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Revision Memo

- 12/03** Highlights of revisions:
- Minor corrections and additions to definitions section
 - Minor corrections throughout body of section



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SCOPE

This subsection covers general considerations involved in flow of fluids through pipes and through piping-related equipment, such as orifices, valves, and fittings. Calculation methods for determining pressure drops are given in [Subsection B](#) for single-phase liquid flow, in [Subsection C](#) for single-phase gas flow, and in [Subsection D](#) for two-phase (vapor-liquid) flow.

For pressure drop through tower packing, see [Section III, "Fractionating Towers,"](#) [Subsection G, "Packing and Grid."](#) Flow of gas-solids mixtures and fluidization is covered in [Section VI, "Fluid Solids."](#)

For mechanical considerations involved in piping design and layout, see ASME Std. B31.3, "Process Piping," plus the Global Practices listed below.

REFERENCES

DESIGN PRACTICES

(Besides other subsections of this section)

Section II	Design Temperature, Design Pressure and Flange Rating
Section III	Fractionating Towers
Section VI	Fluid Solids
Section VIII	Fired Heaters
Section XV	Safety in Plant Design
Section XVI	Thermal Insulation

ENVIRONMENTAL CONTROL DESIGN PRACTICES

Section II-A	Engineering for Water Pollution Control
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GLOBAL PRACTICES

GP 3-2-4	Pressure Relieving Systems
GP 3-3-2	Suction and Discharge Piping for Centrifugal Pumps
GP 3-3-7	Inlet and Exhaust Piping for Steam Turbines
GP 3-3-11	Auxiliary Piping for Machinery
GP 3-4-1	Piping for Fired Equipment
GP 3-5-1	Fill and Discharge Lines, and Auxiliary Piping for Storage Tanks and Vessels
GP 3-6-3	Utility Connections to Piping and Equipment
GP 3-6-4	Vents and Drains, Flushing and Cleaning Connections
GP 3-7-1	Piping Layout, Supports and Flexibility
GP 3-10-1	Piping Selection and Design Criteria
GP 3-12-1	Valve Selection
GP 3-12-2	Gate and Globe Valves
GP 3-12-4	Flanged Ductile Iron Gate Valves
GP 3-16-1	Flanged Joints, Gaskets and Bolting
GP 10-8-1	Combustion Gas Turbines
GP 14-1-1	External Insulation
GP 15-4-1	Flow Instruments

NATIONAL AND INTERNATIONAL STANDARDS

ASME B31.3	Process Piping
ASME B36.10	Wrought-Steel and Wrought Iron Pipe (ISO R64)
ASME B36.19	Stainless Steel Pipe
API 5L	Specifications for Line Pipe

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REFERENCES (Cont)

OTHER LITERATURE

1. Perry and Chilton's Chemical Engineer's Handbook, 5th Ed., Section 5, "Fluid and Particle Mechanics."
2. Crane Technical Paper No. 410, "Flow of Fluids Through Valves, Fittings and Pipe," 1988.
3. Taylor Forge Catalog 571, 3rd Edition, 1961.
4. Tube Turns Catalog, 1964.
5. Design of Piping Systems, M. W. Kellogg, 1967.
6. Refinery Construction Materials Manual (EETD 028).
7. Valve Selection Guide (TMEE 074).
8. Improved Analysis Method for Use In Pipe Pressure Surge Evaluations, EE.62E.86 June 1986.
9. Piping Vibrations Evaluation Guide, EE.21E.89, 1989.

DEFINITIONS

General definitions for this section are presented in alphabetical order below:

- ▶ **Equivalent Hydraulic Diameter, d_{eq}** - 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. Use of d_{eq} in laminar flow will in general give incorrect results.

Equivalent Length (of a Valve or Fitting), L_{eq} - The length of straight pipe which would give the same pressure drop as a valve or fitting of the same nominal diameter under the same flow conditions.

Fanning Friction Factor, f - Empirical factor in the Fanning equation for pressure drop in straight pipe. This factor is a function of Reynolds Number and relative pipe wall roughness, ϵ/d . For a given class of pipe material, the roughness is relatively independent of the pipe diameter, so that in a plot of f vs. Re , d often replaces ϵ/d as a parameter.

The Fanning friction factor should not be confused with the Darcy friction factor, which is four times as large.

- ▶ **Head** - A unit of measurement expressing pressure in terms of the height of fluid required to produce a corresponding level of static pressure. Using this concept, it is also possible to define **velocity head** as the height of fluid producing a pressure equal to the stagnation pressure, the force per unit area required to abruptly stop the flow.

Laminar or Viscous Flow - Laminar flow occurs when adjacent layers of fluid move relative to each other in smooth streamlines, without macroscopic mixing. In laminar flow, viscous shear, which is caused by molecular momentum exchange between fluid layers, is the predominant influence in establishing the fluid flow. This flow type occurs in pipes when $Re < 2,100$.

Newtonian Fluids - Fluids in which viscosity is independent of shear rate and time. Most liquids and all gases belong to this group.

Non-Newtonian Liquids - Liquids in which viscosity depends on shear rate and/or time. Examples are some slurries, emulsions, and polymer melts and solutions.

Pipe Resistance Coefficient, N - Analogous to the Resistance Coefficient, K , but applied to friction in straight pipe.

Relative Roughness - Ratio of absolute pipe wall roughness ϵ to inside diameter d , in consistent units.

Resistance Coefficient, K - Empirical coefficient in the friction loss equation for valves and fittings. It expresses the number of velocity heads lost by friction for the particular valve or fitting. The coefficient is usually a function of the nominal diameter.

Reynolds Number, Re - A dimensionless number which expresses the ratio of inertial to viscous forces in fluid flow. The Reynolds number for pipe flow is given by the following expression:

$$Re = \frac{K_1 d V \rho}{\mu} \quad \text{Eq. (1)}$$

where:

Re = Reynolds number

d = Inside diameter of pipe, inches (mm)

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- V = Linear fluid velocity averaged over pipe cross section, ft/s (m/s)
 ρ = Fluid density, lb_m/ft³ (kg/m³)
 μ = Fluid viscosity, centipoise (Pa•s)
 K_1 = 124 (Customary)
 K_1 = 10⁻³ (Metric)

Shear Rate - The velocity gradient (change in velocity with position).

Shear Stress - Force per unit area. Force in direction of flow; area in plane normal to velocity gradient.

Sonic or Critical Velocity (Choked Flow) - The maximum velocity that a gas or gas-liquid mixture can attain in a conduit at a given upstream pressure (except in certain converging-diverging nozzles), no matter how low the discharge pressure is. For gases this maximum velocity is equal to the speed of sound at the local conditions.

Steam Hammer - Steam hammer is excessive pipe vibrations that occur due to the collapse of large vapor bubbles in a cool liquid stream.

Streamline - A streamline is defined as a line which lies in the direction of flow at every point at a given instant.

Transition Flow - Flow regime lying between laminar and turbulent flow. In this regime velocity fluctuations may or may not be present and flow may be intermittently laminar and turbulent. This flow type occurs in pipes when 2,100 < Re < 4,000.

Turbulent Flow - Turbulent flow occurs when macroscopic mixing results both perpendicular to, and in the direction of, the main flow. Turbulent flow is characterized by fluid particles having fluctuating motions and erratic paths. It is the flow that occurs when inertial forces are the predominant influence in establishing the fluid flow. This flow type occurs in pipes in industrial situations when Re > 4,000. Under very controlled laboratory situations, laminar flow may persist at Re > 4,000.

Water Hammer - Water hammer is the dynamic pressure surge that results from the sudden transformation of the kinetic energy in a flowing fluid into pressure when the flow is suddenly stopped. The sudden closing of a valve can cause a water hammer. Water hammer pressure can be large enough to shatter pump casings or burst line pipe and should, therefore, be considered in the design of pipes.

BASIC DESIGN CONSIDERATIONS

The considerations discussed below affect the basis for the design procedure given later in this subsection.

LINE SIZING

In most cases, line size is determined by the length of the line and the allowable pressure drop. The allowable pressure drop, in turn, may be influenced by many factors, including process requirements, economics, safety, and noise or vibration limitations.

Unless set by process or safety considerations, optimum line size is determined by balancing piping and valving investment against pump or compressor investment and driver operating cost. All expensive lines should be considered individually and the minimum investment case for the lines and pumping equipment should be calculated. Examples of expensive lines are:

1. Alloy lines (see Refinery Construction Materials Manual).
2. Lines larger than 12 in. (300 mm) diameter.
3. Long offsite lines, i.e., lines longer than 1,000 ft (300 m).
4. Onsite carbon steel lines having a large number of valves and fittings.

There may be particular instances (i.e., small lines in extremely high-pressure service) where the use of tubing instead of pipe should be considered since both inside diameter and wall thickness can be specified for tubing. However, the **Global Practices** or affiliate limits on minimum pipe size must also be considered.

[Table 1 of Subsection B](#) gives some guidelines for optimum pressure drops in carbon steel lines. This list has been prepared on the basis of "average" lines in the range of 600 ft (200 m) or less. These values should be viewed as guidelines and can be modified for economic reasons. For example, the transfer line from a hydrocracker to the high-pressure separator might be sized for pressure drops of 3.5 to 4.0 psi/100 ft (80-90 kPa/m) to minimize alloy pipe size.

Valve sizing is also affected by economics. Typically it is economically desirable to use a valve of less than line size in lines 10 in. (250 mm) or larger in diameter.

The type of fitting used may also be affected by economics. A fitting which slightly increases pressure drop may be sufficiently lower in cost to effect an overall net saving. An example is the choice between (low-cost) mitered bends and (higher-cost) long-radius elbows in a high-pressure piping system. In cases where the choice of type of fitting is not obvious, a decision should be made, or a note should be put into the Design Specification suggesting that the contractor make such a study.

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Some lines must be sized based on process considerations. Examples of these are compressor headers, furnace coil outlet transfer lines, Dowtherm lines, and lines around vacuum equipment.

Some lines are sized based on safety considerations. Examples are safety valve inlet and outlet piping, and blowdown system piping. For design basis and calculation methods, see [Section XV, "Safety in Plant Design."](#)

SELECTION OF PIPING SCHEDULE

To select a piping schedule, pipe diameter (inside or outside diameter) and pipe wall thickness must be known (see [Table 1](#)). Pipe inside diameter is calculated as mentioned under **LINE SIZING**. For pipe sizes of 12 in. (300 mm) and smaller, the inside diameter of standard pipe corresponds closely to the nominal pipe size. For larger sizes, however, the nominal size corresponds to the outside diameter.

Minimum wall thickness for any pipe subject to internal or external pressure is a function of allowable stress of the pipe material, pipe diameter, design pressure, and corrosion and erosion rates. In addition, minimum wall thickness of a pipe subject to external pressure is a function of the length of the pipe section, since it influences the collapse strength of the pipe. Finally, the minimum wall thickness for any pipe must include a suitable fabrication tolerance.

Techniques for calculating the minimum wall thickness for pipes subject to internal or external pressures are given under **DESIGN PROCEDURES**.

PIPING VIBRATION

Large units and equipment increase the potential for complex vibration problems. In particular, gas piping systems with control valves have experienced problems of fatigue failure where excessive turbulence and high acoustic energy existed. The turbulent forces can excite certain complex modes of vibration in the piping. These resulting vibrations can lead to stresses exceeding the endurance limit for the materials and thus, fatigue failure.

Problems of this type should be considered early in the design stage of a plant. Explicit guidelines for such involved problems are not available but from limited data collected from affiliate experience, certain guidelines have been developed to assist the designer in recognizing a potential problem. Conditions requiring a check of acoustically-induced vibration problems in gas streams are as follows:

Valves where:

1. Downstream line size is 16 in. (400 mm) or greater, mass flow rate is greater than 200,000 lb/h (25 kg/s), or upstream-to-downstream valve pressure ratio is greater than 3.
2. Downstream line size is 8 in. (200 mm) to 14 in. (350 mm), downstream line velocity is greater than 50% of sonic, and upstream-to-downstream valve pressure ratio is greater than 3.
3. Downstream line size is less than 8 in. (200 mm) but swaged up or teed to 8 in. (200 mm) or larger line, downstream line velocity is greater than 50% of sonic and upstream-to-downstream valve pressure ratio is greater than 3.

Tee Connections where the size of the run is 16 in. (400 mm) and greater, mass flow rate is greater than 200,000 lb/h (25 kg/s), and sonic velocity conditions exist at the throat (exit) of the branch connection.

Vibration and pulsation can also occur with two-phase gas-liquid flow in the slugging regime and flow in this regime should be avoided where possible. When unavoidable, appropriate mechanical support must be provided.

The above is merely a guide for detecting potential problems. When a piping system problem is suspected, the Mechanical Engineering Section of ExxonMobilMobil Engineering should be consulted for an evaluation and solution.

PIPING FLEXIBILITY

Most piping systems are restrained against free thermal movement by the vessels, exchangers, compressors, pumps, and other equipment that are interconnected by the piping. This thermal movement must be absorbed within the restrained system through the bending of offset legs or expansion loops which are used to give the piping system inherent flexibility. The use of offset legs and expansion loops leads to increased run lengths of pipe and should be considered in making flow calculations. Piping flexibility, to provide for thermal movement, must be adequate to serve two purposes:

- Keep the piping reactions on connected equipment (platefin exchangers, pumps, compressors, etc.) within acceptable limits.
- Maintain bending stresses in the pipe itself within a range such that direct or fatigue failure and joint leakage are avoided.

For piping flexibility analysis, consult the Mechanical Engineering Section of ExxonMobilMobil Engineering.

For **additional mechanical considerations** involved in piping design and layout, see ASME B31.3, "Process Piping," published by the American Society of Mechanical Engineers. See also the latest issue of each of the following ExxonMobilMobil Engineering Global Practices:

- GP 3-2-4 Pressure Relieving Systems
- GP 3-3-2 Suction and Discharge Piping for Centrifugal Pumps

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GP 3-3-7	Inlet and Exhaust Piping for Steam Turbines
GP 3-4-1	Piping for Fired Equipment
GP 3-5-1	Fill and Discharge Lines, and Auxiliary Piping for Storage Tanks and Vessels
GP 3-6-3	Utility Connections to Piping and Equipment
GP 3-10-1	Piping Selection and Design Criteria

WATER HAMMER

The significance of hydraulic surge-induced damage in piping systems is well known. Such surge pressures and forces have caused pipe to jump off its supports, damaged anchors and restraints, and resulted in leaks and shutdowns in process plants and terminal facilities. Pressure evaluations are sometimes required in piping systems to ensure that excessive operating pressures and reaction loads do not occur as a result of normal changes in unit operations.

To minimize hydraulic surge in piping systems, two design aspects have to be considered. First, the conflicting requirements for surge force minimization and allowance for pipe differential thermal expansion must be balanced. On the one hand, to minimize the impact of unbalanced surge forces, designs would tend to have rigidly supported piping and a minimum number of bends. On the other hand, designing for differential thermal expansion would lead to minimizing supports and providing bends for flexibility. Second, the total energy in the system should be minimized. Pumps, which are the energy source, should not be overdesigned.

General design recommendations for minimizing surge forces are:

- Minimize the number of bends in the system.
- Use the largest enclosed angle and radius possible for bends.
- Place bends as far apart as possible.
- Put supports as near as possible to each side of the bend.
- Eliminate all unnecessary changes of piping size in a system.
- Provide supports near all large components.
- Provide bypasses at pump stations.
- Install control valves on pump discharges.
- Use actuator with two-speed rate of valve stroke, and valve with high initial head loss coefficient.
- Limit flow velocity to a maximum of 10 ft/sec (3 m/s) in pipes, and 35 ft/sec (10 m/s) in loading arms.

As a general rule, closure times of valves in pipes up to 24 in. (600 mm) in diameter should exceed 15 seconds. For pipe diameters of 24 in. (600 mm) or larger, the closure time should be at least 30 seconds. The contractor should verify, using appropriate detailed calculations that the pressure increase due to valve closure will not overpressure or damage the line. Valve operators of the air pneumatic piston type should be avoided, because they may cause pressure surges due to sudden closing of valves. Additional information may be found in "Improved Analysis Method for Use in Pipe Pressure Surge Evaluations," EE.62E.86, June, 1986. If surge forces are unavoidable, protection devices should be used, including safety valves or rupture disks for tube split protection on high pressure exchangers, pulsation bottle for positive displacement pumps, LPG line surge drums, etc. Contact the Mechanical Engineering Section of ExxonMobilMobil Engineering for assistance in evaluating surge problems.

STEAM HAMMER

Injection of condensable vapors (e.g., steam) into cool liquids should be done through multi-hole spargers to prevent excessive vibrations due to the collapse of large vapor bubbles. The minimum pressure drop through sparger holes should be about 0.5 psi (3.4 kPa). Vapor may also be injected through a Venturi type injector, e.g., steam injection for hydrostatic testing of pressure vessels. Intensive mixing of steam and cool water in the injector will condense the steam, raise the water temperature, and minimize pipe vibrations.

PIPING FOR BOILER WATER MAKEUP TO ONSITE STEAM GENERATORS

For horizontal steam drums, it is normal practice to inject the makeup water below the liquid level of the steam drum. For vertical steam drums in which the makeup water is saturated, it may be injected into the boiler feed line, into the liquid return line, or into the vapor space of the steam drum itself. For vertical drums in which makeup water is not saturated, it should be injected below the liquid level of the steam drum.

VALVING REQUIREMENTS

Requirements governing selection, use, design, and inspection of valves are covered in the Valve Selection Guide (Ref. 7) and each of the following Global Practices:

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GP 3-2-4	Pressure Relieving Systems
GP 3-6-3	Utility Connections to Piping and Equipment
GP 3-6-4	Vents and Drains, Flushing and Cleaning Connections
GP 3-12-1	Valve Selection

WATER PIPING AND VALVING FOR COOLERS AND CONDENSERS

Piping Requirements - Water disposal from coolers and condensers depends on considerations of possible water contamination, i.e., whether the water pressure at the water main is higher or lower than the oil pressure. In the case of elevated condensers, the static head of the water should be subtracted from the water main pressure.

When the water pressure at the main is *higher* than the oil pressure, once-through water is sent to the clean water sewer system. If the water pressure at the main is *lower* than the oil pressure, once-through water is disposed of as follows:

1. To a water disengaging drum when the oil vapor pressure is greater than 15 psia (109 kPa) at 100°F (40°C) and subsequently to the clean water sewer. (The use of water disengaging drums is covered in detail in [Section XV](#).)
2. Directly to the clean water sewer in the case of all heavier hydrocarbons.

Some means of temporarily diverting clean sewer water (see [ENVIRONMENTAL CONTROL DESIGN PRACTICES SECTION XIX](#)) to the main oily water treatment system should be provided, to guard against high oil contents resulting from process cooler leakage. In *recirculating systems*, this can readily be done at the cooling tower and no special onsite diversion capability is required. However, diversion of a large *once-through cooling* water stream may hydraulically overload a treatment system. Therefore, consideration should be given to providing the capability for diverting the effluent to a retention pond and/or skimming prior to reduced rate discharge to the treatment system or, if the quality is satisfactory, to the receiving water body. In some instances, it may be practical to use the rainwater retention pond as temporary holdup for contaminated effluent.

Valving Requirements - The following principles should be followed:

1. A throttling valve (e.g., globe or butterfly) is installed on only one side unless the cooler or condenser must be removable from service (for cleaning, repair, etc.) while the rest of the unit continues to operate.
2. If the cooler or condenser must be removable during operation, a block valve should be provided on the opposite side from the throttling valve.
3. When oil pressure is more than 150% of the design pressure of the water side, refer to [Section XV](#) for a discussion of overpressure on the low-pressure side of heat exchangers resulting from a split tube. This may require a pressure relief valve on the exchanger piping or a car-sealed open valve in the water outlet.
4. For elevated coolers and condensers in which the water effluent is discharged to a sewer, the throttle valve should be on the effluent line to prevent pulling a vacuum on the water side of the exchanger. Otherwise, there may be corrosion problems caused by oxygen desorption. This does not apply to recirculating water, since the static head due to the cooling tower elevation will prevent pulling a vacuum on the water side.

The diagram on the next page illustrates various cases of water valving which may be encountered and the location of the throttle valve for each case. Note that in Cases I and III, the location of the throttle valve on the water effluent line satisfies Item 4. In Cases II, III and V, check valves are installed on the water inlet lines to the exchangers to prevent hydrocarbon leakage from backing up into the water main.

