

PIPE-FLO Stock

User's Manual & Method of Solution



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INTRODUCTION

PIPE-FLO Stock Overview

PIPE-FLO Stock is a comprehensive piping design and analysis software package that provides you with a clear picture of the entire system. Using PIPE-FLO Stock you can:

- Draw a piping system schematic on the FLO-Sheet showing all the pumps, components, tanks, control valves and interconnecting pipelines.
- Calculate systems containing a wide variety of paper stock slurries — up to 6% concentration.
- Size the individual pipelines using electronic pipe and valve data tables.
- Select pumps and control valves from manufacturers' electronic catalogs, optimizing pump and system operation.
- Calculate how the system operates including pressures, flow rates, and net positive suction head available (NPSHa).
- Calculate the annual operating costs for pumps in the system.
- Create FLO-Links to provide immediate access to supporting documents needed to design, build, and operate the piping system.

New this version

- Isometric drawings – Draw or display pipeline diagrams in the new isometric grid mode, complete with rotatable text and symbols.
- Customized shapes – Create your own symbols for tanks, pumps, control valves, and other components.
- Copy & paste improvements – Copy all or part of a system from one project file to another.
- AutoCalc – See calculated changes in your piping system as you make them. No more repeated toggling between calculation and drawing modes.

- Link to Microsoft® Excel – Setup a two-way data exchange with Microsoft® Excel spreadsheets using the new XLink tool.
- Customized results – Alter piping schematic and fly-by viewer text to show only the items you want to see.

Getting Started

Installation

PIPE-FLO Stock comes in both stand alone and network versions. Standalone versions are installed in the standard manner (insert the CD and run Setup.exe), but include a hardware key that must be attached to the computer before PIPE-FLO Stock will run properly. Instead of a hardware key, network versions include special licensing software and setup options. Please consult the network.pdf document on the root of the installation CD for detailed information about configuring and administering PIPE-FLO Stock network packages.

Learning to use the software

Learning new software can be a daunting experience. To speed up the process, PIPE-FLO Stock includes a comprehensive tutorial accessible directly from the program's startup screen. Simply launch the software, click the Software Tutorial button and choose either the Metric or US unit-based tutorial.

The tutorial is designed to walk users through all aspects of the software as quickly as possible by demonstrating, step by step, the process of building a piping system..

Using Program Help

PIPE-FLO Stock's help system has been designed to answer the most common types of questions as they arise. Help may be accessed in the following ways:

- When viewing any dialog box, click its Help button to bring up a description of the dialog and its choices.
- At any time, pressing the **F1** key, clicking the Help (question mark) button on the toolbar, or selecting **Contents** or **Index** items from the program's Help menu will bring up the full Help file.
- From within the Help interface you may use the **Contents** tab to browse the help file by category, use the **Index** tab to browse for specific topic items by name, or use the **Search** tab to look for any help topics that contain specific key words.
- The Help interface's **Glossary** tab lists and defines many of the technical terms that are used throughout the software.
- Many Help topics also contain a **Related Topics** button. This button cross-references other topics which are related to the topic you are currently viewing.

Technical Support

The purchase or upgrade of your PIPE-FLO Stock software includes one year of Engineered Software's TechNet technical support service. This service includes:

- All program upgrades
- Web-based software training
- Discounts on FLO-Master training classes
- Unlimited access to Engineered Software's online knowledge base (www.eng-software.com/kb) and other web-based support services
- Email and telephone support for installation and program troubleshooting issues
- Email and telephone support from Engineered Software's engineering staff for questions about your own piping system models

Limited support for issues with program operation and access to the online knowledge base are still available after your TechNet subscription expires. For information on renewing a lapsed TechNet subscription, please call our sales department at 800-786-8545.

Contacting Engineered Software

When you can't find the answers to your questions in PIPE-FLO Stock's Online Help or in Engineered Software's knowledge base (www.eng-software.com/kb), you can contact our technical support in one of the following ways:

- By e-mail at **solutions@eng-software.com**
- By phone at 360-292-4060
- By fax at 360-412-0672

When contacting us, you should include the following information:

- Your name
- Company name
- Program serial number
- Program version number
- Your phone number, fax number, and e-mail address
- A detailed description of your question or problem

PIPING SYSTEM ANALYSIS

Introduction

This section of the reference book describes the engineering methods used and the assumptions made by the PIPE-FLO Stock program. The calculations associated with system elements, such as pipes, pumps, components, and controls, is discussed, along with the methodology applied in performing the piping system calculations.

Fluids

PIPE-FLO Stock has two types of fluids to choose from: pulp/water suspension (paper stock) or water only. The consistency of stock is the percent (by weight) of pulp in the mixture. For paper stock, the following definitions apply:

- Oven Dry (O.D.) consistency is the amount of pulp left in a sample after drying in an oven at 212 °F (100 °C) or higher.
- Air Dry (A.D.) consistency is the amount of pulp left in a sample after drying in atmosphere. Air Dry stock contains 10% more moisture than Oven Dry stock.

Friction Loss of Pulp Suspensions In Pipe

PIPE-FLO Stock calculates the friction losses and pressures within paper stock piping systems using the method outlined in the TAPPI Technical Information Sheet (TIS) 410-14. The friction loss curve for paper stock is complex and non-linear and can be affected by many factors. To determine pipeline friction loss, PIPE-FLO Stock follows the analytical method outlined in Reference 1. This method is applicable to oven-dried stock consistencies from 2 to 6 percent. In most cases, oven-dried stock consistencies of less than 2% are considered to have the friction loss characteristic of water.

Figure 1 below shows typical friction loss curves of two different chemical pulp consistencies ($C_2 > C_1$).

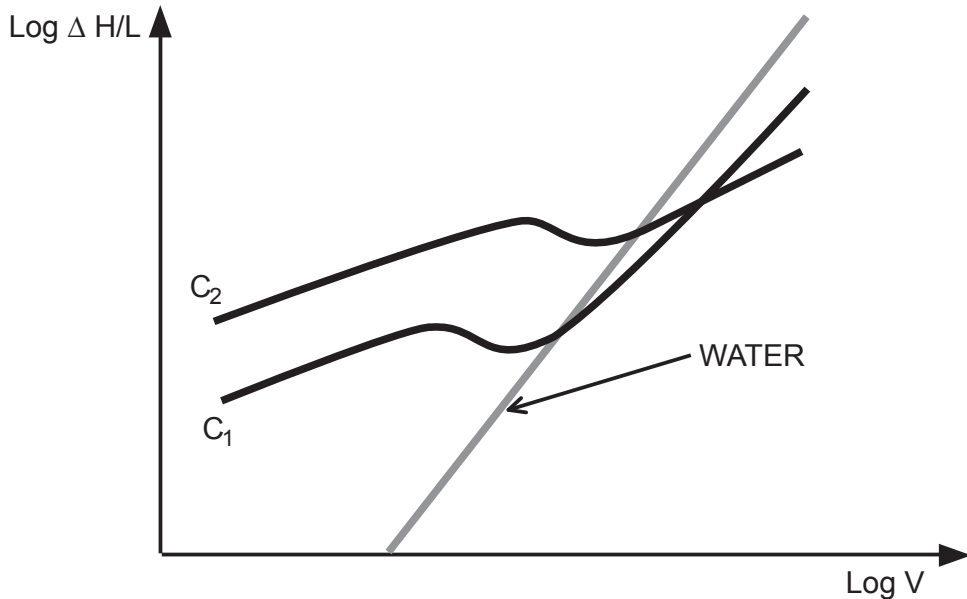


Figure 1 Chemical Pulp

Figure 2 shows the same curves for a mechanical pulp.

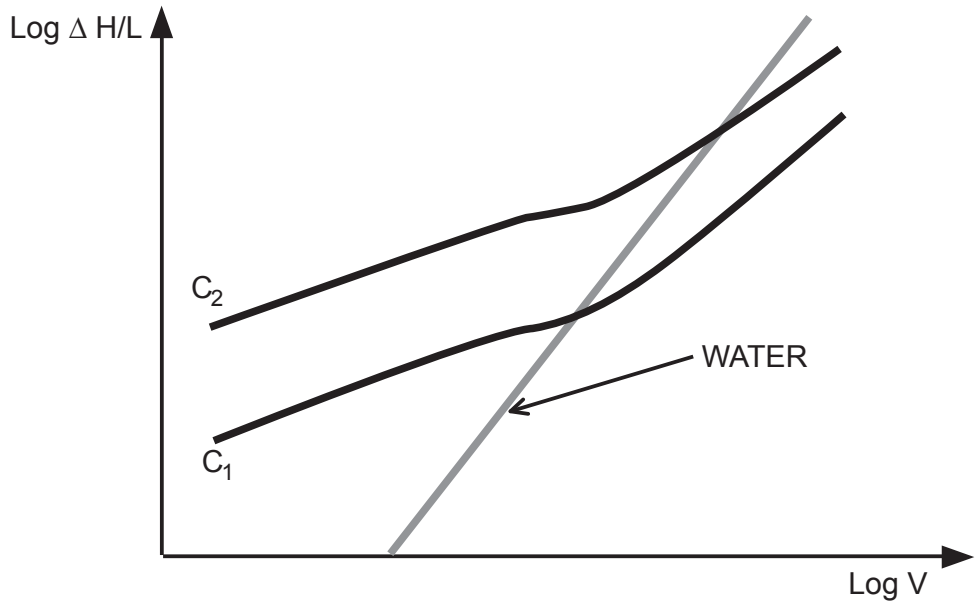


Figure 2 Mechanical Pulp

The friction loss curve for water is superimposed over the top of the pulp friction loss curves in both Figure 1 and Figure 2.

For a chemical pulp, the friction loss curve is divided into three regions, shown below in Figure 3.

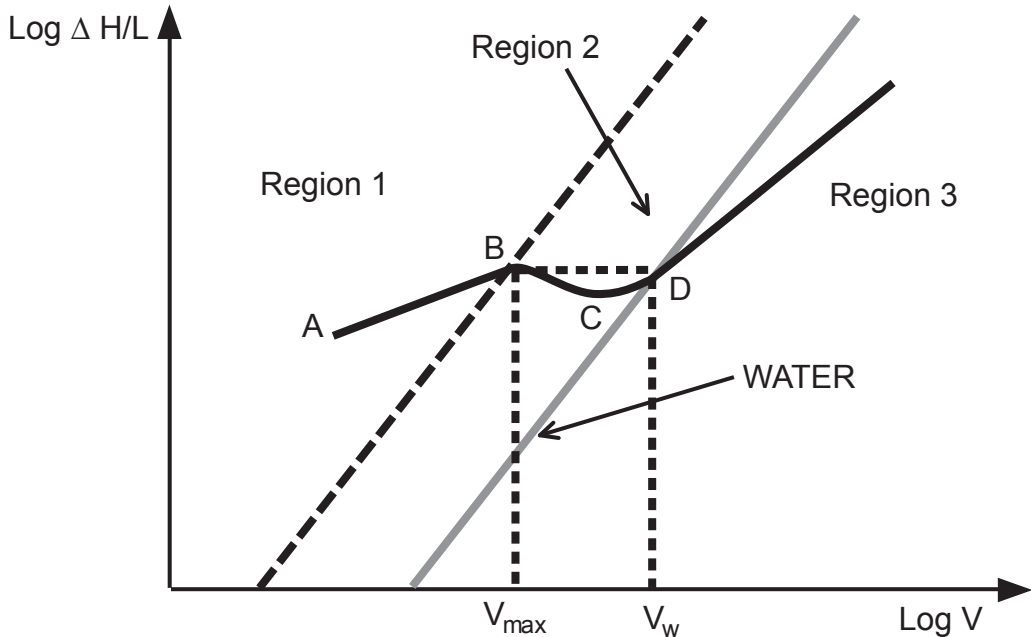


Figure 3

A description of these regions is listed below:

- Region 1** The linear region of the curve (labeled AB in Figure 3) in which the friction loss for a given pulp is a function of consistency, velocity, and pipe diameter. The velocity at the upper limit of this linear region is designated V_{max} .
- Region 2** The region in which there is an initial decrease in friction loss followed by an increase (labeled BCD in Figure 3). The intersection of the pulp friction loss curve and the water friction loss curve (point D) is termed the onset of drag reduction. The velocity at this point is designated V_w .

Region 3 This region is separated from Region 2 by the friction loss curve for water. The friction loss curve for pulp suspensions in this region (labeled DE in Figure 3) is below water curve. This is due to a phenomenon called drag reduction.

The friction loss curve for a mechanical pulp only has Regions 1 and 3, see Figure 4 below.

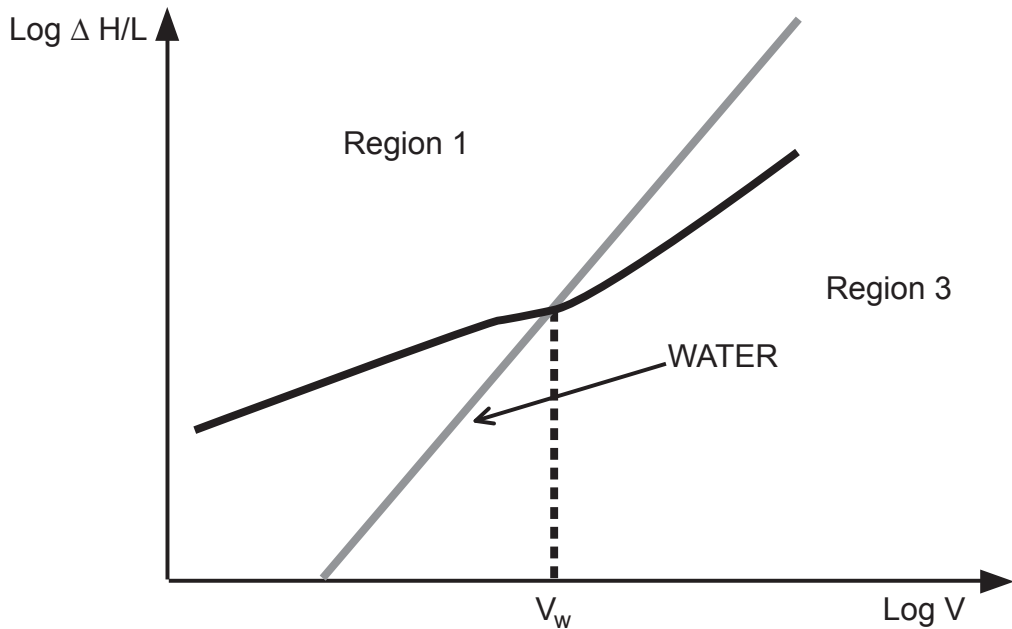


Figure 4

For this pulp type, the friction loss curve crosses the water curve at V_w and there is no true V_{max} .

Calculating the Pressure Drop

To calculate the friction losses in a stock piping system, the bulk velocity must be determined for each pipeline.

The bulk velocity is calculated as follows:

$$V = 1273200Q/D^2$$

equation 1

V = bulk velocity (m/s)

Q = flow rate (m³/s)

D = pipe inside diameter (mm)

The bulk velocity will fall into one of the three regions discussed above. Once it has been determined in which region the design velocity occurs, the appropriate equations for calculating the pipe friction loss may be selected. The equations for each region are listed below.

Region 1

The upper limit of Region 1 is designated V_{max} (see point B in Figure 3). The value of V_{max} is determined as follows:

$$V_{\max} = K' C^{\sigma}$$

equation 2

V_{max} = maximum velocity (m/s)

K' = numeric coefficient (constant for a given pulp)

C = consistency (oven-dried, expressed as a percentage, *not* decimally)

σ = exponent (constant for a given pulp)

If the numeric constant K' is entered in US units, PIPE-FLO Stock converts it to metric units using the following equation:

$$K_m' = (0.305)K_u'$$

equation 3

K_m' = numerical coefficient, metric units

K_u' = numerical coefficient, US units

If the proposed design velocity is less than V_{max} , the friction loss ($\Delta H/L$) is calculated as follows:

$$\Delta H/L = F K V^\alpha C^\beta D^\gamma$$

equation 4

$\Delta H/L$ = friction loss (m/100 m)

F = factor to correct for temperature, pipe roughness, pulp type, freeness, or safety factor (see discussion below)

K = numerical coefficient (constant for a given pulp)

V = bulk velocity (m/s)

C = consistency (oven-dried, expressed as a percentage, *not* decimally)

D = pipe inside diameter (mm)

α, β, γ = exponents (constant for a given pulp)

If the numeric constant K is entered in US units, PIPE-FLO Stock converts it to metric units using the following equation:

$$K_m = K_u(1/0.3048)^6 (0.03937)^7$$

equation 5

K_m = numerical coefficient, metric units

K_u = numerical coefficient, US units

Region 2

The lower limit of Region 2 is V_{max} (point B in Figure 3) and the upper limit is V_w (point D in Figure 3), the onset of drag reduction. The value of V_w is determined as follows:

$$V_w = 1.22 C^{1.40}$$

equation 6

V_w = bulk velocity at the onset of drag reduction (m/s)

C = consistency (oven-dried, expressed as a percentage, *not* decimally)

If the velocity is between V_{max} and V_w , the friction loss may be calculated using equation 4 with V_{max} substituted for the velocity. This provides a conservative approximation for the friction loss in Region 2 (refer to Figure 3).

Region 3

For bulk velocities greater than V_w , the friction loss is conservatively calculated using the water curve (see Figure 3). There are two different methods available in PIPE-FLO Stock for the water curve calculations. The first method uses the Blasius equation:

$$(\Delta H/L)_w = 264V^{1.75} D^{-1.25}$$

equation 7

$(\Delta H/L)_w$ = friction loss (m/100m)

V = bulk velocity (m/s)

D = pipe inside diameter (mm)

The second method uses the Darcy-Weisbach equation to calculate the pressure drop in a pipeline. This method is discussed in more detail below.

Determination of Correction Factor, F

The correction factor used in equation 4 is calculated as follows:

$$F = F1 * F2 * F3 * F4 * F5$$

equation 8

Each component of the correction factor is described below.

F1 Temperature correction factor. Friction loss calculations are based on a reference pulp temperature of 35 °C. The friction loss may be increased or decreased by 1 percent for each 1 °C below or above 35 °C as follows:

$$F1 = 1.35 - 0.01 T (\text{°C}).$$

- F2** Pipe roughness correction factor. This factor varies due to manufacturing processes of the piping, surface roughness, age, etc. Typical values for PVC and stainless steel piping are:
- F2 = 1.0 for PVC pipe
- F2 = 1.25 for stainless steel pipe
- F3** Pulp type correction factor. Typical values are:
- F3 = 1.0 for pulps that have never been dried and reslurried
- F3 = 0.8 for pulps that have been dried and reslurried
- This factor may be incorporated in the numerical coefficient, K. If it is, a factor of one should be used for F3.
- F4** Correction factor for beating. In PIPE-FLO Stock, this factor is called Freeness. Freeness is used to indicate the degree of refining or to define the pulp for comparison purposes.
- F5** Safety factor.

Note that if the correction factor F is greater than one, the intersection of the pulp friction loss curve and the water curve occurs to the right of V_w . See Figure 5.

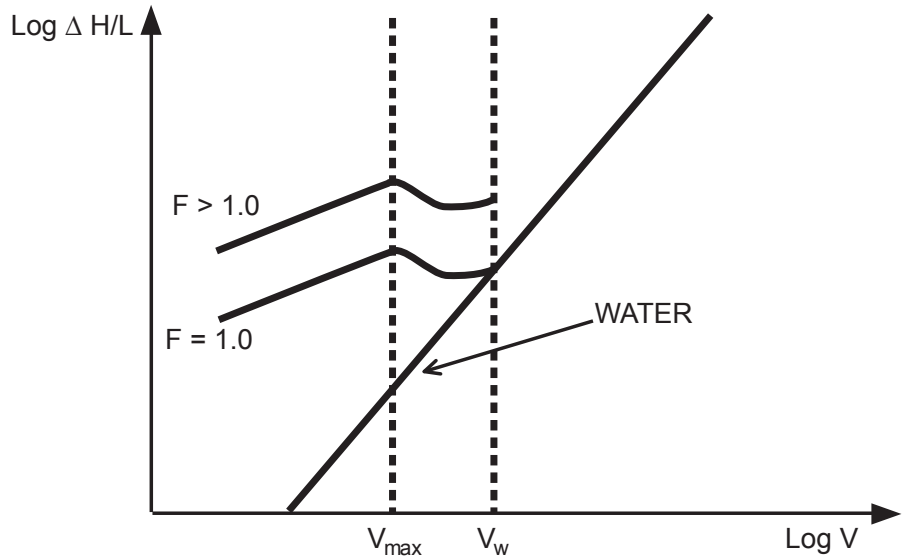


Figure 5

As can be seen in the case illustrated above, for velocities greater than V_w , using the water equation to calculate the friction loss results in a value lower than the friction loss at V_{max} . A similar situation arises if a correction factor of less than one is used, since the pulp friction loss equation would then move downward, and the actual intersection of the two curves would occur at a point prior to V_w .

PIPE-FLO Stock handles the situation described above in the following way: First, it is determined whether or not the bulk velocity is above or below V_{max} . If it is below, the friction loss is calculated with the bulk velocity substituted into equation 4 (the pulp friction loss equation). If the bulk velocity is above V_{max} , the program calculates the friction loss using both the pulp friction loss equation (equation 4) with V_{max} and the water equation with the bulk velocity. Whichever equation yields the larger friction loss is selected as the proper solution, without attempting to determine V_w . This ensures that the calculated friction loss for velocities above V_{max} is always at or above the friction loss for V_{max} .

Since there is no true V_{max} for mechanical pulps (see Figure 4), the program calculates the friction loss using equation 4 (with the bulk velocity) and also using the water equation. The friction loss is then the greater of these two.

Valve and Fitting Losses

In all three regions, the friction loss due to valves and fittings is added to the pulp friction loss and is computed using the equation shown below:

$$HL = KV^2/2g$$

equation 9

HL = friction loss due to valves and fittings (m)

K = loss coefficient for a given valve or fitting

V = bulk velocity (m/s)

g = acceleration due to gravity (9.81 m/s²)

Generally, the loss coefficient for pulp suspensions in a given valve or fitting exceeds the loss coefficient for water in the same bend or fitting. To account for this increased loss, PIPE-FLO Stock increases the K value for a valve or fitting by 20 percent for each 1 percent increase in oven-dried stock consistency over 2%.

The calculation of the loss coefficient for valves and fittings (K) is discussed below.

The Darcy-Weisbach Equation

The flow of fluids is greatly influenced by the viscous nature of the fluid. The viscosity of a fluid introduces shear forces between fluid particles as well as between the boundary walls and the fluid particles. The energy which is expended to overcome the fluid shear forces is converted into heat. This conversion of fluid energy to heat results in a fluid pressure drop.

When the fluid shear stress is entered into the Euler equation for ideal flow, the result is a partial differential equation for which no general solution is known (Refer to a fluid dynamics textbook for this exercise). This requires engineers to rely on empirical formulas derived from experimental observations for the solution of fluid dynamics problems.

PIPE-FLO Stock gives users the option of using the Darcy-Weisbach equation for the water curve. This method takes into account fluid viscosity and pipe roughness. The Darcy-Weisbach equation is as follows:

$$dP = \rho f(L/D)v^2/2g$$

equation 10

dP = pressure drop
 ρ = fluid density
 f = Darcy friction factor
 L = length of pipe
 D = pipe diameter
 v = mean fluid velocity
 g = gravitational constant

Often, the Darcy-Weisbach is equation expressed in the following way:

$$dP = K\rho v^2/2g \quad \text{where } K = f(L/D)$$

equation 11

The K in the above equation is the total resistance coefficient for the pipeline. This “total K” is a combination of the K value for the pipe and the K value for the valves and fittings in the pipeline. Therefore, the pipeline pressure drop calculated is a combination of the pressure drop due to the pipe and valves.

The only factor in the Darcy-Weisbach equation that is not readily available is the unitless Darcy friction factor, f. Friction factor values have been arrived at by experimentation and empirical formulas have been developed to accurately predict the friction factor under a wide range of fluid conditions.

Determining the Pipe Friction Factor

For both laminar and non-laminar flow, the friction factor is a function of the Reynolds number. The Reynolds number is a dimensionless parameter which describes the characteristics of the fluid flowing in the piping system.

Reynolds developed the following relationship:

$$Re = 354W/(d\mu)$$

equation 12

W = flow rate, kg/hr

d = pipe diameter, mm

μ = fluid dynamic viscosity, centipoise

It was determined that for Newtonian fluids with a Reynolds number below a specific value, the fluid particles move in slip streams or laminar layers. Above a critical value of Reynolds number, the motion of the fluid particles becomes random or turbulent.

For engineering calculations, the upper practical limit of laminar flow has been set at a Reynolds number of $Re = 2100$. Above the laminar flow region, the flow starts to become turbulent. As the Reynolds number of the system increases, the flow becomes more turbulent, until the motion of the fluid particles is completely turbulent. The range between laminar flow and fully turbulent flow is referred to as the transition region.

The friction factor for laminar flow is dependent only on the Reynolds number and is expressed by the following relationship:

$$f = 64/Re$$

equation 13

If PIPE-FLO Stock calculates a Reynolds number less than 2100, it uses equation 13 to determine the friction factor when performing pressure drop calculations.

A word of caution: when determining pressure drop around the critical Reynolds number of 2100, the flow may shift from laminar to turbulent depending on the piping system. For this reason, a pipeline should not be designed close to the critical Reynolds number.

The friction factor calculation in the transition and turbulent range is more complex. It is a function of the Reynolds number and the ratio of the pipe material surface roughness to the pipe inside diameter.

Nikuradse performed a series of experiments in order to develop a relationship between the friction factor and Reynolds number in pipes with turbulent flow. The value of material surface roughness was arrived at by coating the interior of a smooth pipe with uniform grains of sand. The results of his experimentation presented some valuable relationships. He made the following discoveries:

- 1 At high Reynolds numbers the pipe friction factor becomes constant.
- 2 For rough pipes the ratio of surface material roughness to pipe diameter, or relative roughness, is more important than the Reynolds number for determining the friction factor.

Since Nikuradse used pipes with an artificial roughness applied, his friction factor values had little direct application for engineering materials. C. F. Colebrook experimented with commercial pipes of various materials and roughness and developed the following equation for pipes in the transition region to the complete turbulence zone:

$$1/(f^{1/2}) = -0.869\ln[(e/D)/3.7 + 2.523/(R_e f^{1/2})]$$

equation 14

Since this relationship has the friction factor term on both sides of the equation, it must be solved by iteration.

Iterative equations are easily solved by computer, but they take longer to solve than a straightforward relationship. For this reason, PIPE-FLO Stock uses an equation from Reference 6 that provides a direct calculation of the friction factor and is within 1% of the Colebrook equation:

$$f = 1.325/[\ln(e/(3.7D) + 5.74/R_e^{0.9})]^2$$

equation 15

PIPE-FLO Stock uses equation 15 to calculate the friction factor in pipelines with Reynolds numbers greater than 2100. This equation gives accurate values of the friction factor and can be solved quickly without performing iterative calculations.

Valves and Fittings

In order to include valves and fittings in the calculation of the pipeline pressure drop, a K value must be computed for each valve and fitting. Valve manufacturers have performed experiments on various valves and fittings in order to arrive at empirical pressure drop expressions for specific types of piping system components. The relationship between the K value and pipe length is as follows:

$$K = f_T(1000L/d)$$

equation 16

f_T = turbulent friction factor

L = length, m

d = pipe diameter, mm

As mentioned above, the K value for various fittings has been arrived at through experimentation. For any valve, a length over diameter (L/D) coefficient can be determined by equating the pressure drop through the valve to the equivalent length of pipe measured in pipe diameters. When the (L/D) coefficient is multiplied by the turbulent friction factor for clean commercial steel pipe at various diameters, the K value for the valve is determined. To determine the turbulent friction factor, PIPE-FLO Stock uses the following equation from Nikuradse:

$$f_T = 8[2.457\ln(3.707d/e)]^2$$

equation 17

There are some resistances to flow in piping systems that are independent of the friction factor. These resistances are determined only by the change in fluid velocity and the change in direction of flow. Losses associated with changes in pipe diameter (both gradual and abrupt) or pipeline entrances or exits fall into this category.

Differential Pressure Calculator

In some cases, it may be necessary to insert a resistance in the pipeline to restrict the flow to a certain value at a given pressure drop. The dP Calculator feature of PIPE-FLO Stock calculates the K value needed to achieve a differential pressure for a specified flow rate. The K value is calculated using the following formula:

$$K = 1.59923\Delta P d^4 \rho / W^2$$

equation 18

The inside diameter is used when calculating a K value with equations 18 and 19. If you later change the pipe diameter, you should reinstall the K value.

ΔP = Change in pressure, bars
 d = Pipe diameter, mm
 ρ = fluid density kg/m³
 W = Mass flow rate, kg/hr

Cv Values

Many valve manufacturers express the pressure drop characteristics of their valves using a flow coefficient (Cv) rather than a K value. By definition, Cv is the number of gallons per minute of 60°F water which will pass through a valve with a fixed pressure drop of 1 psi.

When users specify a Cv value for a pipeline, PIPE-FLO Stock calculates the K value using the following correlation:

$$K \cong 891d^4 / C_v^2$$

equation 19

*Users can also specify a Kv value for a pipeline. Kv is related to Cv by the following conversion factor:
 $K_v = 0.86477 * C_v$*

d = inside pipe diameter, inches

Reducers

A change in fitting diameter causes a pressure loss due to the change in velocity of the fluid as it passes through the fitting. The pressure drop is also dependent on the rate at which the change of direction in the fitting occurs.

For example, a 12x6 reducer with a 12 inch approach length has a smaller pressure drop than a 12x6 reducer with a 6 inch approach length. This holds true when the flow in the reducer is either contracting or expanding.

The equations used by PIPE-FLO Stock to calculate reducer K values are listed below. Notice that these equations vary with the angle of approach, which is determined from the approach length specified by the user (see Figure 6 below).

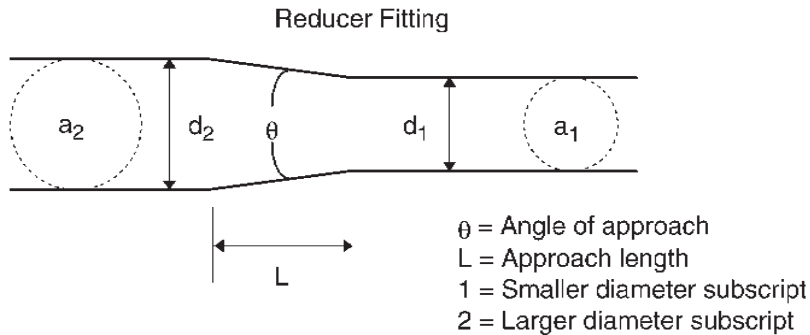


Figure 6

For an enlargement, the direction of flow in Figure 6 is from the smaller diameter (d_1) to the larger diameter (d_2). For a contraction, the direction of flow is from the larger diameter (d_2) to the smaller diameter (d_1).

Reducer Contraction

$$K_1 = 0.8\sin(\theta/2)(1-\beta^2) \quad (\theta \leq 45^\circ)$$

equation 20a

$$K_1 = \frac{1}{2}(1-\beta^2)(\sin(\theta/2))^{1/2} \quad (45^\circ < \theta \leq 180^\circ)$$

equation 20b

Reducer Enlargement

$$K_1 = 2.6\sin(\theta/2)(1-\beta^2)^2 \quad (\theta \leq 45^\circ)$$

equation 21a

$$K_1 = (1-\beta^2)^2 \quad (45^\circ < \theta \leq 180^\circ)$$

equation 21b

θ = Angle of approach

β = $d_{\text{minor}} / d_{\text{major}}$

Reduced Seated Valves and Fittings

Reduced seated valves are broken down into three sections: the reducer (contraction) section, the valve section, and the enlarger section (see Figure 7 below). A K value is determined for each section in relation to the size of the valve in the pipeline.

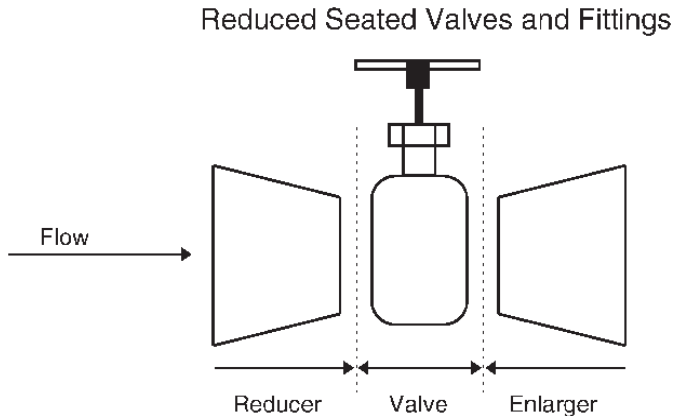


Figure 7

The total K value for the valve consists of K values for the reducer, the valve section, and the enlarger. Since the K value for the valve section is dependent on the valve seat diameter instead of the pipeline diameter, it must be adjusted by a correction factor to determine the correct K value for the diameter of the pipe. The valve correction factor is the ratio of valve seat diameter divided by pipeline diameter (often called beta) raised to the fourth power.

The total K for the reduced seat valve is:

$$K_2 = K_{\text{Reducer}} + K_1/\beta^4 + K_{\text{Enlarger}}$$

equation 22

K_2 = K value of the total valve

K_1 = K value of reduced seat

K_{Reducer} = K value of reducer

K_{Enlarger} = K value of enlarger

$\beta = d_{\text{valve}}/d_{\text{pipe}}$

PIPE-FLO Stock Valve Table Formulas

PIPE-FLO Stock uses the method outlined in the Crane Technical Paper 410 when calculating the K values for valves and fittings. PIPE-FLO Stock's standard and specialty valve tables are set up such that each valve and fitting type references a predefined K value formula. Below is a listing of these formulas, the types of valves or fittings they support, and the input information PIPE-FLO Stock requires from the user when defining the valve.

Formula 1 - Pipe Contraction

Formula 1 is used to calculate the K value for pipe contractions. PIPE-FLO Stock determines which of the Formula 1 equations to use based on the reducer angle of approach (θ). For pipe contractions, the user must enter the reducer diameters and approach length in the Valve & Fitting dialog box. From this information, PIPE-FLO Stock selects the appropriate equation and calculates the K value.

$$K_1 = 0.8\sin(\theta/2)(1-\beta^2) \quad (\theta \leq 45^\circ)$$

$$K_1 = \frac{1}{2}(1-\beta^2)(\sin(\theta/2))^{1/2} \quad (45^\circ < \theta \leq 180^\circ)$$

Formula 1

Formula 3 - Pipe Enlargement

Formula 3 is used to calculate the K value for pipe enlargements. PIPE-FLO Stock determines which of the Formula 3 equations to use based on the reducer angle of approach (θ). For pipe enlargements, the user must enter the reducer diameters and approach length in the Valve & Fitting dialog box. From this information, PIPE-FLO Stock selects the appropriate equation and calculates the K value.

$$K_1 = 2.6\sin(\theta/2)(1-\beta^2)^2 \quad (\theta \leq 45^\circ)$$

$$K_1 = (1-\beta^2)^2 \quad (45^\circ < \theta \leq 180^\circ)$$

Formula 3

Formula 5 - Reduced Seat Valve, Gradual Change in Diameter

Formula 5 is used to calculate the K value for reduced seated valves with a gradual change in diameter. Examples of valves which use Formula 5 are ball and gate valves. Formula 5 is a combination of Formulas 1 and 3 (discussed above) and the K value of the reduced seat valve type. For each supported valve or fitting, a full seat L/D coefficient is stored in the valve table. PIPE-FLO Stock determines the angle of approach from the reduced seat diameter and the approach length specified by the user in the Valve & Fitting dialog box. If a reduced seat and approach length are not specified, the program assumes that the valve is full seated.

$$K_2 = K_{\text{Reducer}} + K_1/\beta^4 + K_{\text{Enlarger}}$$

Formula 5

Formula 7 - Reduced Seat Valve, Abrupt Change in Diameter

Formula 7 is used to calculate the K value for reduced seated valves with an abrupt change in diameter. Examples of valves using Formula 7 are globe, angle, lift check, and stop check valves. Formula 7 is a combination of Formulas 1 and 3 (with the angle of approach set to 180°) and the K value of the reduced seat valve type. A full seat L/D coefficient is stored in the table for each supported valve or fitting. The user must specify the reduced seat diameter in the Valve and Fitting dialog box. If a reduced seat is not specified, the program assumes that the valve is full seated.

$$K_2 = K_{\text{Reducer}} + K_1/\beta^4 + K_{\text{Enlarger}}$$

Formula 7

Formula 8 - Elbows and Bends

Formula 8 is used to calculate the K value for elbows and bends. A coefficient is stored in the valve and fitting table for each r/d ratio. In the Valve & Fitting dialog box, the user must specify the angle of the elbow.

$$K_b = (n-1)(0.25\pi f_r(r/d) + 0.5K) + K$$

Formula 8

n = number of 90° bends

K = resistance coefficient for one 90° bend

Formula 9 - L/D Varies with Pipe Diameter

Formula 9 is used to calculate the K value for valves that have an L/D coefficient that varies with pipe diameter. L/D coefficients for a range of pipe diameters are stored in the valve table. Valves that fall into this category are butterfly valves and tilting disk check valves. PIPE-FLO Stock automatically selects the appropriate coefficient based on the pipe diameter the valve is installed in.

$$K = f_T (L/D)$$

Formula 9

Formula 10 - Full Seated Valves and Fittings

Formula 10 is used to calculate K values for valves and fittings that do not support reduced seated diameters. A full seat L/D coefficient is stored in the table for each supported valve or fitting. Valves and fittings which use Formula 10 include plug, foot, and swing check valves as well as tees and miter bends.

$$K = f_T (L/D)$$

Formula 10

Formula 11 - Fixed K Value

Formula 11 is used to enter a valve or fitting with a fixed K value. A K value is stored in the table for each supported valve or fitting. Examples of Formula 11 fittings are pipe entrances and exits.

Formula 12 - Fixed Cv Value

Formula 12 is used to enter a valve with a fixed Cv value. A Cv value is stored in the table for each supported valve. PIPE-FLO Stock calculates the K value for fixed Cv valves using equation 19.

Formula 13 - Cv Value Varies with Pipe Diameter

Formula 13 is used for valves that have a Cv value that varies with pipe diameter. Cv values for a range of pipe diameters are stored in the valve table. PIPE-FLO Stock automatically selects the appropriate coefficient based on the pipe diameter the valve is installed in and calculates the K value using equation 19.

A maximum of 100 size ranges can be specified for a Formula 13 valve.

Tanks

When installing a tank in PIPE-FLO Stock, users have the following options:

- Specifying a tank geometry. There are ten different geometries to choose from.
- Defining a custom tank by specifying the tank volume as a function of liquid level.
- Specifying an infinite geometry/no geometry. This is used to model “tanks” whose geometry is effectively infinite, such as a large reservoir, and for which the addition or removal of fluid would not change the level or volume of the tank. You can also use this option if you are not concerned about the tank geometry.

Each tank can have up to six connecting pipelines, which can penetrate the tank at varying heights. The height is referenced to the bottom of the tank.

Volume Equations

When a specific tank geometry is selected (or a custom tank defined), PIPE-FLO Stock calculates the tank volume for the specified liquid level. Conversely, using the Level Calculator feature, the program calculates a tank level given a specified volume. The equations below are obtained from References 7 and 8.

In the horizontal tank volume equations, the fluid cross-sectional area in the cylindrical section of the tank is calculated using equation 23:

$$A_f = R^2 \cos^{-1}[(R - h)/R] - (R - h)(2Rh - h^2)^{1/2}$$

equation 23

A_f = fluid cross-sectional area of fluid
 R = radius of the tank cylindrical section
 h = height of the fluid in the tank, measured from the lowest part of the tank to the fluid surface

The following variables are used in the horizontal tank equations below:

V_f = total fluid volume in the tank

A_f = fluid cross-sectional area of fluid

L = length of tank cylindrical section

a = distance tank heads extend beyond ($a > 0$) or into ($a < 0$) the tank cylindrical section

R = radius of the tank cylindrical section

h = height of the fluid in the tank, measured from the lowest part of the tank to the fluid surface

Horizontal Tank with Conical Heads

$0 \leq h < R$:

$$V_f = A_f L + (2aR^2/3)K$$

equation 24a

$h = R$:

$$V_f = A_f L + (2aR^2/3)\pi/2$$

equation 24b

$R < h \leq 2R$:

$$V_f = A_f L + (2aR^2/3)(\pi - K)$$

equation 24c

Where

$$K = \cos^{-1}(M) + M^3 + \cosh^{-1}(1/M) - 2M(1 - M^2)^{1/2}$$

$$M = |(R - h)/R|$$

Horizontal Tank with Ellipsoidal Heads

$$V_f = A_f L + \pi a h^2 [1 - (h/3R)]$$

equation 25

Horizontal Tank with Spherical Heads

$h = R, |a| \leq R:$

$$V_f = A_f L + (\pi a / 6)(3R^2 - a^2)$$

equation 26a

$h = D, |a| \leq R:$

$$V_f = A_f L + (\pi a / 3)(3R^2 - a^2)$$

equation 26b

$h = 0$ or $a = 0, R, -R:$

$$V_f = A_f L + \pi a h^2 [1 - (h/3R)]$$

equation 26c

$h \neq R, D; a = 0, R, -R; |a| \geq 0.01D:$

$$V_f = A_f L + (a/|a|) \{ (2r^3/3) [\cos^{-1}((R^2 - rw)/R(w - r)) + \cos^{-1}((R^2 + rw)/R(w + r)) - (z/r)(2 + (R/r)^2) \cos^{-1}(w/R)] - 2(wr^2 - w^3/3) \tan^{-1}(y/z) + 4wyz/3 \}$$

equation 26d

$h \neq R, D; a = 0, R, -R; |a| < 0.01D:$

$$V_f = A_f L + (a/|a|) \{ 2 \int_w^R (r^2 - x^2) \tan^{-1}[(r^2 - x^2)/(r^2 - R^2)] dx - A_f z \}$$

equation 26e

Where

$$r = (a^2 + R^2)/(2|a|), a \neq 0$$

$$a = \pm (r - [(r^2 - R^2)^{1/2}]), +(-) \text{ for convex (concave) heads}$$

$$w = R - h$$

$$y = (2Rh - h^2)^{1/2}$$

$$z = (r^2 - R^2)^{1/2}$$

Horizontal Tank with Flat Heads

$$V_f = A_f L$$

equation 27

The following variables are used in the vertical tank equations below:

V_f = total fluid volume in the tank

a = distance tank heads extend beyond ($a > 0$) or into ($a < 0$) the tank cylindrical section

D = diameter of the tank cylindrical section

h = height of the fluid in the tank, measured from the lowest part of the tank to the fluid surface

Vertical Tank with Conical Bottom (Convex)

$h < a$:

$$V_f = (\pi/4)(Dh/a)^2(h/3)$$

equation 28a

$h \geq a$:

$$V_f = (\pi D^2/4)(h - 2a/3)$$

equation 28b

Vertical Tank with Conical Bottom (Concave)

$0 \leq h < |a|$:

$$V_f = (\pi D^2/12)[3h + a - (a + h)^3/a^2]$$

equation 29a

$h \geq |a|$:

$$V_f = (\pi D^2/12)(3h + a)$$

equation 29b

Vertical Tank with Ellipsoidal Bottom (Convex)

$h < a$:

$$V_f = (\pi/4)(Dh/a)^2(a - h/3)$$

equation 30a

$h \geq a$:

$$V_f = (\pi D^2/4)(h - a/3)$$

equation 30b

Vertical Tank with Ellipsoidal Bottom (Concave)

$0 \leq h < |a|$:

$$V_f = (\pi D^2/12)[3h + 2a - (a + h)^3(2a - h)/a^2]$$

equation 31a

$h \geq a$:

$$V_f = (\pi D^2/12)(3h + 2a)$$

equation 31b

Vertical Tank with Spherical Bottom (Convex)

$h < a$; ($a \leq D/2$):

$$V_f = (\pi h^2/4)(2a + D^2/2a - 4h/3)$$

equation 32a

$h \geq a$; ($a \leq D/2$):

$$V_f = (\pi h^2/4)(2a^3/3 - aD^2/2 + hD^2)$$

equation 32b

Vertical Tank with Spherical Bottom (Concave)

$0 \leq h < |a|$:

$$V_f = (\pi/12)\{3D^2h + (a/2)(3D^2 + 4a^2) + (a + h)^3[4 - (3D^2 + 12a^2)/(2a(a + h))]\}$$

equation 33a

$h \geq a$:

$$V_f = (\pi/12)[3D^2h + (a/2)(3D^2 + 4a^2)]$$

equation 33b

Vertical Tank with Flat Bottom

$$V_f = \pi(D^2/4)h$$

equation 34

Rectangular Tank

$$V_f = XYh$$

equation 35

X, Y = cross-sectional dimensions
h = height of the fluid in the tank

Spherical Tank

$$V_f = (\pi/3)h^2(1.5D - h)$$

equation 36

D = tank diameter
h = height of the fluid in the tank

Custom Tank

To model a tank geometry that is not available in PIPE-FLO Stock, users can specify a custom tank. A custom tank is defined by specifying the tank volume as a function of the liquid level. Up to five sets of data points can be entered. PIPE-FLO Stock linearly interpolates between the specified level/volume data to calculate the volume at intermediate levels.

Pumps

When a pump is installed in the system, the energy or pressure rise due to the pump must be factored into the loop energy equations. A pump causes a head rise corresponding to the flow in the upstream pipeline. PIPE-FLO Stock models pumps using specific pump head curve data. In this way, the actual head vs. flow relationship for that pump can be used in the network calculations. A typical head curve for a centrifugal pump is shown in Figure 8.

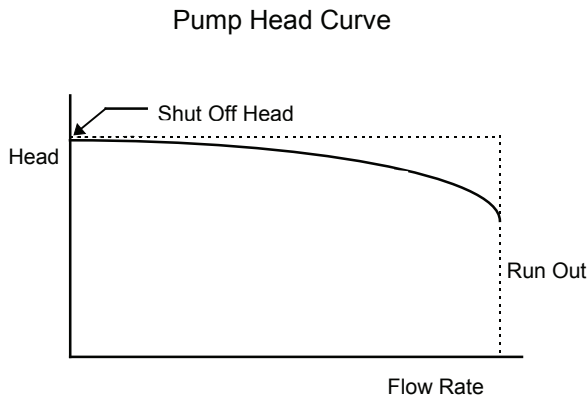


Figure 8

In addition to head data, users have the option of specifying efficiency and NSPHr (net positive suction head required) data. This data can also be imported into the piping model from a manufacturer's electronic catalog. When a system calculation is performed, PIPE-FLO Stock linearly interpolates between the specified pump curve data.

Speed Adjustments

If either a minimum or a maximum speed is specified for a pump, the pump speed can be adjusted. PIPE-FLO Stock performs this adjustment using the affinity laws. (See the Pump Selection section for a complete listing of these equations.) If variable speed operation is selected for a pump, PIPE-FLO Stock automatically calculates the speed required to achieve a user specified flow rate.

Diameter Adjustments

Impeller diameters can also be changed in increments as specified by the pump manufacturer. The impeller can only be adjusted between the maximum and minimum diameters. For manually entered pump curves, impellers are trimmed by 1/16" or 1 mm.

Preferred Operating Region

For each pump, a preferred operating region (expressed as a percentage of the best efficiency point flow rate) is specified. The default values are 70% and 120%. Users can change or delete these values if desired. If the calculated pump flow rate is outside of the preferred operating region, a warning is issued.

Minimum Flow and Range Errors

If a pump that has been imported from a manufacturer's catalog has a minimum flow specified, PIPE-FLO Stock compares the calculated flow rate to the minimum flow. If the calculated flow rate is below the minimum flow rate, a warning is issued.

If the calculated flow rate through the pump is beyond the data point range entered for the pump model, PIPE-FLO Stock provides notification that the pump exceeds runout. If the pump can still be used with an increased flow rate, the pump should be modeled again with an extended flow rate range and the system calculation rerun. If it is not possible to use the same pump with a higher flow rate, another pump should be selected and installed in the system. A warning is issued when this condition occurs.

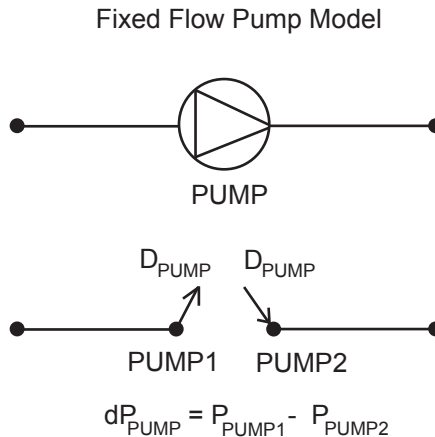
Running a Pump at a Fixed Flow Rate

Instead of entering performance curve data, the user can also specify a fixed flow rate and have PIPE-FLO Stock calculate the total head required for the pump.

The following points about fixed flow rate pumps should be noted:

- When a fixed flow rate is specified for a pump, the performance curve data (if specified) is overridden.
- PIPE-FLO Stock models a fixed flow pump by creating two nodes in the system where the pump is installed (refer to Figure 9). A flow demand value equal to the set flow rate is taken out of the first pump node (the suction node) and an equal flow demand is set entering the second node (the discharge node).
- If a pump status is listed as invalid, it means that you have set the flow rate lower than what would naturally occur through the line if the pump was not installed. The pump then acts as “valve” in order to limit the flow rate to the set value. If this occurs, you should either increase the set flow rate or remove the pump.

Figure 9



PIPE-FLO Stock calculates the pressure at each node. The program checks the calculated results to insure that the pump is operating properly (the suction pressure must be less than the discharge pressure).

Calculating NPSH Available

For each pump in the system, PIPE-FLO Stock calculates the Net Positive Suction Head available (NPSHa) using the following equation:

$$\text{NPSHa} = (\text{Pa} - \text{Pv} + \text{Pn})/\rho$$

equation 37

Pa = atmospheric pressure

Pv = vapor pressure (absolute)

Pn = gage pressure at the pump suction

ρ = fluid density

If NPSHr data is specified for a pump, PIPE-FLO Stock checks that the available NPSH is greater than the pump's required NPSH multiplied by the margin ratio ($\text{NPSHa} > \text{NPSHr} \times \text{margin ratio}$) when a calculation is performed. If the NPSHa is insufficient ($\text{NPSHa} < \text{NPSHr} \times \text{margin ratio}$), a warning is issued.

Components

Any device with a head loss (pressure drop) vs. flow relationship can be modeled in PIPE-FLO Stock, including heat exchangers, cleaners, or similar devices. When a system calculation is performed, PIPE-FLO Stock linearly interpolates between the specified curve data.

A constant pressure drop device can be modeled as well by specifying a single pressure drop value. When a calculation is performed, the pressure drop specified will be the pressure drop across the component, regardless of the flow rate through the component.

If the calculated flow rate through the component is beyond the data point range entered for the component model, PIPE-FLO Stock provides notification that the component is out of range. If this occurs, the range of flow rate data for the component should be extended or a different component should be used.

Flow Control Valves

Flow control valves (FCVs) maintain the flow rate in a line to a fixed value and calculate the differential pressure across the control required to regulate the flow rate.

The following points about FCVs should be noted:

- The direction of flow through the FCV is determined from the direction of the connecting pipelines.
- PIPE-FLO Stock models an FCV by creating two nodes in the system where the valve is installed (refer to Figure 10). A flow demand value equal to the set flow rate is taken out of the first node (the inlet node) and an equal flow demand is set entering the second node (the outlet node).
- If an FCV is status is Invalid, you should first check the direction of flow through the line. If the flow direction is correct, the invalid flag means that you have set the flow rate in the FCV to a value higher than would naturally occur in the line and the FCV is acting as a “pump” in order to achieve the set flow rate. In an actual piping system, the valve would be 100% open, so you should change valve setting to fully open and let PIPE-FLO Stock calculate the flow rate.

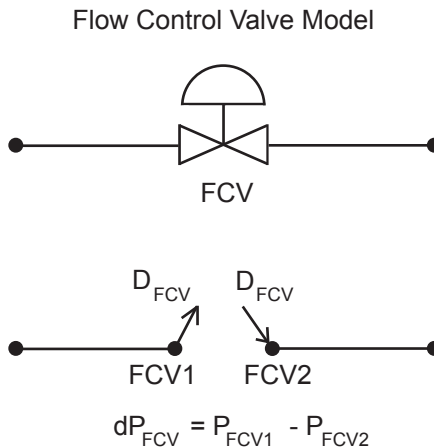


Figure 10

Using Control Valve Catalog Data

For valves set to a manual position, the valve inlet pressure is assumed to be equal to the pressure specified in the upstream fluid zone.

For each control, you can import control valve catalog data. PIPE-FLO Stock can then calculate the required valve position for a variety of valve settings and system configurations. Manual control operation can also be modeled by fixing the valve to a set position. Calculations for control valves with catalog data are performed using the equations outlined in the Control Valve Selection section.

Valve data can also be manually entered or imported from manufacturers' valve selection programs when the programs have export capability. The calculations for these valves are performed using the same equations that are used for catalog valves.

NOTE: The required valve file format for manufacturers' exported files is documented in the cvalve.xls file located in the same folder as the PIPE-FLO Stock program.

System Fluid Pressure

The Bernoulli theorem states that the total energy of the fluid anywhere in the system is composed of three components: the pressure head, the velocity head, and the elevation head. This relationship is expressed in the following way:

$$H = P/\rho + v^2/2g + Z$$

equation 38

H = total head
 P = pressure
 ρ = fluid density
 v = fluid velocity
 Z = elevation
 g = gravitational constant

Provided no work is done on the fluid, the energy of the fluid must remain the same throughout the piping system. The pressure at any point in the system can be found if the energy at one point is known and the velocity and elevation heads are known. Since all real piping systems have friction losses, a system energy loss will result in the form of heat released due to friction. This loss is the head loss calculated in the pulp friction loss equation and Blasius or Darcy-Weisbach equations, and it must be factored into the Bernoulli equation when determining the system pressures. The fluid energy at any point in the system can be determined from equation 39:

$$P_1/\rho + v_1^2/2g + Z_1 = P_2/\rho + v_2^2/2g + Z_2 + H_L$$

equation 39

When performing the pressure calculation at a node in the system, the fluid velocity value is unknown at the node so it is not factored into the pressure calculation. This is a valid assumption because the fluid velocity in a process system is designed to be fairly constant.

System Volume Calculations

The total system volume is calculated as follows:

$$V = \sum A_i L_i + \sum V_{f_i}$$

equation 40

- V = total system volume
- A_i = cross-sectional area of a pipe
- L_i = length of a pipe
- V_{f_i} = tank fluid volume

The total volume includes both open and closed pipelines as well as pipelines that are disconnected from the system. The tank volumes are calculated using the liquid levels in the active lineup.

NOTE: The system volume printed on the list report includes the tank volumes calculated using the liquid levels for the active lineup. The bill of materials report lists the maximum total tank volume, which assumes the maximum liquid level for each tank.

Lineup Calculations

PIPE-FLO Stock calculates the pressure drops and pressures throughout branched piping systems. A typical branched system is shown below in Figure 11.

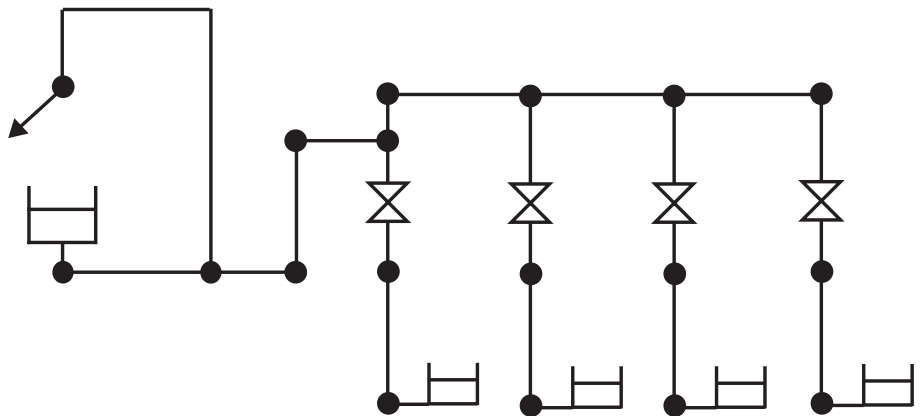


Figure 11

Note that the flow rate in each branch of the system is specified, either by a control valve or by a set demand.

PIPE-FLO Stock does not calculate results for looped systems, two of which are shown below in Figure 12 and Figure 13.

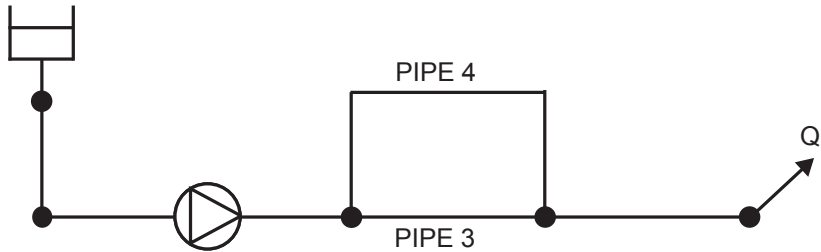


Figure 12

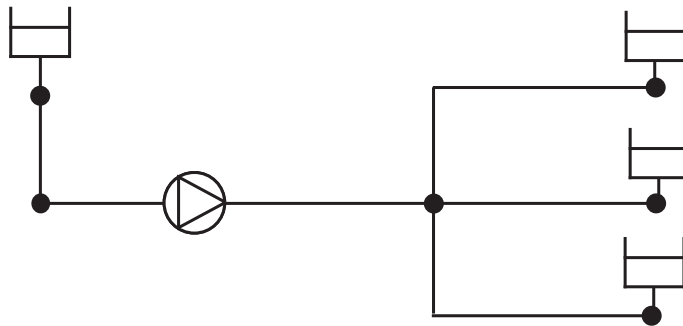


Figure 13

In Figure 12, a network equation must be generated to determine the distribution of flow between PIPE3 and PIPE4. Similarly in Figure 13, network equations must be generated to determine the distribution of flow to the 3 outlet tanks. PIPE-FLO Stock does not perform calculations for systems with loops such as these.

Calculations are only performed for branched systems where the flow rate in each pipeline is specified by setting flow demands or installing flow control valves or flow control pumps. An example of a branched system is shown in Figure 14.

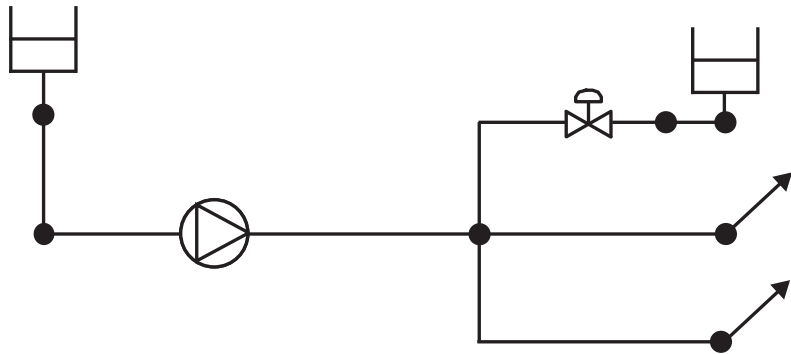


Figure 14

Note that installing a flow control valve in either PIPE3 or PIPE4 in the system shown in Figure 12, or in the pipelines leading to the outlet tanks in the system shown in Figure 13 eliminates the need for network equations and the systems are no longer considered looped.

References

- 1 TAPPI Technical Information Sheet (TIS) 410-14, Technical Association of the Pulp and Paper Industry, Atlanta, GA (1988).
- 2 Goulds Pump Manual, 6th edition, Goulds Pumps, Inc., 1995.
- 3 Crane, Crane Technical Paper 410, "Flow of Fluids through Valves, Fittings, and Pipe" twenty fourth printing, Crane Company 1988.
- 4 Brater and King, "Handbook of Hydraulics" sixth edition, McGraw-Hill, New York 1976.
- 5 Vennard, "Elementary Fluid Mechanics" fourth edition, John Wiley & Sons, Inc., New York, London, 1961.
- 6 Streeter - Wylie, "Fluid Mechanics" eighth edition, McGraw Hill, Inc., New York, 1985.
- 7 Jones, D., "Computing Fluid Tank Volumes," Chemical Processing, November 2002.
- 8 Jones, D., "Computing Fluid Volumes in Vertical Tanks," Chemical Processing, December 2003.

Additional Definitions and Conversion Factors

A.D. = Air Dry Stock (Contains 10% Water)
O.D. = Oven Dry Stock (All Water Removed), also called Bone Dry (B.D.)

$A.D. = 1.11 \times O.D.$
 $O.D. = 0.90 \times A.D.$

$A.D. = 1.11 \times O.D. \text{ T/D}$
 $O.D. = 0.90 \times A.D. \text{ T/D}$

$A.D. \text{ Consistency} = 1.11 \times O.D. \text{ Consistency}$

$O.D. \text{ Consistency} = 0.90 \times A.D. \text{ Consistency}$

T/D or TPD or S. T/D = Short Tons Per Day

One Short Ton = 2000 lbs.

M. T/D = Metric Tons per Day

One Metric Ton = 2205 lbs.

A.D.S. T/D = Air Dry Short Tons/Day

A.D.M. T/D = Air Dry Metric Tons/Day

$S. \text{ T/D} = 1.1025 \times M. \text{ T/D}$

$(\text{Production in A.D.S. T/D} \times 15) / \% \text{ O.D. Consistency} = \text{Flow in GPM}$

$(\text{Production in A.D.S. T/D} \times 16.67) / \% \text{ A.D. Consistency} = \text{Flow in GPM}$

Pulp Design Data Coefficients and Exponents

The table listed below is reproduced from Reference 2. These coefficients and exponents are specified when defining fluid zones. This data is provided in the PIPE-FLO Stock fluid table.

Table of Coefficients and Exponents

Pulp Type	Pipe Material	K'	σ	K	α	β	γ
Unbeaten aspen sulfite never dried	Stainless Steel	0.85 (0.26)	1.6	5.3 (235)	0.36	2.14	-1.04
Long fibered kraft never dried CSF = 725	PVC	0.98 (0.3)	1.85	11.80 (1301)	0.31	1.81	-1.34
	Stainless Steel	0.89 (0.27)	1.5				
Long fibered kraft never dried CSF = 650	PVC	0.85 (0.26)	1.9	11.30 (1246)	0.31	1.81	-1.34
Long fibered kraft never dried CSF = 550	PVC	0.75 (0.23)	1.65	12.10 (1334)	0.31	1.81	-1.34
Long fibered kraft never dried CSF = 260	PVC	0.75 (0.23)	1.8	17.00 (1874)	0.31	1.81	-1.34
Bleached kraft pine dried and reslurried	PVC	0.79 (0.24)	1.5	8.80 (970)	0.31	1.81	-1.34
	Stainless Steel	0.59 (0.18)	1.45				
Long fibered kraft dried and reslurried	PVC	0.49 (0.15)	1.8	9.40 (1036)	0.31	1.81	-1.34
Kraft birch dried and reslurried	PVC	0.69 (0.21)	1.3	5.20 (236)	0.27	1.78	-1.08
Stone groundwood CSF = 114	PVC	4.0 (1.22)	1.4	3.81 (82)	0.27	2.37	-0.85
Refiner groundwood CSF = 150	PVC	4.0 (1.22)	1.4	3.40 (143)	0.18	2.34	-1.09
Newsprint broke CSF = 75	PVC	4.0 (1.22)	1.4	5.19 (113)	0.36	1.91	-0.82
Refiner groundwood (hardboard)	PVC	4.0 (1.22)	1.4	2.30 (196)	0.23	2.21	-1.29
Refiner groundwood (insulating board)	PVC	4.0 (1.22)	1.4	1.40 (87)	0.32	2.19	-1.16
Hardwood NSSC CSF = 620	PVC	0.59 (0.18)	1.8	4.56 (369)	0.43	2.31	-1.2
Unbleached sulfite	Copper	0.98 (0.3)	1.2	12.69 (1438)	0.36	1.89	-1.33
Bleached sulfite	Copper	0.98 (0.3)	1.2	11.40 (1291)	0.36	1.89	-1.33
Kraft	Copper	0.98 (0.3)	1.2	11.40 (1291)	0.36	1.89	-1.33
Bleached straw	Copper	0.98 (0.3)	1.2	11.40 (1291)	0.36	1.89	-1.33
Unbleached straw	Copper	0.98 (0.3)	1.2	5.70 (646)	0.36	1.89	-1.33

NOTE: Parentheses indicate metric units.

PUMP SELECTION

PIPE-FLO Stock's pump selection module selects and evaluates centrifugal pumps. Centrifugal is a broad classification of pumps which use kinetic energy to move the fluid. They use the centrifugal force of a rotating impeller to impart kinetic energy to the fluid (as opposed to jet pumps and eductors).

The Hydraulic Institute Standards (Reference 1) is the basis for the pump selection module. The Hydraulic Institute is composed of organizations and individuals who manufacture and sell pumps in the open market. When there is a discrepancy between the program reference book and the current revision of the Hydraulic Institute Standards, the Standards take precedence.

PIPE-FLO Stock selects pumps from a pump catalog and evaluates their operation in an application. Within the range of the manufacturer's recommendations, the program allows you to adjust the pump parameters and see the effect it has on the pump operation.

Definitions

The definitions that follow are found in Reference 1.

Head The quantity used to express a form (or combination of forms) of the energy content of the liquid, per unit weight of the liquid, referred to any arbitrary datum. All head quantities are in terms of foot-pounds of energy per pound of liquid, or feet of liquid.

Flow The unit of flow rate in the United States is expressed in units of gallons per minute (gpm). The standard fluid for all pump curves is water at 60 °F.

NPSH The net positive suction head is the total suction head in feet of liquid (absolute) determined at the suction nozzle and the referred datum less the vapor pressure of the liquid in feet (absolute). NPSHa is the net positive suction head available in the pumping system. NPSHr is the net positive suction head required by the pump.

Pump Input The horsepower delivered to the pump shaft (designated as brake horsepower).

Pump Efficiency The ratio of the energy delivered by the pump to the energy supplied to the pump shaft (the ratio of the liquid horsepower to the brake horsepower).

Pump Head Curve

Pump vendors perform pump tests to determine the operating characteristics of the pumps they manufacture. The pumps are tested as outlined in Reference 1. All pump data used by PIPE-FLO Stock is supplied by the pump manufacturers who are solely responsible for the content.

Catalog Search Criteria

PIPE-FLO Stock compiles a list of pumps that meet the criteria specified by the user. This criteria includes the manufacturer's catalog, the types and speeds, and the design point (head and flow rate). The catalog search can be further limited by specifying that the design point must be to the left of a pump's best efficiency point (BEP). Users can also specify a head tolerance, which is expressed as a percentage of the design point head. Specifying a tolerance places pumps on the selection list that do not meet the design point, or are outside of the selection window. This allows the consideration of pumps that are "near misses."

Advanced Search Criteria

Advanced criteria can be used to further refine the catalog search. Pumps that do not meet one or more of the specified criteria are listed in red on the selection list. A detailed warnings list is also provided for each pump. The available criteria is listed below:

Preferred Operating Region

The preferred operating region has a lower and upper limit and is expressed as a percentage of the best efficiency point (BEP) flow rate. If the design point is outside of the preferred operating region, a warning flag is issued.

Secondary Operating Point

The secondary operating point is a flow rate and head specified by the user. If the secondary operating point is outside of the selection window, a warning flag is issued.

Pump Limits

Max temperature: The maximum operating temperature is compared to the maximum temperature specified in the catalog by the manufacturer. If the maximum temperature value exceeds the catalog value, a warning flag is issued.

Max suction pressure: The maximum pressure at the pump suction is added to the shutoff dP and then this sum is compared to the maximum pressure specified in the catalog by the manufacturer. If the maximum suction pressure plus the shutoff dP is greater than the catalog maximum pressure, a warning flag is issued.

Max sphere size: The largest particle size in the fluid is compared to the maximum sphere size specified in the catalog by the manufacturer. If the maximum sphere size exceeds the catalog value, a warning flag is issued.

Max power: The maximum power for the pump assembly or magnetic drive is compared to the power limit specified in the catalog by the manufacturer. If the maximum power exceeds the catalog value, a warning flag is issued.

Max suction specific speed (N_{ss}): The maximum suction specific speed is compared to the suction specific speed specified in the catalog by the manufacturer. If the catalog value exceeds the maximum suction specific speed, a warning flag is issued.

Curve Limits

Minimum trim: The design curve diameter, expressed as a percentage of the pump's maximum impeller diameter. If the selected design curve diameter is greater than this value, a warning flag is issued.

Min head rise: The minimum head rise from the design point to shutoff, expressed as a percentage from the design point head to the shutoff head. If a pump's head rise from design point to shutoff is less than this value, a warning flag is issued.

Pump Sizing

Each pump in the catalog can have up to ten impeller diameters or speed curves. Each curve can have up to twenty data points describing the pump operation. The data points for the curve consist of the flow rate and head, and optionally the pump's efficiency (or power) and NPSHr.

When the design point of the pump falls between a set of known curves, the program interpolates between them to arrive at a calculated curve. Often manufacturers allow impeller diameters to be adjusted only in fixed increments of their choosing. For example, a manufacturer can force the program to limit the impeller diameter increments to 0.125 inch. Or, they may not allow any trimming of the impellers.

The Affinity Laws

In hydraulically similar pumps, the head and capacity of a pump vary with the rotational speed of the impeller in such a way that the pump head curves retain their characteristic features. The variation of head, capacity, and brake horsepower follow a set of ratios that are known as the Affinity Laws. These laws are expressed in equations 1a, 1b and 1c.

$$(Q_1/Q_0) = (N_1/N_0)(D_1/D_0)$$

equation 1a

$$(H_1/H_0) = (N_1/N_0)^2(D_1/D_0)^2$$

equation 1b

$$(P_1/P_0) = (N_1/N_0)^3(D_1/D_0)^3$$

equation 1c

Q = Capacity, US gpm

N = Impeller speed, rpm

D = Impeller diameter

H = Pump head, ft

P = Pump power, hp

Subscripts

0 = Pump test speed or diameter

1 = New pump speed or diameter

Multi-stage Pumps

Pumps which have multiple impeller stages are designated as multi-stage pumps. For these pump types, the single stage base impeller curves and the impeller trim increment are specified in the manufacturer's catalog along with the range of allowed impeller combinations.

During the pump selection process, PIPE-FLO Stock determines the number of full diameter impeller stages necessary to achieve the design point. Once the number of stages has been determined, the program calculates the impeller diameter needed to go through the design point.

Adjustable Speed Pumps

Some pump manufacturers have pumps available in an Adjustable speed class. These pumps can be stored in a catalog under two different formats. Pumps that use the first format have one speed curve specified along with a maximum speed and a minimum speed. When adjustable speed pumps with this format are selected, PIPE-FLO Stock uses the affinity laws to calculate the speed needed to pass through the specified design point. Pumps that use the second format have up to ten speed curves stored per pump. When the design point of the pump falls between a set of known speed curves, the program interpolates between them to arrive at a calculated curve.

Multiple Pump Configurations

Multiple pumps for both parallel and series configurations can be analyzed. To plot the performance curve for multiple pumps in series, PIPE-FLO Stock multiplies the head values of the single pump curve by the number of pumps in series. The flow values for series configurations are the same as those for a single pump.

To plot the performance curve for multiple pumps in parallel, PIPE-FLO Stock multiplies the flow rate values for a single pump by the number of pumps in parallel. The head values for parallel configurations are the same as those for a single pump.

Net Positive Suction Head

The Net Positive Suction Head (NPSH) is the value of the minimum suction head required to prevent cavitation in a pump. Cavitation is the rapid formation and collapse of vapor pockets in regions of very low pressure.

In a centrifugal pump, cavitation causes a decrease in a pump's efficiency and is capable of causing physical damage to the pump and impeller. Since cavitation has such a detrimental affect on a pump, it must be avoided at all costs. Cavitation can be avoided by keeping the NPSH available (NPSHa) greater than the NPSH required (NPSHr).

The NPSH available can be entered directly or calculated using the NPSHa Calculator.

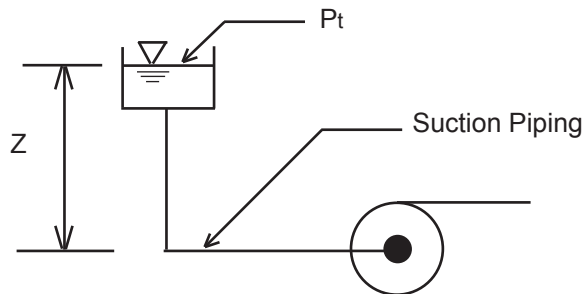


Figure 1

The formula used to calculate the NPSHa is as follows (refer to Figure 1 above):

$$\text{NPSHa} = ((P_t - P_{vp})/\rho) + Z - \text{HL}$$

equation 2

P_t = absolute pressure on the free surface of the liquid in the tank connected to the pump suction

P_{vp} = pumping fluid vapor pressure in absolute pressure units at the operating temperature

ρ = fluid density

Z = static suction head (this value is negative if a suction lift condition exists)

HL = head loss due to friction in the pipeline between the tank and the pump suction.

The units of NPSH are in feet of fluid absolute.

An NPSH margin ratio can also be specified. This factor is applied to the pump's NPSHr value. PIPE-FLO Stock checks that the NPSHa is greater than the pump's NPSHr multiplied by the margin ratio. If it is not, a warning flag is issued.

The NPSHr for a pump is determined by the pump manufacturer and is listed in their catalog. The NPSHr values are arrived at through actual tests as outlined in Reference 1.

If the fluid is a hydrocarbon, or high temperature water, then the required NPSH of the pump may be reduced as outlined in Reference 1. Using the *NPSH Reductions for Pumps Handling Hydrocarbon Liquids and High Temperature Water* chart found in Reference 1, it is possible to reduce the NPSHr values specified by the vendor without causing cavitation.

The PIPE-FLO Stock program does not perform the NPSH reduction calculations. If based on your experience you can reduce the NPSH requirements of the pump, the reduction value should be subtracted from the value presented by PIPE-FLO Stock. Always check with your pump supplier when adjusting the NPSH requirements.

Temperature Variations

Variations in the temperature of the fluid being pumped cause changes in the fluid density. Any reduction in the fluid density results in a reduction of the liquid horsepower, along with a proportional reduction to the input power. As a result, there is little or no change in the pump's efficiency.

Viscosity Variations with Hot Water

The viscosity of a fluid has the greatest impact on the pump curves. Variations in fluid viscosity also have an influence on the pump's efficiency. The changes in efficiency are due to:

- Internal leakage losses within the pump
- Disc friction losses
- Hydraulic skin friction losses

When pumping hot water in circulating pumps, Reference 1 allows vendors to adjust the performance data of their pump using an empirical formula. However, PIPE-FLO Stock does not perform the efficiency variation corrections for circulating hot water.

Viscosity Variations with Viscous Fluids

The viscosity of oils and other viscous fluids (as compared to water) has a more pronounced impact on the operating conditions of the pump. Pumps that are tested with water but are used to transport viscous fluids must have their head, flow, and efficiency values corrected to approximate their performance with the viscous fluid.

The methodology outlined in Reference 6 is used by PIPE-FLO Stock to correct the pump performance curves for viscous conditions. The correction equations are based on a pump performance Reynolds number adjusted for specific speed (parameter B), which has been statistically curve-fitted to a body of test data.

The parameter B is calculated as follows:

$$B = 26.6 * [(v^{1/2}) * (HBEP-W^{0.0625})] / [(QBEP-W^{0.375}) * (N^{0.25})]$$

equation 3

v = kinematic viscosity of the pump liquid,
centistokes (cSt)

QBEP-W = the water flow rate at the best
efficiency point, US gpm

HBEP-W = the water head per stage at the
best efficiency flow rate, ft

N = pump speed, rpm

The test data includes conventional single-stage and multi-stage pumps, and covers the following ranges:

$$1 \text{ cSt} < v < 3000 \text{ cSt}$$

$$13 \text{ US gpm} < Q (\text{@ BEP}) < 1140 \text{ US gpm}$$

$$20 \text{ ft} < H \text{ per stage} (\text{@ BEP}) < 430 \text{ ft}$$

$$B < 40$$

NOTE: PIPE-FLO Stock uses 4.3 cSt for the lower limit of the viscosity range (this corresponds to the value listed in Reference 1 and was used in previous versions of the program).

The correction equations are not exact for any particular pump, but are rather a generalized method based on empirical data. This method may be applied to pump performance outside the ranges listed above, however the uncertainty of the performance prediction is increased. In such situations, PIPE-FLO Stock still corrects the pump performance data, then issues a warning to indicate that there is increased uncertainty in the performance prediction.

For a complete listing of the correction equations, please see Reference 6.

Curve Corrections & Losses

In some cases, it may be necessary to apply hydraulic correction factors to a pump's performance data. For example, with vertical turbine pumps, the performance can vary depending on the material used for the impeller. Solids in suspension also affect the operation of a pump, depending on the both the percentage and nature of the solids. Reference 1 does not offer a recommendation for the modification of the pump data in these cases. However, through the use of hydraulic correction factors, PIPE-FLO Stock allows for the modification of the pump data for specific pumping applications.

To adjust the pump data, the program multiplies the appropriate water pump data (head, flow rate, NPSHr and efficiency) by the corresponding correction factors specified by the user. Users also have the option of specifying additional power losses to account for mechanical seal losses.

The correction factors and losses are values that a user should have obtained from his or her own experience or preferably from the pump manufacturer. In the case of slurries, pump vendors should be consulted regarding the impact of solids in suspension on the operation of specific pumps.

NOTE: Speed adjustments on a pump are done prior to applying the hydraulic curve corrections. If viscous conditions exist (viscosity of 4.3 centistokes or greater), hydraulic curve corrections are first applied to the pump performance data, then the viscosity corrections. Power losses are applied after both the curve corrections and viscosity corrections are performed.

Motor Sizing

Motor size tables used by PIPE-FLO Stock can contain up to four different standards. Each standard can have a maximum of four enclosure types. For each standard and enclosure type, the table contains speed, frame, and motor efficiency data.

When specifying the standard and enclosure type to use, the user also specifies the sizing criteria. There are three different criteria available: the power required at the design point flow rate, the maximum power required on the design curve, and the maximum power required for the maximum impeller diameter.

Based on the sizing criteria specified by the user, PIPE-FLO Stock automatically sizes the motor for each pump that is put on the selection list. The smallest motor that meets the sizing criteria is selected. When performing operating cost analyses, the program uses the efficiency data stored in the motor size table.

Energy Cost

The energy cost is the cost of the power required to run a pump for one year. PIPE-FLO Stock can calculate the annual energy cost for pumps running under both fixed and variable speed conditions. This cost information provides another parameter for consideration when comparing the advantages of using one pump over another. It also provides useful information for determining if the cost savings associated with operating a variable speed pump justifies the cost of the variable speed drive.

PIPE-FLO Stock uses information from the operating load profile and the manufacturer's pump curve to calculate the energy cost. If the cost is being calculated for a variable speed drive pump, the resistance curve information is used as well. The pump and motor efficiencies are also factored into the calculation.

For a fixed speed pump, the sequence outlined below is followed for each load specified in the operating load profile.

The brake horsepower is calculated:

$$\text{bhp} = Q \cdot \text{TH} \cdot \rho / (247,000 \cdot \text{eff}_p)$$

equation 4

bhp = brake horsepower
 Q = flow rate, US gpm
 TH = total head, ft
 ρ = fluid density, lb/ft³
 eff_p = pump efficiency

The electrical horsepower is calculated:

$$\text{ehp} = \text{bhp} / \text{eff}_m$$

equation 5

ehp = motor electrical horsepower
eff_m = motor efficiency

The cost for the load is calculated:

$$\text{Cost/Load} = \text{ehp} * (0.7457 \text{ kW/hp}) * T * \text{COST}$$

equation 6

T = duration of load, hrs/yr
COST = power cost, per kWh

Once this process is completed, the total annual energy cost is determined by summing up the costs calculated for each specified load in the profile.

Calculating the energy cost for a variable speed pump requires two more steps for each load specified in the operating load profile. First, the speed of the pump is determined at which the pump curve intersects the selected resistance curve at the required flow rate. Next, the operating condition of the pump is determined for the required speed using the affinity laws. The procedure then follows that for the fixed speed drive as outlined above.

Life Cycle Cost

The life cycle cost (LCC) for a pump is the total “lifetime” cost to purchase, install, operate, maintain, and dispose of the pump. The LCC is calculated as follows:

$$\text{LCC} = C_i + C_{in} + df * \Sigma[C_e + C_m + C_o + C_s + C_{\text{annual other}}] + [C_d + C_{d \text{ other}}]/[1 + (i - p)]^n$$

equation 7

C_i = initial cost

C_{in} = installation and commissioning cost

df = discount factor, a total sum factor over the n years for the present value

C_e = annual energy cost

C_m = annual maintenance and repair cost

C_o = annual operating cost

C_s = annual downtime cost

$C_{\text{annual other}}$ = annual miscellaneous costs

C_d = disposal and decommissioning cost

$C_{d \text{ other}}$ = miscellaneous costs associated with decommissioning the equipment

i = interest rate

p = inflation rate

n = number of years

NOTE: The annual energy cost used in calculating the life cycle cost is the last type of energy cost calculated (fixed speed or variable speed).

For more information, refer to Reference 7.

References

- 1 Hydraulic Institute Standards for Centrifugal, Rotary & Reciprocating Pumps, 14th edition, Hydraulic Institute, 1983.
- 2 Pump Handbook, Igor J. Karassik, William C. Krutzsch, Warren H. Fraser, and Joseph P. Messina, editors; McGraw-Hill, Inc., 1976.
- 3 Science and Engineering Programs, edited by John Heilborn, McGraw-Hill, Inc., 1981.
- 4 Crane, Crane Technical Paper 410, "Flow of Fluids through Valves, Fittings, and Pipe" twenty fourth printing, Crane Company 1988.
- 5 Engineering Handbook AODD Pumps, Yamada America, Inc.
- 6 Effects of Liquid Viscosity on Rotodynamic (Centrifugal and Vertical) Pump Performance, ANSI/HI 9.6.7, 2004.
- 7 Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems, Europump and Hydraulic Institute, 2001.

CONTROL VALVE SELECTION

Introduction

The sizing and selection of valves is based upon many piping system variables. PIPE-FLO Stock's control valve selection module analyzes the operation of the valve while taking into account the hydraulic characteristics of the system.

The source document for the sizing calculations used in PIPE-FLO Stock's control valve selection module is the American National Standard Institute, Instrument Society of America standard ANSI/ISA-S75.01-1985 (R 1995) *Flow Equations for Sizing Control Valves*.

PIPE-FLO Stock provides a quick and effective means of evaluating various valves using the ANSI/ISA standard. The specific formulas from this standard used are supplied in this reference book. When there is a discrepancy between the standard and the reference book, the standard takes precedence.

The majority of valve manufacturers have adopted the ANSI/ISA standard for the sizing of their valves and they provide the necessary factors in their valve catalogs. When there is a discrepancy between a valve manufacturer's data and the data presented in the supplied catalog disks, you should contact the valve manufacturer.

A few valve manufacturers have developed their own proprietary formulas and factors for sizing their valves. PIPE-FLO Stock does not use any proprietary method for sizing valves. Using the ANSI/ISA standard allows the valves from various manufacturers to be compared with the same approach, thus insuring that the best valve is selected for the application.

PIPE-FLO Stock's control valve selection module is not intended to be used to design or test valves.

Sizing Valves For Liquid Service

The equations for the flow of a non-compressible fluid through a valve as described by the standard and used in PIPE-FLO Stock's control valve selection module are as follows:

$$w = N_6 F_p FR C_v (dP/\rho)^{1/2}$$

equation 1

N_6 = conversion coefficient

C_v = valve flow coefficient, dimensionless

F_p = piping geometry factor, dimensionless

FR = Reynolds number factor, dimensionless ($FR = 1$ for turbulent flow)

dP = pressure drop across the valve ($P_1 - P_2$), pressure units

ρ = fluid density, mass/unit volume

Cv Valve Flow Coefficient

The flow coefficient (C_v) describes the flow vs pressure relationship through a valve. By definition, C_v is the number of gallons per minute of 60°F water which will pass through a valve with a fixed pressure drop of 1 psi.

The valve manufacturer supplies the C_v value of the valve for various valve body types, sizes, trim characteristics, and valve positions. The C_v value stored in the valve catalog is a function of the valve travel at 5%, 10%, 20% and every subsequent 10% of rated travel up to and including 100%. PIPE-FLO Stock performs a linear interpolation to determine the C_v values for positions between the increments found in the valve catalog.

Fp Piping Geometry Factor

The Cv values for valves are obtained experimentally by installing the valve in a straight run of pipe without any inlet or outlet reducers. Since many applications of valves do require reducers, the Fp factor takes into account the effects of the inlet and outlet reducers.

The Fp factor is defined as the ratio of the valve Cv installed with reducers to the rated Cv of the valve installed without reducers. The following equation can be used to determine Fp:

$$F_p = (((K_{SUM} C_v^2)/(N_2 D_v^4))+1)^{-1/2}$$

equation 2

N2 = conversion coefficient
Dv = nominal valve diameter

$$K_{SUM} = K_1 + K_2 + K_{B1} - K_{B2}$$

equation 3

K₁ = inlet reducer resistance coefficient
K₂ = outlet reducer resistance coefficient
K_{B1} = inlet Bernoulli coefficient
K_{B2} = outlet Bernoulli coefficient

PIPE-FLO Stock calculates the values of the coefficients with the following equations as found in the standard:

$$K_1 = 0.5 (1 - (D_v^2/D_1^2))^2$$

equation 4A

$$K_2 = 1.0 (1 - (D_v^2/D_2^2))^2$$

equation 4B

$$K_{B1} = 1 - (D_v/D_1)^4$$

equation 4C

$$K_{B2} = 1 - (D_v/D_2)^4$$

equation 4D

D = nominal pipe diameter
D_v = nominal valve diameter
1 = inlet
2 = outlet

PIPE-FLO Stock also performs the F_p calculations during valve selection. The F_p factor is incorporated into the search value of C_v. This insures that the valve is selected based upon the installed piping arrangement. If a valve is evaluated that requires reducers, the following compensation is made to the “search” value for C_v:

$$C_v (\text{search}) = C_v (\text{full size}) / F_p$$

If the flow through the valve is in the laminar and transition range, the standard states that pipe reducers are not to be installed around the valve. The value of F_p is therefore not factored into the sizing equation for the laminar and transition ranges. During sizing calculations, a turbulent flow check is performed. If the flow is found to be in the laminar or transitional range, the program does not consider reduced size valves as a valid option.

Non-turbulent Flow

If the flow through the valve is non-turbulent (due to a high fluid viscosity or low flow rate) a correction factor is added to the sizing equation to correct for the non-turbulent conditions. For fully turbulent flow, the correction factor (FR) is assumed to be 1. For flow in the laminar range, the C_v value can be calculated directly, eliminating the need to calculate the value of FR. When the flow is in the transition range, the FR value is calculated and used in the general sizing equation (equation 1).

Non-turbulent Flow and Valves with Close-coupled Reducers

The ANSI/ISA-S75.01-1985 (R 1995) standard states that for non-turbulent flow conditions, the effect of close-coupled reducers is not known. Thus, when the specified design condition is in the non-turbulent region, PIPE-FLO Stock does not automatically select valves which are smaller than the pipeline size. However, users can manually select valves that are smaller than the pipeline size. In these cases, $F_p = 1$ is assumed.

The correction factors for laminar and transitional flow are described below:

Laminar Flow

The C_v calculation for the laminar flow range is as follows:

$$C_v = (1/F_s)(w\mu / N_s \text{ dP})^{2/3}$$

equation 5

- N_s = conversion coefficient
- F_s = laminar flow factor, dimensionless
- w = mass flow rate
- μ = fluid viscosity (absolute)

The value of F_s is determined by manufacturer testing and is stored in the valve catalog. Note that for each valve body type, the same value of F_s is used for flow to open, flow to close, and full and reduced seated trims.

Transitional Flow

When the flow is in the transitional range, the value of FR varies depending on what type of calculation is being done.

In valve sizing calculations, the following formula is used for FR :

$$FR = 1.044 - 0.358 (C_{vs}/C_{vt})^{0.655}$$

equation 6

- C_{vs} = the C_v value for laminar flow (equation 5)
- C_{vt} = the C_v value for fully developed turbulent flow (equation 1, without F_p)

When calculating the flow rate, the following formula is used for FR:

$$FR = 1.004 - 0.358 (w_s/w_t)^{0.588}$$

equation 7

w_s = the mass flow rate for laminar flow
(equation 5)

w_t = the mass flow for fully developed
turbulent flow (equation 1)

Once FR is calculated using either equation 6 or equation 7 above, it is inserted into the general sizing equation (equation 1). If the FR value calculated is less than 0.48, the flow through the valve is laminar and equation 5 is used in all sizing calculations. When FR is greater than 0.98, the flow is considered turbulent and equation 1 is used with FR set equal to 1.

Whenever the flow through a valve is non-turbulent, a laminar line is displayed on the Flow vs dP and %Open vs Flow Graph Windows.

Choked Flow Conditions

As the inlet pressure to the valve is held constant and the outlet pressure is decreased, the flow rate through the valve will increase. This is true until the static pressure at the vena contracta (the point of lowest pressure in the valve) falls below the vapor pressure of the fluid. The maximum pressure drop and flow rate for the valve have been reached and choked flow occurs, resulting in either cavitation or flashing. If the outlet pressure is greater than the vapor pressure of the liquid, cavitation occurs. If the outlet pressure is equal to or less than the vapor pressure of the liquid, flashing occurs.

The calculation of the choked flow and pressure conditions are as follows:

$$Q_{MAX} = N_6 F_{LP} C_v ((P_1 - P_{vc}) \rho)^{1/2}$$

equation 8

N_6 = conversion coefficient

Q_{MAX} = maximum mass flow rate

P_{vc} = absolute pressure at vena contracta

F_{LP} = liquid pressure recovery factor with
reducers installed, dimensionless

The value of P_{vc} can be calculated from the following formula:

$$P_{vc} = F_F P_v$$

equation 9

F_F = liquid critical pressure ratio factor,
dimensionless

P_v = vapor pressure at inlet
temperature

The value of Q_{MAX} is displayed on the Flow vs dP and %Open vs Flow Graph Windows when choked flow conditions occur in the specified flow rate range.

F_L Liquid Pressure Recovery Factor

The liquid pressure recovery factor, F_L , is a measure of the valve's ability to convert the kinetic energy of the fluid at the vena contracta back into pressure. The internal geometry of the valve determines the value of F_L . It is a function of the direction of flow through the valve, the valve position, and whether the valve has a full or reduced seated trim.

The values of F_L used in PIPE-FLO Stock's control valve selection module are supplied in the manufacturer's catalog. F_L values are stored for each valve body type for flow to open, flow to close, and full and reduced seated trims at 10% increments of valve position.

If a manufacturer does not provide a value for a particular condition, the program will display a warning message and allow the user to enter a value. It is strongly recommended that users consult with the manufacturer for the suitability of the valve to operate under such conditions.

If reducers are installed around the valve, their effects are factored into the value of F_L . A new factor, called F_{LP} , is calculated and used in the valve sizing equation for non-compressible fluids with reducers. F_{LP} is calculated as follows:

$$F_{LP} = F_L [(F_L^2 (K_1 + K_{B1})/N_2)(C_v^2 / Dv^2)^2 + 1]^{-1/2}$$

equation 10

N_2 = conversion coefficient

F_F Liquid Critical Pressure Ratio Factor

The liquid critical pressure ratio factor, FF, is the ratio of the apparent vena contracta pressure of the liquid under choked flow conditions to the vapor pressure of the liquid at the inlet temperature. The following equation (as found in the standard) is used to calculate the value of FF used in the choked flow equations:

$$F_F = 0.96 - 0.28 (P_v/P_c)^{1/2}$$

equation 11

P_c = critical pressure of the liquid

P_v = vapor pressure of the liquid

The above equation is based on the assumption that the fluid is always in thermodynamic equilibrium. Because this is usually not the case for a liquid as it flashes across a valve, the flow rate predicted using equation 11 will be less than the actual flow rate.

Sizing Valves for Compressible Service

The equations for the flow of a gas or vapor through a valve as described by the standard and used in PIPE-FLO Stock's control valve selection module are as follows:

$$w = N_6 F_p C_v Y (X P_1 \rho)^{1/2}$$

equation 12

N_6 = conversion coefficients

w = mass flow rate

X = ratio of pressure drop to absolute inlet static pressure dP/P_1 , dimensionless

Y = expansion factor, dimensionless

ρ = density of the fluid, mass per unit volume

The piping geometry factor (F_p) is identical to the one used in the calculations for non-compressible fluids. The Reynolds factor (FR) is not used in the gas sizing equation because for a gas it can be assumed that the flow through a valve is always turbulent. The values of Y and X are unique to the gas sizing equation and are explained below.

Y Expansion Factor

The expansion factor (Y) accounts for the change in the fluid density as it passes from the valve inlet to the vena contracta. The value of Y is affected by the following factors:

- 1 Ratio of the valve trim area to the inlet area
- 2 Shape of the flow path
- 3 Pressure drop ratio (X)
- 4 Ratio of specific heats (k) of the fluid.

The effect of items 1, 2, and 3 are accounted for in the pressure drop ratio factor, XT . The value of XT is determined experimentally for each valve. XT factors are supplied in the manufacturer's catalog.

The effect of item 4 is accounted for by using the ratio of specific heat factor, F_k .

The calculated value of Y is determined by the following equation:

$$Y = 1 - X / (3 F_k X_T)$$

equation 13

(limits $0.67 \leq Y \leq 1.0$)

F_k = ratio of specific heat factor,
dimensionless

X = ratio of pressure drop to absolute
inlet static pressure dP/P_1 ,
dimensionless

X_T = pressure drop ratio factor,
dimensionless

Ratio of Pressure Drop to Inlet Pressure (X)

The value of X is the ratio of the differential pressure to the inlet static pressure. X is defined in the standard as follows:

$$X = (P_1 - P_2) / P_1$$

equation 14

(limit $X = X_T F_k$)

As the differential pressure increases and the inlet pressure is held constant, the value of X increases. This results in a higher mass flow rate through the valve. The value of X continues to increase until it equals $X_T F_k$. This corresponds to a minimum value of 0.67 for Y. When this condition occurs, the flow through the valve is sonic. Once sonic flow is achieved, the reduction of outlet pressure has no further effect on the mass flow rate through the valve.

PIPE-FLO Stock's control valve selection module program checks for sonic or choked flow and indicates when these conditions exist.

Fk Ratio of Specific Heats Factor

The flow rate through a valve is affected by the ratio of specific heats for the compressible fluid. The factor F_k accounts for this effect. The standard uses the following formula to determine F_k .

$$F_k = k / 1.40$$

equation 15

k = ratio of specific heats

The ratio of specific heats (k) can be found in fluid tables for most common gases.

Rated Pressure Drop Ratio Factor (X_T)

The value of X_T is determined experimentally and supplied by the valve manufacturer. The valve catalog stores X_T values for each valve body type for flow to open, flow to close, and full and reduced seated trims at 10% increments of valve position. If a manufacturer does not supply a value for X_T , the valve is not suitable for use with compressible fluids. If a manufacturer only provides a partial data set for X_T , the user is given the opportunity to manually enter a value. Users are strongly urged to contact the manufacturer to insure that the valve is suitable for a particular application.

If there is a reducer on the valve inlet, its effect must be factored into X_T , resulting in a new factor designated as X_{TP} . The value of X_{TP} is calculated by the following equation:

$$x_{TP} = (x_T / F_p^2) [(x_T K_{IN} C_v^2 / (N_5 Dv^4)) + 1]^{-1}$$

equation 16

N_5 = conversion coefficient

$K_{IN} = (K_1 + K_{B1})$

References

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- 5 Vennard, "Elementary Fluid Mechanics" fourth edition, John Wiley & Sons Inc., New York, 1961.