U.S. Customary Units</b>	
Volume flow rate: $Q =$	0.5 ft <sup>3</sup> /s	Elevation at point 1 =	0 ft
Pressure at point 1 =	-3.5 psig	Elevation at point 2 =	80 ft
Pressure at point 2 =	0 psig	If Ref. pt. is in pipe: Set $v_1$ "= B20" OR Set $v_2$ "= E20"	
Velocity at point 1 =	9.74 ft/s -->	Vel head at point 1 =	1.47 ft
Velocity at point 2 =	54.24 ft/s -->	Vel head at point 2 =	45.68 ft
<b>Fluid Properties:</b>		May need to compute: $v = \eta/\rho$	
Specific weight =	64.00 lb/ft <sup>3</sup>	Kinematic viscosity =	2.01E-05 ft <sup>2</sup> /s
<b>Pipe 1: 3-in Schedule 40 steel pipe</b>		<b>Pipe 2: 2 1/2-in Schedule 40 steel pipe</b>	
Diameter: $D =$	0.2557 ft	Diameter: $D =$	0.2058 ft
Wall roughness: $\varepsilon =$	1.50E-04 ft	Wall roughness: $\varepsilon =$	1.50E-04 ft [See Table 8.2]
Length: $L =$	0 ft	Length: $L =$	82 ft
Area: $A =$	0.05135 ft <sup>2</sup>	Area: $A =$	0.03326 ft <sup>2</sup> [ $A = \pi D^2/4$ ]
$D/\varepsilon =$	1705	$D/\varepsilon =$	1372 Relative roughness
$L/D =$	0	$L/D =$	398
Flow Velocity =	9.74 ft/s	Flow Velocity =	15.03 ft/s [ $v = Q/A$ ]
Velocity head =	1.472 ft	Velocity head =	3.508 ft [ $v^2/2g$ ]
Reynolds No. =	1.24E+05	Reynolds No. =	1.54E+05 [ $N_R = vD/\nu$ ]
Friction factor: $f =$	0.0203	Friction factor: $f =$	0.0205 Using Eq. 8-7
<b>Energy losses-Pipe 1:</b>		K	Qty.
Pipe: $K_1 =$	0.00	1	Energy loss $h_{L1} =$ 0.00 ft
Element 2: $K_2 =$	0.00	1	Energy loss $h_{L2} =$ 0.00 ft
Element 3: $K_3 =$	0.00	1	Energy loss $h_{L3} =$ 0.00 ft
Element 4: $K_4 =$	0.00	1	Energy loss $h_{L4} =$ 0.00 ft
Element 5: $K_5 =$	0.00	1	Energy loss $h_{L5} =$ 0.00 ft
Element 6: $K_6 =$	0.00	1	Energy loss $h_{L6} =$ 0.00 ft
Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} =$ 0.00 ft
Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} =$ 0.00 ft
<b>Energy losses-Pipe 2:</b>		K	Qty.
Pipe: $K_1 =$	8.16	1	Energy loss $h_{L1} =$ 28.61 ft
Elbow: $K_2 =$	0.54	1	Energy loss $h_{L2} =$ 1.89 ft
Nozzle: $K_3 =$	32.60	1	Energy loss $h_{L3} =$ 114.37 ft
Element 4: $K_4 =$	0.00	1	Energy loss $h_{L4} =$ 0.00 ft
Element 5: $K_5 =$	0.00	1	Energy loss $h_{L5} =$ 0.00 ft
Element 6: $K_6 =$	0.00	1	Energy loss $h_{L6} =$ 0.00 ft
Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} =$ 0.00 ft
Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} =$ 0.00 ft
<b>Results:</b>		Total energy loss $h_{Ltot} =$ 144.88 ft	
		Total head on pump: $h_A =$ 277.0 ft	
		Power added to fluid: $P_A =$ 16.11 hp	
		Pump efficiency = 76.00 %	
		Power input to pump: $P_I =$ 21.20 hp	

APPLIED FLUID MECHANICS		I Pressure SI: CLASS I SERIES SYSTEMS	
<b>Objective: Pressure: Point 2</b>		Reference points for the energy equation:	
Problem 11.7-Mott-Modified		Pt. 1: In pipe at Point A	
Fig. 11.17		Pt. 2: In pipe at Point B	
<b>System Data: SI Metric Units</b>			
Volume flow rate: $Q = 2.83E-05 \text{ m}^3/\text{s}$		Elevation at point 1 = 0 m	
Pressure at point 1 = 100 kPa		Elevation at point 2 = 1.2 m	
*Pressure at point 2 to be determined*		If Ref. pt. is in pipe: Set $v_1$ "= B20" OR Set $v_2$ "= E20"	
Velocity at point 1 = 0.346 m/s -->		Vel head at point 1 = 0.006104 m	
Velocity at point 2 = 0.346 m/s -->		Vel head at point 2 = 0.006104 m	
<b>Fluid Properties:</b> May need to compute: $\nu = \eta/\rho$			
Specific weight = 12.2625 kN/m <sup>3</sup>		Kinematic viscosity = 2.40E-07 m <sup>2</sup> /s	
<b>Pipe 1: 1/2-in x 0.049 steel tube</b>		<b>Pipe 2: None</b>	
Diameter: $D = 0.01021 \text{ m}$		Diameter: $D = 0.09797 \text{ m}$	
Wall roughness: $\epsilon = 1.50E-06 \text{ m}$		Wall roughness: $\epsilon = 1.50E-06 \text{ m}$ See Table 8.2	
Length: $L = 30 \text{ m}$		Length: $L = 0 \text{ m}$	
Area: $A = 8.19E-05 \text{ m}^2$		Area: $A = 7.54E-03 \text{ m}^2$ [ $A = \pi D^2/4$ ]	
$D/\epsilon = 6807$		$D/\epsilon = 65313$ Relative roughness	
$L/D = 2938$		$L/D = 0$	
Flow Velocity = 0.346 m/s		Flow Velocity = 0.0038 m/s [ $\nu = Q/A$ ]	
Velocity head = 0.006104 m		Velocity head = 0.0000 m	
Reynolds No. = 1.47E+04		Reynolds No. = 1.53E+03 [ $N_R = \nu D/\nu$ ]	
Friction factor: $f = 0.0282$		Friction factor: $f = 0.0563$ Using Eq. 8-7	
<b>Energy losses-Pipe 1:</b> K Qty.			
Pipe: $K_1 = f(L/D) = 82.96$		1 Energy loss $h_{L1} = 0.5064 \text{ m}$ Friction	
Check Valve: $K_2 = 1.95$		1 Energy loss $h_{L2} = 0.0119 \text{ m}$ ( $f_T = 0.013$ )	
Globe Valve: $K_3 = 4.420$		1 Energy loss $h_{L3} = 0.0270 \text{ m}$ ( $f_T = 0.013$ )	
Return Bends: $K_4 = 0.65$		8 Energy loss $h_{L4} = 0.0317 \text{ m}$ ( $f_T = 0.013$ )	
Element 5: $K_5 = 0.00$		1 Energy loss $h_{L5} = 0.00 \text{ m}$	
Element 6: $K_6 = 0.00$		1 Energy loss $h_{L6} = 0.00 \text{ m}$	
Element 7: $K_7 = 0.00$		1 Energy loss $h_{L7} = 0.00 \text{ m}$	
Element 8: $K_8 = 0.00$		1 Energy loss $h_{L8} = 0.00 \text{ m}$	
<b>Energy losses-Pipe 2:</b> K Qty.			
Pipe: $K_1 = f(L/D) = 0.00$		1 Energy loss $h_{L1} = 0.00 \text{ m}$ Friction	
Element 2: $K_2 = 0.00$		1 Energy loss $h_{L2} = 0.00 \text{ m}$	
Element 3: $K_3 = 0.00$		1 Energy loss $h_{L3} = 0.00 \text{ m}$	
Element 4: $K_4 = 0.00$		1 Energy loss $h_{L4} = 0.00 \text{ m}$	
Element 5: $K_5 = 0.00$		1 Energy loss $h_{L5} = 0.00 \text{ m}$	
Element 6: $K_6 = 0.00$		1 Energy loss $h_{L6} = 0.00 \text{ m}$	
Element 7: $K_7 = 0.00$		1 Energy loss $h_{L7} = 0.00 \text{ m}$	
Element 8: $K_8 = 0.00$		1 Energy loss $h_{L8} = 0.00 \text{ m}$	
Total energy loss $h_{L\text{tot.}} = 0.5770 \text{ m}$			
<b>Results:</b>			
Pressure at target point: 78.21 kPa			

APPLIED FLUID MECHANICS		I Pressure US:	CLASS I SERIES SYSTEMS
<b>Objective: Pressure: Point 2</b>		Reference points for the energy equation:	
Problem 11.3		Pt. 1: In pipe at Point A at outlet of pump	
Fig. 11.13		Pt. 2: In pipe at Point B at inlet to the hydraulic cylinder	
<b>System Data:</b>		<b>US Customary Units</b>	
Volume flow rate: $Q = 0.13363 \text{ ft}^3/\text{s}$		Elevation at point 1 = 0 ft	
Pressure at point 1 = 212.77 psig		Elevation at point 2 = 25 ft	
Pressure at point 2 = 200 psig		If Ref. pt. is in pipe: Set v1 "= B20" OR Set v2 "= E20"	
Velocity at point 1 = 5.73 ft/s		Vel head at point 1 = 0.51 ft	
Velocity at point 2 = 5.73 ft/s		Vel head at point 2 = 0.51 ft	
<b>Fluid Properties:</b>		May need to compute: $v = \eta/\rho$	
Specific weight = 56.16 lb/ft <sup>3</sup>		Kinematic viscosity = 3.44E-05 ft <sup>2</sup> /s	
<b>Pipe 1: 2-in Sch. 40 steel pipe</b>		<b>Pipe 2: None</b>	
Diameter: $D = 0.1723 \text{ ft}$		Diameter: $D = 0.1723 \text{ ft}$	
Wall roughness: $\epsilon = 1.50\text{E-}04 \text{ ft}$		Wall roughness: $\epsilon = 1.50\text{E-}04 \text{ ft}$ See Table 8.2	
Length: $L = 50 \text{ ft}$		Length: $L = 0 \text{ ft}$	
Area: $A = 2.33\text{E-}02 \text{ ft}^2$		Area: $A = 2.33\text{E-}02 \text{ ft}^2$ [ $A = \pi D^2/4$ ]	
$D/\epsilon = 1149$		$D/\epsilon = 1149$ Relative roughness	
$L/D = 290$		$L/D = 0$	
Flow Velocity = 5.73 ft/s		Flow Velocity = 5.73 ft/s [ $v = Q/A$ ]	
Velocity head = 0.510 ft		Velocity head = 0.510 ft [ $v^2/2g$ ]	
Reynolds No. = 2.87E+04		Reynolds No. = 2.87E+04 [ $N_R = vD/\nu$ ]	
Friction factor: $f = 0.0260$		Friction factor: $f = 0.0260$ Using Eq. 8-7	
<b>Energy losses-Pipe 1:</b>			
$K$	Qty.		
Pipe: $K_1 = f(L/D) =$	7.55 1	Energy loss $h_{L1} =$	3.85 ft Friction
Control valve: $K_2 =$	6.50 1	Energy loss $h_{L2} =$	3.32 ft
2 elbows: $K_3 =$	0.57 2	Energy loss $h_{L3} =$	0.58 ft ( $f_T=0.019$ )
Element 4: $K_4 =$	0.00 1	Energy loss $h_{L4} =$	0.00 ft
Element 5: $K_5 =$	0.00 1	Energy loss $h_{L5} =$	0.00 ft
Element 6: $K_6 =$	0.00 1	Energy loss $h_{L6} =$	0.00 ft
Element 7: $K_7 =$	0.00 1	Energy loss $h_{L7} =$	0.00 ft
Element 8: $K_8 =$	0.00 1	Energy loss $h_{L8} =$	0.00 ft
<b>Energy losses in Pipe 2:</b>			
	Qty.		
Pipe: $K_1 = f(L/D) =$	0.00 1	Energy loss $h_{L1} =$	0.00 ft
Element 2: $K_2 =$	0.00 1	Energy loss $h_{L2} =$	0.00 ft
Element 3: $K_3 =$	0.00 1	Energy loss $h_{L3} =$	0.00 ft
Element 4: $K_4 =$	0.00 1	Energy loss $h_{L4} =$	0.00 ft
Element 5: $K_5 =$	0.00 1	Energy loss $h_{L5} =$	0.00 ft
Element 6: $K_6 =$	0.00 1	Energy loss $h_{L6} =$	0.00 ft
Element 7: $K_7 =$	0.00 1	Energy loss $h_{L7} =$	0.00 ft
Element 8: $K_8 =$	0.00 1	Energy loss $h_{L8} =$	0.00 ft
<b>Results:</b>		Total energy loss $h_{Ltot} = 7.75 \text{ ft}$	
		Total change in pressure: -12.77 psi	
		<b>Pressure at target point: 200.00 psig</b>	

APPLIED FLUID MECHANICS		II-A & II-B SI: CLASS II SERIES SYSTEMS	
<b>Objective: Volume flow rate</b>		<b>Method II-A: No minor losses</b>	
Example Problem 11.3 Figure 11.7		Uses Equation 11-3 to estimate the allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data: SI Metric Units</b>			
Pressure at point 1 = 120 kPa		Elevation at point 1 = 0 m	
Pressure at point 2 = 60 kPa		Elevation at point 2 = 0 m	
Energy loss: $h_L = 6.95$ m			
<b>Fluid Properties:</b> May need to compute: $v = \eta/\rho$			
Specific weight = 8.63 kN/m <sup>3</sup>		Kinematic viscosity = 1.08E-05 m <sup>2</sup> /s	
<b>Pipe data: 6-in Schedule 40 steel pipe</b>		<b>Results: Maximum values</b>	
Diameter: $D = 0.1541$ m			
Wall roughness: $\epsilon = 4.60E-05$ m			
Length: $L = 100$ m			
Area: $A = 0.018651$ m <sup>2</sup>			
$D/\epsilon = 3350$		Volume flow rate: $Q = 0.0569$ m <sup>3</sup> /s Using Eq. 11-3	
		Velocity: $v = 3.05$ m/s	

CLASS II SERIES SYSTEMS		Volume flow rate: $Q = 0.0538$ m <sup>3</sup> /s	
<b>Method II-B: Use results of Method IIA;</b>		Given: Pressure $p_1 = 120$ kPa	
Include minor losses;		Pressure $p_2 = 60.18$ kPa	
then pressure at Point 2 is computed		<b>NOTE: Should be &gt; 60 kPa</b>	
<b>Additional Pipe Data:</b>		<b>Adjust estimate for Q until <math>p_2</math> is greater than desired pressure.</b>	
$L/D = 649$		Velocity at point 1 = 2.88 m/s  --> If velocity is in pipe:	
Flow Velocity = 2.88 m/s		Velocity at point 2 = 2.88 m/s  --> Enter "=B24"	
Velocity head = 0.424 m		Vel. head at point 1 = 0.424 m	
Reynolds No. = 4.12E+04		Vel. head at point 2 = 0.424 m	
Friction factor: $f = 0.0228$			
<b>Energy losses in Pipe:</b>			
Pipe: $K_1 = f(L/D) =$	14.76	1	Energy loss $h_{L1} = 6.26$ m Friction
2 std. elbows: $K_2 =$	0.45	2	Energy loss $h_{L2} = 0.38$ m
Butterfly valve: $K_3 =$	0.68	1	Energy loss $h_{L3} = 0.29$ m
Element 4: $K_4 =$	0.00	1	Energy loss $h_{L4} = 0.00$ m
Element 5: $K_5 =$	0.00	1	Energy loss $h_{L5} = 0.00$ m
Element 6: $K_6 =$	0.00	1	Energy loss $h_{L6} = 0.00$ m
Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} = 0.00$ m
Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} = 0.00$ m
			Total energy loss $h_{Ltot} = 6.93$ m

<b>APPLIED FLUID MECHANICS</b>		<b>II-A &amp; II-B US: CLASS II SERIES SYSTEMS</b>	
<b>Objective: Volume flow rate</b> Problem 11.10		<b>Method II-A: No minor losses</b> Uses Equation 11-3 to find maximum allowable volume flow rate to maintain desired pressure at point 2 for a given pressure at point 1	
<b>System Data:</b>		<b>US Customary Units</b>	
Pressure at point 1 =	250 psig	Elevation at point 1 =	55 ft
Pressure at point 2 =	180 psig	Elevation at point 2 =	0 ft
Energy loss: $h_L = 202.22$ ft			
<b>Fluid Properties:</b>		May need to compute: $v = \eta/\rho$	
Specific weight =	68.47 lb/ft <sup>3</sup>	Kinematic viscosity =	1.59E-04 ft <sup>2</sup> /s
<b>Pipe data: 4-in Sch 40 steel pipe</b>		<b>Results: Maximum values</b>	
Diameter: $D =$	0.512 ft	Volume flow rate: $Q =$	1.4500 ft <sup>3</sup> /s Using Eq. 11-3
Wall roughness: $\epsilon =$	4.00E-04 ft	Velocity: $v =$	7.04 ft/s
Length: $L =$	5000 ft		
Area: $A =$	0.20589 ft <sup>2</sup>		
$D/\epsilon =$	1280		

<b>CLASS II SERIES SYSTEMS</b>		Volume flow rate: $Q =$	1.45 ft <sup>3</sup> /s
<b>Method II-B: Use results of Method IIA;</b> Include minor losses; then pressure at Point 2 is computed		Given: Pressure $p_1 =$	250 psig
		Pressure $p_2 =$	179.77 psig
		<b>NOTE: Should be &gt;</b>	180 psig
<b>Additional Pipe Data:</b>		<b>Adjust estimate for <math>Q</math> until <math>p_2</math></b> <b>is equal or greater than desired.</b>	
$L/D =$	9766	Velocity at point 1 =	7.04 ft/s  --> If velocity is in pipe:
Flow Velocity =	7.04 ft/s	Velocity at point 2 =	7.04 ft/s  --> Enter "=B24"
Velocity head =	0.770 ft	Vel. head at point 1 =	0.77 ft
Reynolds No. =	2.27E+04	Vel. head at point 2 =	0.77 ft
Friction factor: $f =$	0.0269		
<b>Energy losses in Pipe:</b>			
Pipe: $K_1 = f(L/D) =$	263.18	1	Energy loss $h_{L1} = 202.69$ ft Friction
Element 2: $K_2 =$	0.00	1	Energy loss $h_{L2} = 0.00$ ft
Element 3: $K_3 =$	0.00	1	Energy loss $h_{L3} = 0.00$ ft
Element 4: $K_4 =$	0.00	1	Energy loss $h_{L4} = 0.00$ ft
Element 5: $K_5 =$	0.00	1	Energy loss $h_{L5} = 0.00$ ft
Element 6: $K_6 =$	0.00	1	Energy loss $h_{L6} = 0.00$ ft
Element 7: $K_7 =$	0.00	1	Energy loss $h_{L7} = 0.00$ ft
Element 8: $K_8 =$	0.00	1	Energy loss $h_{L8} = 0.00$ ft
			Total energy loss $h_{Ltot} = 202.69$ ft

APPLIED FLUID MECHANICS	III-A & III-B SI: CLASS III SERIES SYSTEMS
Objective: Minimum pipe diameter Problem 11.18	<b>Method III-A:</b> Uses Equation 11-13 to compute the minimum size of pipe of a given length that will flow a given volume flow rate of fluid with a limited pressure drop. (No minor losses)
<b>System Data: SI Metric Units</b>	<b>Fluid Properties:</b>
Pressure at point 1 = 150 kPa	Specific weight = 9.53 kN/m <sup>3</sup>
Pressure at point 2 = 0 kPa	Kinematic Viscosity = 3.60E-07 m <sup>2</sup> /s
Elevation at point 1 = 0 m	<b>Intermediate Results in Eq. 11-13:</b>
Elevation at point 2 = 0 m	L/gh <sub>L</sub> = 0.194292
Allowable Energy Loss: h <sub>L</sub> = 15.74 m	Argument in bracket: 2.89E-22
Volume flow rate: Q = 0.06 m <sup>3</sup> /s	<b>Final Minimum Diameter:</b>
Length of pipe: L = 30 m	Minimum diameter: D = 0.0908 m
Pipe wall roughness: ε = 1.50E-06 m	

CLASS III SERIES SYSTEMS	Specified pipe diameter: D = 0.09797 m 4-inch Type K copper tube
<b>Method III-B:</b> Use results of Method III-A; Specify actual diameter; Include minor losses; then pressure at Point 2 is computed.	<b>If velocity is in the pipe, enter "B23" for value</b>
<b>Additional Pipe Data:</b>	Velocity at point 1 = 7.96 m/s
Flow area: A = 0.007538 m <sup>2</sup>	Velocity at point 2 = 7.96 m/s
Relative roughness: D/ε = 65313	Vel. head at point 1 = 3.229 m
L/D = 306	Vel. head at point 2 = 3.229 m
Flow Velocity = 7.96 m/s	<b>Results:</b>
Velocity head = 3.229 m	Given pressure at point 1 = 150 kPa
Reynolds No. = 2.17E+06	Desired pressure at point 2 = 0 kPa
Friction factor: f = 0.0108	<b>Actual pressure at point 2 = 48.13 kPa</b>
	<b>(Actual p<sub>2</sub> should be &gt; desired pressure)</b>
<b>Energy losses in Pipe:</b>	
Pipe Friction: K <sub>1</sub> = f(L/D) = 3.31 1	Energy loss h <sub>L1</sub> = 10.69 m
Element 2: K <sub>2</sub> = 0.00 1	Energy loss h <sub>L2</sub> = 0.00 m
Element 3: K <sub>3</sub> = 0.00 1	Energy loss h <sub>L3</sub> = 0.00 m
Element 4: K <sub>4</sub> = 0.00 1	Energy loss h <sub>L4</sub> = 0.00 m
Element 5: K <sub>5</sub> = 0.00 1	Energy loss h <sub>L5</sub> = 0.00 m
Element 6: K <sub>6</sub> = 0.00 1	Energy loss h <sub>L6</sub> = 0.00 m
Element 7: K <sub>7</sub> = 0.00 1	Energy loss h <sub>L7</sub> = 0.00 m
Element 8: K <sub>8</sub> = 0.00 1	Energy loss h <sub>L8</sub> = 0.00 m
	<b>Total energy loss h<sub>Ltot</sub> = 10.69 m</b>

<b>APPLIED FLUID MECHANICS</b>	<b>III-A &amp; III-B US: CLASS III SERIES SYSTEMS</b>
<b>Objective: Minimum pipe diameter</b> Example Problem 11.6	<b>Method III-A:</b> Uses Equation 11-8 to compute the minimum size of pipe of a given length that will flow a given volume flow rate of fluid with a limited pressure drop. (No minor losses)
<b>System Data: SI Metric Units</b>	<b>Fluid Properties:</b>
Pressure at point 1 = 102 psig	Specific weight = 62.4 lb/ft <sup>3</sup>
Pressure at point 2 = 100 psig	Kinematic Viscosity = 1.21E-05 ft <sup>2</sup> /s
Elevation at point 1 = 0 ft	<b>Intermediate Results in Eq. 11-8:</b>
Elevation at point 2 = 0 ft	
Allowable Energy Loss: h <sub>L</sub> = 4.62 ft	Argument in bracket: 5.77E-09
Volume flow rate: Q = 0.5 ft <sup>3</sup> /s	<b>Final Minimum Diameter:</b> Minimum diameter: D = 0.3090 ft
Length of pipe: L = 100 ft	
Pipe wall roughness: ε = 1.50E-04 ft	

<b>CLASS III SERIES SYSTEMS</b>	Specified pipe diameter: D = 0.3355 ft 4-inch Schedule 40 steel pipe
<b>Method III-B:</b> Use results of Method III-A; Specify actual diameter; Include minor losses; then pressure at Point 2 is computed.	<b>If velocity is in the pipe, enter "=B23" for value</b>
<b>Additional Pipe Data:</b>	Velocity at point 1 = 5.66 ft/s
Flow area: A = 0.08840 ft <sup>2</sup>	Velocity at point 2 = 5.66 ft/s
Relative roughness: D/ε = 2237	Vel. head at point 1 = 0.497 ft
L/D = 298	Vel. head at point 2 = 0.497 ft
Flow Velocity = 5.66 ft/s	<b>Results:</b> Given pressure at point 1 = 102 psig Desired pressure at point 2 = 100 psig
Velocity head = 0.497 ft	
Reynolds No. = 1.57E+05	
Friction factor: f = 0.0191	
<b>Energy losses in Pipe:</b>	
Pipe Friction: K <sub>1</sub> = f(L/D) = 5.70 1	Energy loss h <sub>L1</sub> = 2.83 ft
Two long rad. elbows: K <sub>2</sub> = 0.34 2	Energy loss h <sub>L2</sub> = 0.34 ft
Butterfly valve: K <sub>3</sub> = 0.77 1	Energy loss h <sub>L3</sub> = 0.38 ft
Element 4: K <sub>4</sub> = 0.00 1	Energy loss h <sub>L4</sub> = 0.00 ft
Element 5: K <sub>5</sub> = 0.00 1	Energy loss h <sub>L5</sub> = 0.00 ft
Element 6: K <sub>6</sub> = 0.00 1	Energy loss h <sub>L6</sub> = 0.00 ft
Element 7: K <sub>7</sub> = 0.00 1	Energy loss h <sub>L7</sub> = 0.00 ft
Element 8: K <sub>8</sub> = 0.00 1	Energy loss h <sub>L8</sub> = 0.00 ft
	<b>Total energy loss h<sub>Ltot</sub> = 3.55 ft</b>

APPLIED FLUID MECHANICS		System Curve US: CLASS I SERIES SYSTEMS	
<b>Objective: System Curve</b>		Reference points for the energy equation:	
Ex. Problem 13.4 Fig. 13.40		Pt. 1: Surface of lower reservoir Pt. 2: Surface of upper reservoir	
<b>System Data: U.S. Customary Units</b>			
Volume flow rate: $Q = 0.5011 \text{ ft}^3/\text{s}$		Elevation at point 1 = 0 ft	
Pressure at point 1 = 0 psig		Elevation at point 2 = 80 ft	
Pressure at point 2 = 35 psig		If Ref. pt. is in pipe: Set $v_1$ "= B20" OR Set $v_2$ "= E20"	
Velocity at point 1 = 0.00 ft/s -->		Vel head at point 1 = 0.00 ft	
Velocity at point 2 = 0.00 ft/s -->		Vel head at point 2 = 0.00 ft	
<b>Fluid Properties:</b> May need to compute: $v = \eta/\rho$			
Specific weight = 62.40 lb/ft <sup>3</sup>		Kinematic viscosity = 1.21E-05 ft <sup>2</sup> /s	
<b>Pipe 1: 3 1/2-in Schedule 40 steel pipe</b>		<b>Pipe 2: 2 1/2-in Schedule 40 steel pipe</b>	
Diameter: $D = 0.2957 \text{ ft}$		Diameter: $D = 0.2058 \text{ ft}$	
Wall roughness: $\epsilon = 1.50\text{E-}04 \text{ ft}$		Wall roughness: $\epsilon = 1.50\text{E-}04 \text{ ft}$ [See Table 8.2]	
Length: $L = 8 \text{ ft}$		Length: $L = 360 \text{ ft}$	
Area: $A = 0.06867 \text{ ft}^2$		Area: $A = 0.03326 \text{ ft}^2$ [ $A = \pi D^2/4$ ]	
$D/\epsilon = 1971$		$D/\epsilon = 1372$ Rel. roughness	
$L/D = 27$		$L/D = 1749$	
Flow Velocity = 7.30 ft/s		Flow Velocity = 15.06 ft/s [ $v = Q/A$ ]	
Velocity head = 0.827 ft		Velocity head = 3.524 ft [ $v^2/2g$ ]	
Reynolds No. = 1.78E+05		Reynolds No. = 2.56E+05 [ $N_R = vD/\nu$ ]	
Friction factor: $f = 0.0192$		Friction factor: $f = 0.0197$ Using Eq. 8-7	
<b>Energy losses-Pipe 1:</b>			
	K	Qty.	Total K
Pipe: $K_1 =$	0.519	1	0.519
Entrance: $K_2 =$	0.500	1	0.500
Gate Valve: $K_3 =$	0.136	1	0.136
Element 4: $K_4 =$	0.000	1	0.000
Element 5: $K_5 =$	0.000	1	0.000
Element 6: $K_6 =$	0.000	1	0.000
Element 7: $K_7 =$	0.000	1	0.000
Element 8: $K_8 =$	0.000	1	0.000
			Energy loss $h_{L1} =$ 0.43 ft
			Energy loss $h_{L2} =$ 0.41 ft
			Energy loss $h_{L3} =$ 0.11 ft
			Energy loss $h_{L4} =$ 0.00 ft
			Energy loss $h_{L5} =$ 0.00 ft
			Energy loss $h_{L6} =$ 0.00 ft
			Energy loss $h_{L7} =$ 0.00 ft
			Energy loss $h_{L8} =$ 0.00 ft
<b>Energy losses-Pipe 2:</b>			
	K	Qty.	Total K
Pipe: $K_1 =$	34.488	1	34.488
Check Valve: $K_2 =$	1.800	1	1.800
Butterfly Valve: $K_3 =$	0.810	1	0.810
Standard Elbow: $K_4 =$	0.540	2	1.080
Exit Loss: $K_5 =$	1.000	1	1.000
Element 6: $K_6 =$	0.000	1	0.000
Element 7: $K_7 =$	0.000	1	0.000
Element 8: $K_8 =$	0.000	1	0.000
			Energy loss $h_{L1} =$ 121.53 ft
			Energy loss $h_{L2} =$ 6.34 ft
			Energy loss $h_{L3} =$ 2.85 ft
			Energy loss $h_{L4} =$ 3.81 ft
			Energy loss $h_{L5} =$ 3.52 ft
			Energy loss $h_{L6} =$ 0.00 ft
			Energy loss $h_{L7} =$ 0.00 ft
			Energy loss $h_{L8} =$ 0.00 ft
			Total energy loss $h_{Ltot} =$ 139.01 ft
<b>Results:</b>			Total head on pump: $h_A =$ 299.8 ft

Figure 13.41 Total head on the pump at the desired operating point for Example Problem 13.4

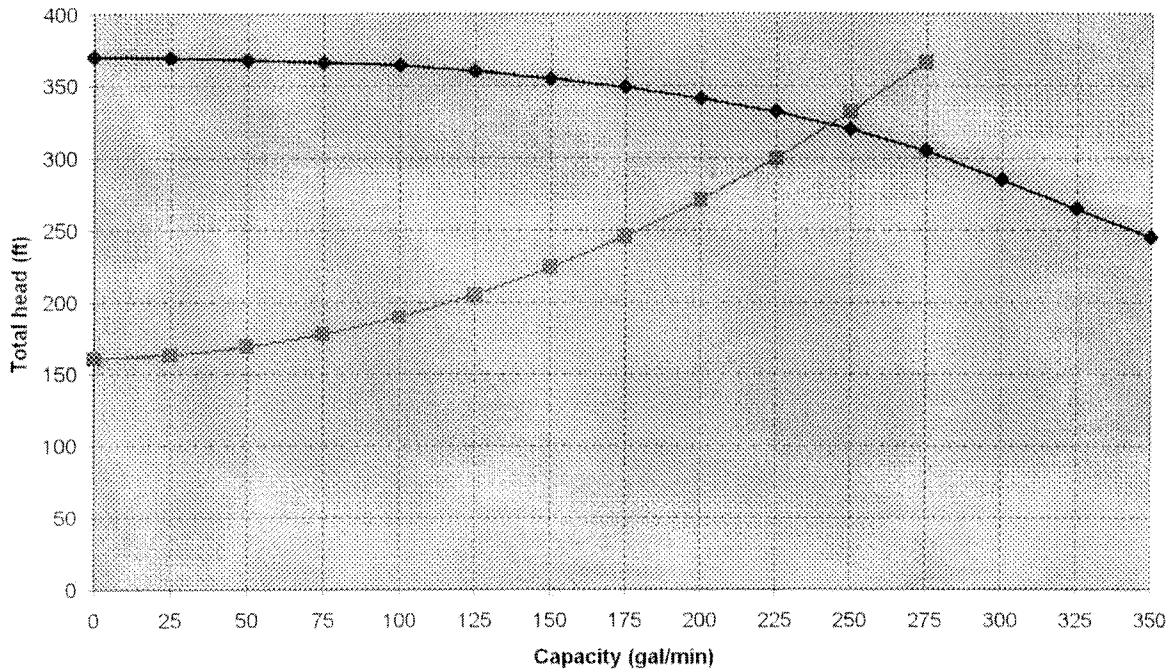
SYSTEM CURVE - Table 13.3

Q (gpm)	Q (cfs)	$h_a$ (ft)
0	0	160.8
25	0.056	162.9
50	0.111	168.6
75	0.167	177.6
100	0.223	189.9
125	0.278	205.4
150	0.334	224.1
175	0.390	246.1
200	0.445	271.3
225	0.501	299.8
250	0.557	331.4
275	0.612	366.3
300	0.668	
325	0.724	
350	0.780	

PUMP CURVE: 2X3-10 PUMP WITH 9-IN IMPELLER-From Fig. 13.27

Q (gpm)	Total head (ft)
0	370
25	369
50	368
75	366
100	364
125	360
150	355
175	349
200	341
225	332
250	320
275	305
300	285
325	265
350	245

Figure 13.42 Operating Point for Example Problem 13.4



**Friction Factor Calculation using Swamee-Jain Equation 8-7****Problem 8.28: Friction factor only; SI data****Use consistent SI or U.S. Customary units****Fluid Properties:** Water at 75 deg C  
Kinematic Viscosity  $3.83E-07 \text{ m}^2/\text{s}$  or  $\text{ft}^2/\text{s}$ Volume flow rate:  $Q = 2.15E-04 \text{ m}^3/\text{s}$  or  $\text{ft}^3/\text{s}$ **Pipe Data:** 1/2 in Type K CopperPipe wall roughness:  $\epsilon = 1.50E-06 \text{ m}$  or  $\text{ft}$ Pipe diameter =  $0.01339 \text{ m}$  or  $\text{ft}$ Flow area:  $A = 0.000141 \text{ m}^2$  or  $\text{ft}^2$   
Relative roughness:  $D/\epsilon = 8927$ Flow Velocity =  $1.53 \text{ m/s}$  or  $\text{ft/s}$ Reynolds No. =  $5.34E+04$ **Friction factor:  $f = 0.0209$  Using Eq. 8-7**