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## Revision Memo

## 12/03 Highlights of revisions:

- Added example problem showing the use of equations for calculating pressure drop in tees
- Minor corrections throughout body of section



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## SCOPE

This section presents methods for determining pressure drop through piping and related equipment for Newtonian liquids. For general design considerations other than pressure drop, see [Section XIV-A](#).

## REFERENCES

### DESIGN PRACTICES

(Besides other sections of this section)

- [Section III](#)      Fractionating Towers
- [Section XI](#)      Compressors
- [Section XII](#)      Instrumentation

### OTHER LITERATURE

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## DEFINITIONS

See [Section XIV-A](#).

## BASIC DESIGN CONSIDERATIONS

The considerations discussed below provide the basis for calculation procedures given later in this section.

### GENERAL CONSIDERATIONS

In most piping designs, the primary requirement is to find an inside diameter that will permit a certain required throughput at a given pressure drop. This usually involves a trial and error procedure. A diameter is chosen and the pressure drop is calculated for the required throughput. If the calculated pressure drop is too great, a larger diameter is taken for the next trial. If the pressure drop is smaller than necessary, a smaller diameter is chosen.

Typical pressure drops that may be used for pipe sizing are shown in [Table 1](#). In case of expensive construction materials, an economic analysis would be desirable to find the optimum line size. In cases of very high pressure and steam traced lines, it may also be desirable to find the optimum line size.

### PRINCIPLES OF PRESSURE DROP CALCULATION

The basic equation for calculating pressure drop for liquid flow in pipes and fittings is the generalized Bernoulli equation, which assumes constant density:

|                  |                 |                                                          |                                                                                                              |
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$$\underbrace{\frac{K_{11} \Delta P}{\rho}}_{\text{Pressure change}} = \underbrace{\frac{\alpha \Delta \left( \frac{V^2}{2} \right)}{g_c}}_{\text{Kinetic energy change}} + \underbrace{\frac{g \Delta z}{g_c}}_{\text{Elevation change}} + \underbrace{K_{12} F}_{\text{Friction or head loss}} \quad \text{Eq. (1)}$$

**where:**

$K_{11} = 144$  (Customary)

$K_{11} = 10^{-3}$  (Metric)

$F =$  Friction or head loss, ft lb<sub>f</sub>/lb<sub>m</sub> (kPa·m<sup>3</sup>/kg)

$g =$  Acceleration of gravity, ft/s<sup>2</sup> (m/s<sup>2</sup>)

$g_c =$  Dimensional constant, 32.174 ft lb<sub>m</sub>/lb<sub>f</sub> s<sup>2</sup> (1.0 kg m/N s<sup>2</sup>)

$K_{12} = 1.0$  (Customary)

$K_{12} = 10^{-3}$  (Metric)

$\Delta P =$  Pressure change, lb<sub>f</sub>/in.<sup>2</sup> (kPa): inlet pressure - outlet pressure

$V =$  Velocity of the fluid, ft/s (m/s)

$\Delta \left( \frac{V^2}{2} \right) =$  Change in fluid kinetic energy (outlet-inlet) ft<sup>2</sup>/s<sup>2</sup> (m<sup>2</sup>/s<sup>2</sup>)

$z =$  Elevation, ft (m)

$\Delta z =$  Change in elevation (outlet elev - inlet elev), ft (m)

$\rho =$  Density, lb<sub>m</sub>/ft<sup>3</sup> (kg/m<sup>3</sup>)

$\alpha =$  Constant depending on velocity profile ( $\alpha = 1.1$  for turbulent flow,  $\alpha = 2.0$  for laminar flow)

All design equations presented in this section are derived from this equation. The significance of the terms are as follows. The “Pressure change” term is the **pressure drop** (inlet minus outlet pressure), and for most cases this drop is positive. The “Kinetic energy change” is the outlet fluid kinetic energy minus the inlet fluid kinetic energy per unit mass of fluid flowing, and may be positive or negative. The “Elevation change” is the outlet elevation minus the inlet elevation (really the change in potential energy per unit mass flowing) and may also be positive or negative. The “Friction or head loss” term is always positive, and represents the irreversible conversion of mechanical energy to internal energy. Inspection of [Eq. \(1\)](#) shows that the kinetic and elevation terms may result in a positive or negative pressure drop, but the friction term always results in a pressure decrease, or positive pressure drop. The relative importance of the terms in the equation varies from application to application. For constant-diameter horizontal pipes, only the friction term on the right-hand side of [Equation \(1\)](#) is non-zero. For vertical or inclined pipes, one must include the elevation term; and for cross-section changes, the kinetic energy term.

For liquids one may, in general, assume constant viscosity and density. Non-Newtonian liquids are an exception to this rule and are discussed below. Another exception is non-isothermal flow, due either to heat exchange, or to heat production or consumption in the liquid by chemical reaction or friction losses.

Where the flow may be assumed to be isothermal across the pipe cross-section, but is not isothermal along the length of the pipe, the pressure drop can be determined by dividing the pipe into a number of lengths and calculating the pressure drop in each section. When the flow cannot be assumed to be isothermal across the pipe cross-section and the viscosity depends strongly on temperature, special calculation methods must be used. When problems of this type arise, consult the Reactor and Fluid Dynamics Section of ExxonMobil Engineering.

## NON-NEWTONIAN LIQUIDS

Fluids in which viscosity is dependent on shear rate or time are called non-Newtonian. The following fluids may belong to this category:

- Dense emulsions
- Dense slurries
- Polymer solutions
- Polymer melts

|                                                                                                              |                                                          |                |             |
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- Some heavy crude oils

For these fluids, the regular liquid flow equations are not applicable.

Most non-Newtonian fluids belong to one of the following classes:

- Bingham plastics - A minimum shear stress is required to obtain flow.  
Examples: fine suspensions and pastes.
- Pseudoplastic fluids - Viscosity decreases with increasing shear rate (velocity gradient). These are commonly referred to as “shear thinning” fluids.  
Examples: polymer solutions and melts, some slurries, emulsions.
- Dilatant fluids - Viscosity increases with increasing shear rate. These are commonly referred to as “shear thickening” fluids. These are less common than Bingham plastics and pseudoplastic fluids. Certain slurries exhibit dilatant behavior.  
Viscosity may also be time-dependent:
- Thixotropic fluids - Viscosity decreases with time after application of a constant shear stress.
- Rheopectic fluids - Viscosity increases with time after application of a constant shear stress.
- Viscoelastic fluids - Liquids that partially return to their original form when the shear stress is released.

Because of the complicated rheological behavior of non-Newtonian fluids, it is not possible to give a single generally valid design equation for pressure drop. In general, rheological properties will first have to be determined in the laboratory for a suitable shear stress range and time frame.

For problems which arise in handling non-Newtonian liquids, consult the Reactor and Fluid Dynamics Section. An introduction to simple calculation methods for pressure drop is given in **Reference (4)**.

## HORIZONTAL STRAIGHT PIPE

Pressure drop in horizontal straight pipe of constant diameter is caused by friction and can be calculated from the Fanning friction equation. The experimental factor in this equation, called the Fanning friction factor,  $f$ , is a function of Reynolds number and relative pipe wall roughness (Figure 1). For a given class of pipe material, roughness is relatively independent of pipe diameter; therefore the friction factor can be expressed as a function of Reynolds number and pipe diameter (Figures 2A and 2B). For laminar flow ( $Re < 2100$ ), the friction factor is independent of pipe wall roughness and can be expressed as a function of Reynolds number alone [Eq. (4)].

$$\Delta p = 4K_{X1}f \frac{L}{D} \frac{\rho V^2}{2g_c} \quad \text{Eq. (1a)}$$

**where:**  $K_{X1} = 1/144$  (Customary)  
 $K_{X1} = 10^{-3}$  (Metric)  
 $D$  = Pipe diameter, ft (m)  
 $f$  = Fanning friction factor, dimensionless (dimensionless)  
 $g_c$  = Dimensional constant, 32.174 ft lb<sub>m</sub> / lb<sub>f</sub> s<sup>2</sup> (1.0 kg m/N s<sup>2</sup>)  
 $L$  = Length of straight pipe section from inlet to outlet, ft (m)  
 $\Delta P$  = Frictional pressure drop, lb<sub>f</sub>/in.<sup>2</sup> (kPa)  
 $V$  = Velocity of the fluid, ft/s (m/s)  
 $\rho$  = Density, lb<sub>m</sub>/ft<sup>3</sup> (kg/m<sup>3</sup>)

A transition region lies between Reynolds numbers of about 2,100 and 4,000. Here the flow may be intermittently laminar and turbulent or essentially fully turbulent, depending on such factors as change of cross-section or presence of valves, fittings or obstructions in the piping. In this regime, the friction factor is difficult to determine and lies somewhere between the limits for laminar and turbulent flow. For most commercial applications, however, flow tends to be turbulent and the higher value of the friction factor should be used.

The accuracy of the Fanning friction equation is tied directly to the accuracy of the friction factor. In general, values for the friction factor are determined experimentally. Measurement uncertainty associated with the experimental determination reduces the accuracy of the Fanning equation and expected accuracies are  $\pm 15\%$  for smooth tubing

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and  $\pm 10\%$  for commercial steel pipe. Fouling can reduce the cross-sectional area or increase pipe wall roughness with time. Therefore, when calculating pressure drop, one should allow for fouling.

Most studies of the effect of fouling on pressure drop have been for water piping. For such piping, instead of the Fanning correlation, an empirical correlation known as the Hazen-Williams correlation has been most widely used. The correlation contains a coefficient known as the H-W "C" factor, which is used to account for surface condition and fouling. **Reference 5** compiles head loss tables versus pipe size and flow rate along with recommended "C" factors for various types of service. For further information, consult the Reactor and Fluid Dynamics Section.

**Note:** In some references [e.g., (2)] the Darcy friction factor,  $f_D$ , is used instead of the Fanning friction factor. They are related by the equation  $f_D = 4f$ , and calculated results are identical.

## EFFECT OF FITTINGS

Bends, tees, valves, orifices and other flow restrictions cause additional pressure drop in a pipe. Fittings that have the same nominal diameter as the pipe can be accounted for in terms of an *equivalent length* of straight pipe. This equivalent length can be calculated from the resistance coefficients of the fittings [Figures 5A - 5E and 6 and Eq. (17)]. The equivalent length is then added to the actual length of the pipe and the sum is used in the Fanning equation for predicting the total friction pressure drop. It should be recognized during design that the actual resistance coefficient of bends, tees, and valves may deviate from the values presented in Figures 5 and 6 by as much as  $\pm 25\%$ .

Also, the use of equivalent lengths or resistance coefficients is, as published, essentially an approximate correlation of a complex problem. If pressure drop is a critical factor for safety, economic, or other considerations, consult with the Reactor and Fluid Dynamics Section.

When piping details are not available, the following guidelines may be used for estimating equivalent length:

**Onsite Lines** - Actual pipe length can be estimated from the plot plan, tower heights, etc. For a rough estimate the equivalent length of fittings in onsite piping adds between 200% and 500% to the actual length. Accordingly, a multiplier of 3.0 to 6.0 may be applied to the estimated length of straight pipe. A better estimate can be obtained from Table 2 as long as the components in the circuit are known. If the designer wants even better accuracy, he must know all the components in the circuit, make a preliminary pipe routing on the plot plan and finally add an appropriate allowance.

**Offsite Lines** - For offsite lines, the approximate length of straight pipe can be estimated from the plot plan. Since fittings in offsite lines usually have an equivalent length of 20% to 80% of the actual length, a multiplier of 1.2 to 1.8 can be applied to the estimated length of straight pipe.

## EXPANSIONS AND CONTRACTIONS

The pressure drop in cross-section changes, such as exits and entrances of process vessels, reducers and diffusers, consists of two components: one for friction and one for change in kinetic energy. Calculation of the **friction loss is based on the diameter of the smaller of the two pipes** with no obstructions.

For pipes ending in an area of very large cross-section, such as a process vessel, the frictional pressure drop is equal to the gain in pressure caused by the change in kinetic energy. As a result, the net pressure change over the cross-section change is zero.

For a very gradual contraction, **friction** pressure drop is calculated based on a straight piece of pipe with inside diameter equal to the narrowest cross-section of the contraction.

In pressure drop calculations for lines containing fittings and cross-section changes, the line is first broken into sections of constant nominal diameter. The friction pressure drop of each change in cross-section is accounted for in the equivalent length of the smaller diameter pipe attached to it as defined by Eq. (16). The pressure drop due to the various changes in kinetic energy in the line is determined by calculating the overall change in kinetic energy between the inlet and outlet of the line.

## NON-HORIZONTAL PIPES

In case of non-horizontal pipes, an elevation term must be added to the pressure change calculated for friction loss and kinetic energy [Eq. (6)].

## COMBINING AND DIVIDING OF STREAMS

When a stream is split in two or more substreams there is both a friction loss and a pressure change due to the change in kinetic energy. The same applies to the combining of streams. For tees the total pressure change is given by Eq. (8). For Y's see Reference 8, and for manifolds see Reference 9. Further information may be obtained by consulting with the Reactor and Fluid Dynamics Section.

|                                                                                                              |                                                          |                |             |
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## ORIFICES, FLOW NOZZLES AND VENTURIS

For orifices, flow nozzles, and venturis, two pressure drops can be distinguished:

**Flow Measurement Pressure Drop** is a pressure drop used in connection with flow measurements, which does not include pressure recovery downstream of the constriction. For orifices and flow nozzles, this pressure drop is measured across flange taps; for venturis, between an upstream tap and a tap at the narrowest cross-section. The flow coefficients presented in [Figures 7A, 7B, and 8](#) relate to this pressure drop.

**Total Pressure Drop** is the pressure drop between a point upstream of the restriction and a point several pipe diameters downstream. This pressure drop is smaller than the flange tap pressure drop because of pressure recovery (i.e., conversion of momentum into pressure) downstream of the restriction. The total pressure drop can be obtained by multiplying the flange tap pressure drop by a pressure recovery factor ([Figure 10](#)). For determining the pressure drop along a line containing an orifice, flow nozzle, or venturi, one must use the total pressure drop. If the orifice or flow restriction is at the end of a line discharging into a large vessel or the ambient, there is no pressure recovery and the flow measurement pressure drop should be used.

For more detailed information on the flow measurement aspects of orifices, flow nozzles, and venturis see [Section XII](#).

## PERFORATED PIPE DISTRIBUTORS

In most cases, perforated pipe distributors can be designed by the short procedure given in [Section III-H](#). These designs mainly apply to liquid-liquid settlers and fractionation towers where a relatively low velocity is more important than liquid distribution. In these cases, some non-uniformity in liquid distribution may occur, depending on the ratio of the pressure drop across the distributor holes to the pressure drop (or gain) along the pipe. If inertial forces predominate over friction losses in the pipe, flow through the holes will increase in the direction of the closed end. If friction loss along the pipe is more important than inertial forces, the opposite will be the case. When an upstream disturbance, such as that produced by a bend, is superimposed upon a case where inertial forces predominate, flow through the holes near the distributor inlet and near the closed end can be greater than in the middle.

The degree of maldistribution in a liquid distributor can be predicted from [Eq. \(15\)](#). Where less than 5% maldistribution is required, the design procedure given in this section must be used. In this procedure, pressure drop across the holes,  $(\Delta P)_o$ , is

set at ten times the greater of either inlet kinetic energy per unit volume of flowing fluid,  $E_k$ , or the magnitude of the pressure drop over the length of the distributor pipe,  $|(\Delta P)_p|$ .

The following guidelines should be followed for choosing hole diameter and number of holes:

- Minimum hole diameter  $\approx 1/2$ -in. (13 mm) to avoid plugging and to limit the number of holes to a reasonable value. In very clean service, smaller holes may be considered, but in severely fouling service,  $1/2$ -in. (13 mm) holes may be too small.
- Maximum hole diameter = 0.2 times inside diameter of distributor.
- The ratio of hole diameter,  $d_o$ , to inside pipe diameter,  $d_1$ , should be between 0.15 and 0.20 when the criterion  $(\Delta P)_o = 10 E_k$  is used. If it is necessary to use  $d_o/d_1 < 0.10$ , then make  $(\Delta P)_o = 100 E_k$ .
- To provide sufficient pipe strength, the minimum distance (edge-to-edge) between adjacent holes should approximately equal the hole diameter.
- Within the limitations imposed by the above requirements, a larger number of small holes is preferred over a smaller number of large holes.
- If slots are used instead of holes, the slot width should be at least  $1/2$ -in. (13 mm).

To assure optimum distribution, flow conditions upstream and downstream of the distributor should be considered. Conditions upstream of the distributor are controlled by the piping outside of the unit. In general, this means minimizing the number and severity of sharp turns or sudden contractions or enlargements just ahead of the distributor. Conditions downstream of the distributor depend on the geometry of the downstream internals, which are usually designed to maintain uniform distribution for good contacting.

## DESIGN PROCEDURES

The following design methods, equations, and guidelines must be used together with the material given above under **BASIC DESIGN CONSIDERATIONS**. The first section below presents procedures for calculating pressure drop in single piping components. The second section should be used for calculating pressure drop in flow systems containing more than one piping component.

|                  |                 |                                            |                                    |
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## PRESSURE DROP ACROSS SINGLE PIPING COMPONENTS

Use the procedures below for calculating frictional pressure drop across single piping components, such as runs of straight pipe, bends, valves, orifices, etc.

### Straight Pipe

For commercial steel pipe, find the pressure drop in psi/100 ft (kPa/m) from the charts in [Figures 3A](#) and [3B](#) or [4A - 4D](#). For conditions not covered by these charts or more precise answers, use the procedure given below. For non-circular conduits,

calculate the equivalent hydraulic diameter from [Eq. \(2\)](#). The equivalent hydraulic diameter is a characteristic length that defines the size of non-circular cross sections. When calculating friction factors for fully-turbulent flow in non-circular conduits,  $d_{eq}$  replaces the circular cross-section diameter,  $d$ , in all relevant equations. For laminar flow, the friction factor results have been obtained from theoretical consideration and similar theoretical or experimental studies must be performed to obtain friction factors for the non-circular conduit of interest. **Note:** No geometric analogy exists between  $d_{eq}$  and the circular pipe diameter,  $d$  other than the fact that each represents a measure of the size of the cross section. Therefore,  $d_{eq}$  **cannot** be used to calculate velocity,  $V$ , from the flow rate,  $Q$ . However,  $d_{eq}$  can be used to calculate the Reynolds number from [Eq. \(3a\)](#) and, for fully-turbulent flows, the frictional pressure drop from [Eq. \(5\)](#).

$$d_{eq} = 4 \left[ \frac{\text{cross - sectional area}}{\text{wetted perimeter}} \right] \text{ in consistent units} \quad \text{Eq. (2)}$$

**Step 1** - For given diameter and flow rate, calculate the Reynolds number,  $Re$ , from the following equation:

$$Re = K_{3a} \left( \frac{dV\rho}{\mu} \right) \quad \text{Eq. (3a)}$$

$$= K_{3b} \left( \frac{Q\rho}{d\mu} \right); \text{ valid only for circular cross sections} \quad \text{Eq. (3b)}$$

$$= K_{3c} \left( \frac{W}{d\mu} \right); \text{ valid only for circular cross sections} \quad \text{Eq. (3c)}$$

**where:**  $D$  = Inside diameter of pipe or equivalent hydraulic diameter, ft (m)  
 $d$  = Inside diameter of pipe or equivalent hydraulic diameter, in. (mm)  
 $Q$  = Volumetric flow rate, gpm (dm<sup>3</sup>/s)  
 $Re$  = Reynolds number, dimensionless  
 $V$  = Velocity, ft/s (m/s)  
 $W$  = Mass flow rate, thousands lb<sub>m</sub>/h (kg/s)  
 $\rho$  = Density, lb<sub>m</sub>/ft<sup>3</sup> (kg/m<sup>3</sup>)  
 $\mu$  = Viscosity, cP (Pa·s)

|            | Customary          | Metric             |
|------------|--------------------|--------------------|
| $K_{3a}$ = | 123.9              | $10^{-3}$          |
| $K_{3b}$ = | 50.6               | 1.27               |
| $K_{3c}$ = | $6.31 \times 10^3$ | $1.27 \times 10^3$ |

**Step 2** - Look up the friction factor,  $f$ , in [Figures 1](#) or [2A, 2B](#). For values of  $Re$  lower than those covered by these figures, with  $Re < 2100$  (Laminar Flow), calculate  $f$  from the [Eq. \(4\)](#):

$$f = \frac{16}{Re} \quad \text{Eq. (4)}$$

**where:**  $f$  = Friction factor, dimensionless

**Step 3** - Calculate the frictional pressure drop from one of the following equations:

|                                                                                                              |                                                      |                |             |
|--------------------------------------------------------------------------------------------------------------|------------------------------------------------------|----------------|-------------|
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$$(\Delta P)_f = K_{5a} \left( \frac{4 f L}{D} \right) \left( \frac{\rho V^2}{2 g_c} \right) \quad \text{Eq. (5a)}$$

$$= K_{5b} \left( \frac{f L V^2 \rho}{d} \right) \quad \text{Eq. (5b)}$$

$$= K_{5c} \left( \frac{f L Q^2 \rho}{d^5} \right) \quad \text{Eq. (5c)}$$

$$= K_{5d} \left( \frac{f L W^2}{\rho d^5} \right) \quad \text{Eq. (5d)}$$

**where:**  $(\Delta P)_f$  = Frictional pressure drop, psi (kPa)  
 $L$  = Pipe length, ft (m)

|            | <u>Customary</u>      | <u>Metric</u>         |
|------------|-----------------------|-----------------------|
| $K_{5a} =$ | 1/144                 | $10^{-3}$             |
| $K_{5b} =$ | $5.18 \times 10^{-3}$ | 2                     |
| $K_{5c} =$ | $8.63 \times 10^{-4}$ | $3.24 \times 10^6$    |
| $K_{5d} =$ | 13.4                  | $3.24 \times 10^{12}$ |

**Step 4** - In case the pipe is not horizontal, calculate the pressure drop due to the change in elevation from the following equations:

$$(\Delta P)_e = K_{6a} \frac{\rho g}{g_c} (z_2 - z_1) \quad \text{Eq. (6a)}$$

$$= K_{6b} \rho (z_2 - z_1) \quad \text{Eq. (6b)}$$

**where:**  $(\Delta P)_e$  = Pressure drop due to change in elevation, psi (kPa)  
 $z_1, z_2$  = Elevation of beginning and end of pipe, ft (m)

|            | <u>Customary</u>      | <u>Metric</u>         |
|------------|-----------------------|-----------------------|
| $K_{6a} =$ | 1/144                 | $10^{-3}$             |
| $K_{6b} =$ | $6.94 \times 10^{-3}$ | $9.81 \times 10^{-3}$ |

**Step 5** - Find the total pressure drop by adding the frictional pressure drop  $(\Delta P)_f$  and the pressure drop due to change in elevation  $(\Delta P)_e$ .

**Bends** - Use the following procedure:

**Step 1** - Find the resistance coefficient,  $K$ , in [Figure 5C](#) or [5D](#).

For pipes larger than 10 in. (250 mm) I.D., use the resistance coefficient for 10 in. (250 mm) I.D. pipe. If the Reynolds number is such that the flow is not in the region of complete turbulence ( $f$  is constant), the value of  $K$  should be multiplied by the ratio:

|                  |                  |                                                          |                                                                                                           |
|------------------|------------------|----------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
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$$\frac{f_{\text{(at calculated Reynolds number)}}}{f_{\text{(in range of complete turbulence)}}$$

**Step 2** - Calculate the frictional pressure drop from the following equations:

$$(\Delta P)_f = K_{7a} \left( \frac{K_p V^2}{2 g_c} \right) \quad \text{Eq. (7a)}$$

$$= K_{7b} (K_p V^2) \quad \text{Eq. (7b)}$$

$$= K_{7c} \left( \frac{K_p Q^2}{d^4} \right) \quad \text{Eq. (7c)}$$

$$= K_{7d} \left( \frac{K W^2}{\rho d^4} \right) \quad \text{Eq. (7d)}$$

where:

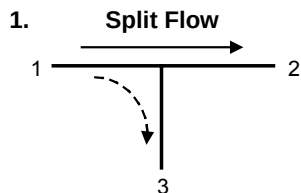
|            | Customary             | Metric               |
|------------|-----------------------|----------------------|
| $K_{7a} =$ | 1/144                 | $10^{-3}$            |
| $K_{7b} =$ | $1.08 \times 10^{-4}$ | $5.0 \times 10^{-4}$ |
| $K_{7c} =$ | $1.8 \times 10^{-5}$  | 810                  |
| $K_{7d} =$ | 0.28                  | $8.10 \times 10^8$   |

**Step 3** - For long non-horizontal bends, add the pressure drop due to the change in elevation calculated from [Eq. \(6\)](#).

**Step 4** - For 90° mitered bends, the curves and table in [Figure 5E](#) may be used. If minimizing pressure drop is critical and the design is based on the use of smooth bends or mitered bends with many segments, care must be taken during detailed design and construction to make sure that miters with few segments are not installed.

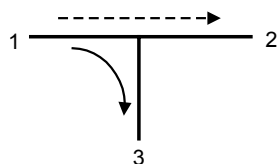
**Tees and Y's** - For blanked-off tees and Y's, use [Eq. \(7\)](#) and the resistance coefficients for tees in [Figure 5C](#) or [5D](#). For tees

in which streams are split or joined, the pressure drop should be calculated from the following equations (**Reference 8**). The joining or splitting of streams is represented schematically prior to each equation. In the diagrams, the solid arrow represents the flow path associated with the pressure drop calculation facilitated by the associated equation.



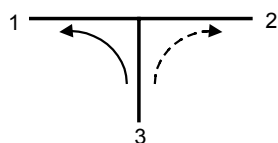
$$(\Delta P)_{1-2} = K_8 \rho (1.36 V_2^2 - 0.64 V_1^2 - 0.72 V_1 V_2) \quad \text{Eq. (8a)}$$

|                                                                                                              |                                                      |                |             |
|--------------------------------------------------------------------------------------------------------------|------------------------------------------------------|----------------|-------------|
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$$(\Delta P)_{1-3} = K_8 \rho (1.8 V_3^2 - 0.368 V_1 V_3)$$

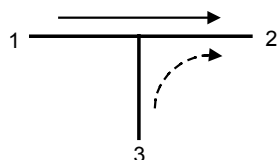
Eq. (8b)



$$(\Delta P)_{3-1} = K_8 \rho (1.8 V_1^2 - 0.368 V_1 V_3)$$

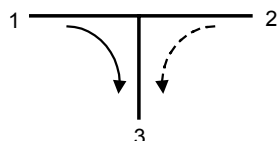
Eq. (8c)

## 2. Join Flow



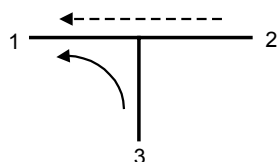
$$(\Delta P)_{1-2} = K_8 \rho \left[ 2V_2^2 - 0.05V_1^2 - 2V_2 \left( 0.205V_3 \frac{Q_3}{Q_2} + V_1 \frac{Q_1}{Q_2} \right) \right]$$

Eq. (8d)



$$(\Delta P)_{1-3} = K_8 \rho \left[ 2V_3^2 - 0.4V_1^2 - 0.41V_3 \left( V_1 \frac{Q_1}{Q_3} + V_2 \frac{Q_2}{Q_3} \right) \right]$$

Eq. (8e)



$$(\Delta P)_{3-1} = K_8 \rho \left[ 2V_1^2 - 0.4V_3^2 - 2V_1 \left( 0.205V_3 \frac{Q_3}{Q_1} + V_2 \frac{Q_2}{Q_1} \right) \right]$$

Eq. (8f)

where:

|         | <u>Customary</u>      | <u>Metric</u>         |
|---------|-----------------------|-----------------------|
| $K_8 =$ | $1.69 \times 10^{-4}$ | $7.83 \times 10^{-4}$ |

Equations (8a-f) account for both frictional pressure drop and pressure drop due to change in kinetic energy. A multiplying factor of 1.25 has been used in these equations to allow for entrance and exit effects when the length of the inlet leading line is short ( $L/D < 10$ ). For Y's, equations similar to Equations (8a-f) can be derived with a method presented in Reference 8.



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**Reference 9** contains procedures for the pressure drop in manifolds. When more accurate calculation of pressure drop for Y's

or in manifolds is required, consult the Chemical Engineering Technology Section of ExxonMobil Engineering.

**Valves** - Find the resistance coefficient, K, by using L/D values in [Table 3](#) and [Figure 5A](#) or [5B](#). Use the same procedure as used for bends. [Figure 9](#) can be used to determine flow coefficient  $C_v$  from K.

**Orifices** - For calculating the "measurement" pressure drop (as measured across flange taps), use the following equations:

$$\Delta P = K_{9a} \left( \frac{\rho Q^2}{C^2 d_o^4} \right) \quad \text{Eq. (9a)}$$

$$= K_{9b} \left( \frac{W^2}{C^2 \rho d_o^4} \right) \quad \text{Eq. (9b)}$$

**where:** C = Flow coefficient, dimensionless ([Figure 7A](#) or [7B](#))  
 $d_o$  = Orifice diameter, in. (mm)

|            | <u>Customary</u>     | <u>Metric</u>      |
|------------|----------------------|--------------------|
| $K_{9a}$ = | $1.8 \times 10^{-5}$ | 810                |
| $K_{9b}$ = | 0.28                 | $8.10 \times 10^8$ |

To obtain the total pressure drop (including pressure recovery downstream of the orifice), multiply  $\Delta P$  from [Eq. \(9\)](#) by the pressure recovery factor, r, of [Figure 10](#).

**Flow Nozzles** - Use same procedures as for orifices, except with a flow coefficient from [Figure 8](#).

**Venturis** - For calculating pressure drop as measured across venturi taps (one upstream and one at the narrowest cross section - diameter  $d_o$ ), use [Eq. \(9\)](#) with the following flow coefficient:

$$C = \frac{0.98}{\sqrt{1 - (d_o / d_1)^4}} \quad \text{Eq. (10)}$$

**where:**  $d_1$  = Inside diameter of upstream pipe, in. (mm)

To obtain the total pressure drop, multiply  $\Delta P$  from [Eq. \(9\)](#) by the pressure recovery factor of [Figure 10](#).

**Contractions and Expansions** - Use the following procedure:

**Step 1** - Look up the appropriate resistance coefficient, K, in [Figure 6](#).

**Step 2** - Calculate the frictional pressure drop from the following equations:

$$(\Delta P)_f = K_{7a} \left( \frac{K \rho V^2}{2 g_c} \right) \quad \text{from Eq. (7a)}$$

$$= K_{7b} (K \rho V^2) \quad \text{from Eq. (7b)}$$

|                                                                                                              |                                                          |                |             |
|--------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|----------------|-------------|
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$$= K_{7c} \left( \frac{K \rho Q^2}{d^4} \right) \quad \text{from Eq. (7c)}$$

$$= K_{7d} \left( \frac{K W^2}{\rho d^4} \right) \quad \text{from Eq. (7d)}$$

**where:**  $d$  = Inside diameter or equivalent hydraulic diameter of the **smaller** diameter pipe, in. (mm)  
 $V$  = Velocity in smaller-diameter pipe, ft/s (m/s), and  $K_{7a-d}$  given on Page 10

Calculate the **frictional pressure drop in a gradual contraction** as if it were a pipe with diameter equal to the smallest diameter in the contraction.

**Step 3** - Calculate the pressure drop due to change in kinetic energy of the flow from the following equation:

$$(\Delta P)_k = K_{11a} \left( \frac{\rho}{2 g_c} \right) (V_2^2 - V_1^2) \quad \text{Eq. (11a)}$$

$$= K_{11b} \rho (V_2^2 - V_1^2) \quad \text{Eq. (11b)}$$

$$= K_{11c} \rho Q^2 \left( \frac{1}{d_2^4} - \frac{1}{d_1^4} \right) \quad \text{Eq. (11c)}$$

$$= K_{11d} \left( \frac{W^2}{\rho} \right) \left( \frac{1}{d_2^4} - \frac{1}{d_1^4} \right) \quad \text{Eq. (11d)}$$

**where:**  $d_1, d_2$  = Upstream and downstream inside diameters or equivalent hydraulic diameters, in. (mm)  
 $V_1, V_2$  = Upstream and downstream velocities, ft/s (m/s)

|             | <u>Customary</u>      | <u>Metric</u>        |
|-------------|-----------------------|----------------------|
| $K_{11a}$ = | 1/144                 | $10^{-3}$            |
| $K_{11b}$ = | $1.08 \times 10^{-4}$ | $5.0 \times 10^{-4}$ |
| $K_{11c}$ = | $1.8 \times 10^{-5}$  | 810                  |
| $K_{11d}$ = | 0.28                  | $8.10 \times 10^8$   |

**Step 4** - For non-horizontal gradual contractions and expansions, calculate the pressure drop due to change in elevation from [Eq. \(6\)](#).

**Step 5** - Calculate the total pressure drop by adding the pressure drops obtained from [Equations \(6\), \(7\)](#) and [\(11\)](#).

|                  |                  |                                                          |                                                                                                              |
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### Perforated Pipe Distributors

Use the following procedure for designing perforated pipe distributors *with less than 5% maldistribution*. (Note: In liquid-liquid settlers and fractionation towers low velocity is more important than liquid distribution and the procedures in [Section III-H](#) should be followed.)

**Step 1** - For the first trial, set the distributor pipe diameter,  $d$ , equal to that of the inlet line.

**Step 2** - Calculate the Reynolds number,  $Re_i$  of the inlet stream from [Eq. \(3\)](#).

**Step 3** - Find the friction factor,  $f$ , from [Figures 1](#), or [2A](#), [2B](#).

**Step 4** - Calculate the kinetic energy per unit volume of the inlet stream,  $E_k$ , in psi (kPa ) from the following equations:

$$E_k = K_{12a} \alpha \left( \frac{\rho V_i^2}{2 g_c} \right) \quad \text{Eq. (12a)}$$

$$= K_{12b} \alpha \rho V_i^2 \quad \text{Eq. (12b)}$$

$$= K_{12c} \alpha \left( \frac{\rho Q^2}{d^4} \right) \quad \text{Eq. (12c)}$$

$$= K_{12d} \left( \frac{\alpha W^2}{\rho d^4} \right) \quad \text{Eq. (12d)}$$

**where:**  $\alpha$  = Velocity correction factor, dimensionless (Use  $\alpha = 1.1$  for turbulent flow, and  $\alpha = 2.0$  for laminar flow)

|             | Customary             | Metric               |
|-------------|-----------------------|----------------------|
| $K_{12a} =$ | 1/144                 | $10^{-3}$            |
| $K_{12b} =$ | $1.08 \times 10^{-4}$ | $5.0 \times 10^{-4}$ |
| $K_{12c} =$ | $1.8 \times 10^{-5}$  | 810                  |
| $K_{12d} =$ | 0.28                  | $8.10 \times 10^8$   |

**Step 5** - Calculate the pressure change  $(\Delta P)_p$  along the pipe due to friction and momentum recovery from the following equations:

$$(\Delta P)_p = \left( \frac{K_{13a1} f L J}{d} - \alpha \right) K_{13a2} \left( \frac{\rho V_i^2}{2 g_c} \right) \quad \text{Eq. (13a)}$$

$$= \left( \frac{K_{13b} f L J}{\alpha d} - 1 \right) E_k \quad \text{Eq. (13b)}$$

**where:**  $J$  = Dimensionless factor from [Figure 11](#) (Use  $J = 0.35$  for first trial)

|              | Customary | Metric          |
|--------------|-----------|-----------------|
| $K_{13a1} =$ | 48.0      | $4 \times 10^3$ |
| $K_{13a2} =$ | 1/144     | $10^{-3}$       |

|                                                                                                              |                                                          |                |             |
|--------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|----------------|-------------|
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$$K_{13b} = 48.0 \quad 4 \times 10^3$$

**Step 6** - Find the required pressure drop,  $(\Delta P)_o$ , across the outlet holes by multiplying the greater of  $E_k$  or  $(\Delta P)_p$  by 10. If the calculated value of  $(\Delta P)_o$  is less than 0.25 psi (1.75 kPa), make  $(\Delta P)_o$  equal to 0.25 psi (1.75 kPa).

**Step 7** - Calculate the required total area of the outlet holes from the following equations:

$$A_o = K_{14a} \frac{Q}{C} \sqrt{\frac{\rho}{(\Delta P)_o}} \quad \text{Eq. (14a)}$$

$$= K_{14b} \frac{W}{C} \left( \frac{1}{\sqrt{\rho(\Delta P)_o}} \right) \quad \text{Eq. (14b)}$$

**where:**  $A_o$  = Total required hole area, in.<sup>2</sup> (mm<sup>2</sup>)

|             | <u>Customary</u>      | <u>Metric</u>      |
|-------------|-----------------------|--------------------|
| $K_{14a} =$ | $3.32 \times 10^{-3}$ | 22.3               |
| $K_{14b} =$ | 0.415                 | $22.3 \times 10^3$ |

For the first trial, take the flow coefficient C equal to 0.60.

**Step 8** - Choose a hole diameter and number of holes to obtain the desired  $A_o$  based on the guidelines presented under "Basic Design Considerations."

**Step 9** - Calculate  $Re_i / n$ , where n is the number of holes of the distributor. If  $Re_i / n < 4,000$ , look up a new flow coefficient in [Figure 7](#), taking  $Re$  in this figure equal to  $Re_i / n$ .

**Step 10** - Using the calculated number of holes, find the factor J from [Figure 11](#) and compare this with the assumed value of 0.35. If this revised value of J affects the value of  $(\Delta P)_o$  by more than 10%, substitute the revised value of J in [Eq. \(13\)](#) and repeat Steps 5 through 10.

The maldistribution in a pipe distributor can be calculated from the following equation:

$$\% \text{ Maldistribution} = 100 \left[ \sqrt{\frac{(\Delta P)_o - (\Delta P)_p}{(\Delta P)_o}} - 1 \right] \quad \text{Eq. (15)}$$

## INTEGRATED PRESSURE DROP CALCULATION FOR PIPING SYSTEMS

Use the procedure below for calculating pressure drop in any flow system containing more than one piping component.

**Step 1 - Constant Flow and Nominal-Diameter Sections** - Break the system in question into sections of constant flow rate and constant nominal diameter. Apply Steps 2 through 6 to each of the sections.

**Step 2 - Equivalent Hydraulic Diameter** - For any section having a non-circular cross-section, calculate the equivalent hydraulic diameter,  $d_{eq}$ , from [Eq. \(2\)](#).

**Step 3 - Reynolds Number** (not needed for rough estimates) - Find the Reynolds number,  $Re$ , for each section from [Eq. \(3\)](#).

**Step 4 - Friction Factor** (not needed for rough estimates) - Find the friction factor,  $f$ , for commercial steel pipe from [Figure 2](#). For other materials use [Figure 1](#) or the correction factors in [Figure 2](#).

For Reynolds numbers smaller than 2100, find the friction factor from [Eq. \(4\)](#).

**Step 5 - Equivalent Length of Fittings** - If piping details are not available, assume for offsite lines that the equivalent length of fittings lies between 20 and 80% of the actual pipe length and for onsite lines 200 to 500%. Estimate pipe length from the plot plan, tower heights, etc.

When the fittings are known or can be estimated, find their total equivalent length,  $L_{eq}$ , from the following equation:

|                  |                  |                                                           |                                                   |
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$$L_{eq} = \left( \frac{K_{16}d}{4f} \right) \Sigma K \quad \text{Eq. (16)}$$

**where:**  $L_{eq}$  = Equivalent length of all fittings, ft (m)  
 $\Sigma K$  = Sum of resistance coefficients of all fittings, dimensionless  
 $K_{16}$  = 1/12 (Customary)  
 $K_{16}$  =  $10^{-3}$  (Metric)

The resistance coefficient, K, of bends, blanked-off tees, and valves is found in [Figures 5A to 5E](#) as function of nominal pipe diameter. For fittings larger than 10 in. I.D., use the resistance coefficient for 10 in. (250 mm) I.D. fittings in [Figures 5C or 5D](#).

The K of contractions and expansions is found in [Figure 6](#), based on the smaller diameter pipe that is attached to them.

For orifices, flow nozzles and venturis, K should be calculated from the following equation:

$$K = \left( \frac{r}{C^2} \right) \left( \frac{d_1}{d_o} \right)^4 \quad \text{Eq. (17)}$$

**where:**  $r$  = Pressure recovery factor ([Figure 10](#)), dimensionless

For orifices and flow nozzles obtain C from [Figure 7 or 8](#).

For venturis:

$$C = \frac{0.98}{\sqrt{1 - (d_o / d_1)^4}} \quad \text{from Eq. (10)}$$

**Step 6 - Frictional Pressure Drop,  $(\Delta P)_f$**  - Find this for commercial steel pipe from [Figure 3A or 3B](#) or [Figure 4](#) by multiplying the pressure drop in psi per 100 ft (kPa per m) by the sum of the actual pipe lengths and the equivalent lengths of all fittings divided by 100 (1 for metric). For more precise answers, or conditions not covered by the charts, calculate the frictional pressure drop in each section of the system from [Eq. \(5\)](#), but use for L the sum of the actual pipe lengths and the equivalent lengths of all fittings.

**Step 7 - Overall Kinetic Energy Change,  $(\Delta P)_k$**  - For each constant-flow section, check the flow cross-sections at beginning and end. If they are not equal, calculate the pressure change  $(\Delta P)_k$  due to the change in kinetic energy from [Eq. \(11\)](#). Note that  $(\Delta P)_k$  can be either positive or negative.

**Step 8 - Overall Elevation Change  $(\Delta P)_e$**  - For each constant-flow section, check the elevation at beginning and end. If it is not equal, calculate the resulting pressure change  $(\Delta P)_e$  from [Eq. \(6\)](#). Note that  $(\Delta P)_e$  can be either positive or negative.

**Step 9 - Total Pressure Drop per Constant-Flow Section** - Find the total pressure drop in each constant-flow section from the following equation:

$$(\Delta P)_t = \Sigma (\Delta P)_f + (\Delta P)_k + (\Delta P)_e \quad \text{Eq. (18)}$$

**where:**  $(\Delta P)_t$  = Total pressure drop, psi (kPa)  
 $\Sigma (\Delta P)_f$  = Sum of frictional pressure drops in all constant nominal diameter sections, psi (kPa)

**Step 10 - Stream Junctions** - For tees, calculate the pressure drop from [Eq. \(8\)](#). For Y's or manifolds see [Reference 8](#) or [Reference 9](#), respectively, or contact the Reactor & Fluid Dynamics Section of ExxonMobil Engineering.

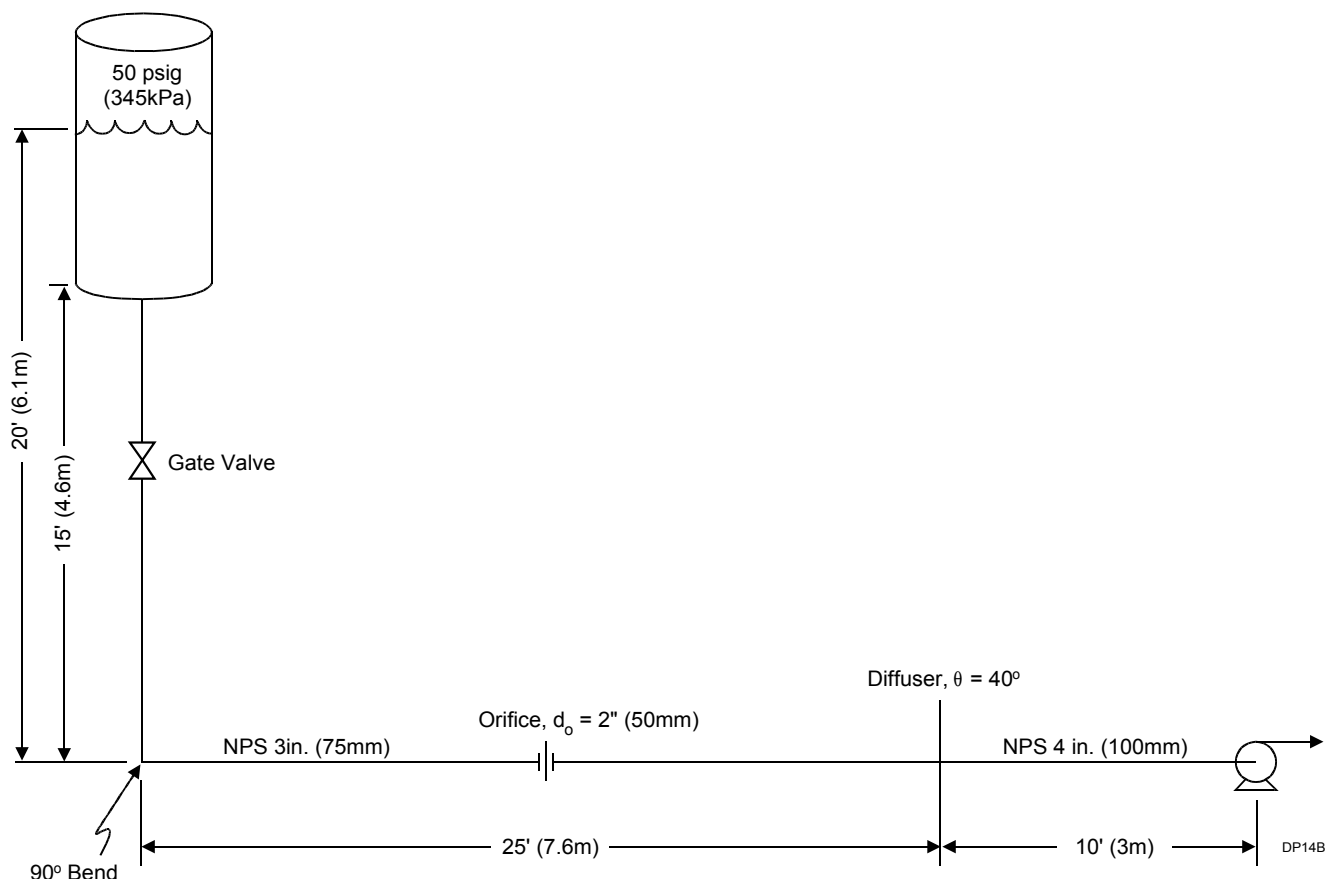
The pressure drop over the entire system is obtained by combining the pressure drops in the various stream junctions with the pressure drops across the various constant-flow sections calculated in Step 9.

|                                                                                                              |                                                      |                         |                         |
|--------------------------------------------------------------------------------------------------------------|------------------------------------------------------|-------------------------|-------------------------|
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### SAMPLE PROBLEMS

#### PROBLEM 1 - INTEGRATED PRESSURE DROP CALCULATION

**Given:** The following flow system, with a constant flow rate through the piping system, from the process vessel to the pump.



|                  | <u>Customary</u>                      | <u>Metric</u>               |
|------------------|---------------------------------------|-----------------------------|
| Liquid flow rate | = 200 gpm                             | 12.6 dm <sup>3</sup> /s     |
| Liquid density   | = 50 lb <sub>m</sub> /ft <sup>3</sup> | 800 kg/m <sup>3</sup>       |
| Liquid viscosity | = 0.30 cP                             | 0.3 x 10 <sup>-3</sup> Pa•s |

**Find:** The suction pressure of the pump.

**Solution:**

**Step 1** - Divide the system into three sections of constant nominal diameter:

- Section I** includes the vessel.
- Section II** includes the contraction at the bottom of the vessel, the NPS 3 (75 mm) line and the diffuser.
- Section III** includes the NPS 4 (100 mm) line, from the diffuser to the pump.

Steps 2 through 6, where applicable, will now be carried out for each of these three sections to find the friction pressure drops.

**Section I** - Because of low velocity in the vessel, friction pressure drop can be neglected.

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**Section II**

**Step 2** - Pipe is round.

**Step 3** - From [Section XIV-A, Table 1](#): Inside pipe diameter  $d = 3.068$  in. (77.9 mm). Reynolds number ([Eq. 3b](#)):

$$Re = \frac{50.6 Q \rho}{d \mu} = \frac{(50.6)(200)(50)}{(3.068)(0.30)} = 550,000 \text{ (rounded)} \quad \text{(Customary)}$$

$$= \frac{1.27 Q \rho}{d \mu} = \frac{(1.27)(12.6)(800)}{(77.9)(0.3 \times 10^{-3})} = 550,000 \text{ (rounded)} \quad \text{(Metric)}$$

**Step 4** - From [Figure 2A](#) or [2B](#): Friction factor,  $f = 0.0046$ , essentially fully turbulent

**Step 5** - First determine the various resistance coefficients:

- Resistance coefficient of the contraction at the vessel bottom:  $K = 0.5$  ([Figure 6](#)).
- Resistance coefficient for the gate valve:  $L/D = 13$  ([Table 3](#)), thus  $K = 0.23$  approximately ([Figure 5A](#) or [5B](#)).
- Resistance coefficient for the 90° long radius ell:  $K = 0.25$  ([Figure 5C](#) or [5D](#)).
- The orifice has an orifice diameter  $d_o$  of 2 in. (50 mm); therefore:

$$\frac{d_o}{d_1} = \frac{2.0}{3.068} = 0.65 \quad \text{(Customary)}$$

$$= \frac{50}{77.9} = 0.65 \quad \text{(Metric)}$$

Flow coefficient of orifice:  $C = 0.67$  ([Figure 7B](#)).

Pressure recovery factor:  $r = 0.58$  ([Figure 10](#)).

Use [Eq. \(17\)](#) to calculate the resistance coefficient of the orifice:

$$K = \left( \frac{r}{C^2} \right) \left( \frac{d_1}{d_o} \right)^4 = \left( \frac{0.58}{(0.67)^2} \right) \left( \frac{3.068}{2} \right)^4 = 7.15 \quad \text{(Customary)}$$

$$= \left( \frac{0.58}{(0.67)^2} \right) \left( \frac{77.9}{50} \right)^4 = 7.15 \quad \text{(Metric)}$$

- Resistance coefficient of the diffuser:  $\beta = 3.026/4.068 = 0.76$ ;  $K = 0.2$  approximately ([Figure 6](#)).

Sum of resistance coefficients:  $\Sigma K = 0.5 + 0.23 + 0.25 + 7.15 + 0.2 = 8.33$

Obtain the equivalent length of valve and other fittings from [Eq. \(16\)](#):

$$L_{eq} = \left( \frac{d}{48 f} \right) \Sigma K = \left( \frac{\left( \frac{1}{12} \right) (3.068)}{(4)(0.0046)} \right) (8.33) = 116 \text{ ft} \quad \text{(Customary)}$$

$$= \left( \frac{10^{-3} d}{4 f} \right) \Sigma K = (10^{-3}) \left( \frac{(77.9)}{(4)(0.0046)} \right) 8.33 = 35.3 \text{ m} \quad \text{(Metric)}$$

**Step 6** - Sum of actual pipe length and equivalent lengths of all fittings:

$$L = 40 + 116 = 156 \text{ ft}$$

(Customary)



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$$L = 12.2 + 35.3 = 47.5 \text{ m} \quad (\text{Metric})$$

Specific gravity,  $S$ , of the liquid relative to water at 60°F:

$$S = \frac{50}{62.37} = 0.80$$

$$\text{Kinematic viscosity } \nu = \frac{\mu}{S} = \frac{0.30}{0.80} = 0.37 \text{ cSt} \quad (\text{Customary})$$

$$\text{Kinematic viscosity } \nu = 10^6 \frac{0.30 \times 10^{-3}}{800} = 0.37 \text{ mm}^2/\text{s} \quad (\text{Metric})$$

Use [Eq. \(5c\)](#) to calculate the frictional pressure drop:

$$(\Delta P)_f = \frac{(8.63 \times 10^{-4})(0.0046)(156)(200)^2(50)}{(3.068)^5} = 4.56 \text{ psi} \quad (\text{Customary})$$

$$(\Delta P)_f = \frac{(3.24 \times 10^6)(0.0046)(47.5)(12.6)^2(800)}{(77.9)^5} = 31.4 \text{ kPa} \quad (\text{Metric})$$

Alternatively, from [Figure 3A](#) or [3B](#), at a flow rate of 200 gpm (12.6 dm<sup>3</sup>/s) and a kinematic viscosity of 0.37 cSt (0.37 mm<sup>2</sup>/s),  $\Delta P/L$  is 3.7 psi/100 ft (0.84 kPa/m).

The friction pressure drop in [Section II](#) is therefore:

$$\Delta P = \left( \frac{156}{100} \right) (3.7) (0.802) = 4.63 \text{ psi} \quad (\text{Customary})$$

$$\Delta P = (417.6) (0.84) (0.802) = 32.0 \text{ kPa} \quad (\text{Metric})$$

Generally, [Eq. \(5\)](#) will give more precise answers than [Figure 3A](#) or [3B](#) and is the recommended method.

### **Section III**

**Step 2** - Pipe is round. From [Section XIV-A, Table 1](#): Inside diameter of 4-in. (100 mm) Pipe = 4.026 in. (102.3 mm).

Since [Section III](#) does not contain any fittings, Steps 3 through 5 may be omitted.

**Step 6** - Length of [Section III](#):  $L = 10 \text{ ft}$  (3.05 m)

Use [Eq. \(3b\)](#) to calculate the Reynolds number in [Section III](#):

$$Re = \frac{50.6 Q \rho}{d \mu} = \frac{(50.6)(200)(50)}{(4.026)(0.30)} = 420,000 \text{ (rounded)} \quad (\text{Customary})$$

$$Re = \frac{1.27 Q \rho}{d \mu} = \frac{(1.27)(12.6)(800)}{(102.3)(0.3 \times 10^{-3})} = 420,000 \text{ (rounded)} \quad (\text{Metric})$$

From [Figure 2](#): Friction factor,  $f = 0.0044$

Use [Eq. \(5c\)](#) to calculate the frictional pressure drop:

$$(\Delta P)_f = \frac{(8.63 \times 10^{-4})(0.0044)(10)(200)^2(50)}{(4.026)^5} = 0.072 \text{ psi} \quad (\text{Customary})$$

$$(\Delta P)_f = \frac{(3.24 \times 10^{-4})(0.0044)(3.05)(12.6)^2(800)}{(102.3)^5} = 0.49 \text{ kPa} \quad (\text{Metric})$$

|                  |                  |                                                           |                                                   |
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Alternatively, from [Figure 3A](#) or [3B](#), at a flow rate of 200 gpm (12.6 dm<sup>3</sup>/s) and a kinematic viscosity of 0.37 cSt (0.37 mm<sup>2</sup>/s),  $\Delta P/L$  is 0.9 psi/100 ft (0.20 kPa/m).

The friction pressure drop in [Section III](#) is therefore:

$$\Delta P = \left( \frac{10}{100} \right) (0.9) (0.802) = 0.07 \text{ psi} \quad (\text{Customary})$$

$$= (3.05) (0.20) (0.802) = 0.49 \text{ kPa} \quad (\text{Metric})$$

**Step 7** - Assume that the diameter of the vessel is very large compared to the pipe diameter.

[Eq. \(11c\)](#) now gives the overall pressure change due to change in kinetic energy from the liquid surface in the vessel to the outlet of the 4-in. (100 mm) pipe:

$$(\Delta P)_k = (1.8 \times 10^{-5}) \rho Q^2 \left( \frac{1}{d_2^4} - \frac{1}{d_1^4} \right) \quad (\text{Customary})$$

$$= (1.8 \times 10^{-5}) (50) (200)^2 \left( \frac{1}{(4.026)^4} - 0 \right) = 0.14 \text{ psi} \quad (\text{Customary})$$

$$(\Delta P)_k = 810 \rho Q^2 \left( \frac{1}{d_2^4} - \frac{1}{d_1^4} \right) \quad (\text{Metric})$$

$$= 810 (800) (12.6)^2 \left( \frac{1}{(102.3)^4} - 0 \right) = 0.94 \text{ kPa} \quad (\text{Metric})$$

**Step 8** - The pressure change due to change in elevation is given by [Eq. \(6b\)](#) taken from the liquid surface in the vessel to the outlet of the 4-in. (100 mm) pipe:

$$(\Delta P)_e = 6.94 \times 10^{-3} \rho (z_2 - z_1) \quad (\text{Customary})$$

$$= (6.94 \times 10^{-3}) (50) (0 - 20) = -6.9 \text{ psi} \quad (\text{Customary})$$

$$= 9.81 \times 10^{-3} \rho (z_2 - z_1) \quad (\text{Metric})$$

$$= 9.81 \times 10^{-3} (800) (0 - 6.1) = -47.9 \text{ kPa} \quad (\text{Metric})$$

**Step 9** - The total pressure drop can be calculated with [Eq. \(18\)](#):

$$(\Delta P)_t = \Sigma (\Delta P)_f + (\Delta P)_k + (\Delta P)_e$$

$$(\Delta P)_t = (0 + 4.56 + 0.072) + 0.14 - 6.9 = -2.13 \text{ psi} \quad (\text{Customary})$$

$$(\Delta P)_t = (0 + 31.4 + 0.49) + 0.94 - 47.9 = -15.1 \text{ kPa} \quad (\text{Metric})$$

Therefore, the suction pressure of the pump is:

$$50 - (\Delta P)_t = 50 - (-2.13) = 52.1 \text{ psig} \quad (\text{Customary})$$

$$345 - (\Delta P)_t = 345 - (-15.1) = 360 \text{ kPa gage} \quad (\text{Metric})$$

**Answer: P = 52.1 psig (360 kPa gage)**