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		Rev: 06
		Rev 05 - Jan 2007 Rev 06 – Nov 2010
KLM Technology Group 03-12 Block Aronia JI Sri Perkassa Dua Tm Tampoi Utama 80000 Johor Bahru, Malaysia	Piping Fluid Flow Material Selection and Line Sizing (ENGINEERING DESIGN GUIDELINE)	Author: Rev 05 - Ling Ai Li Rev 06 – Viska Mulyandasari
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INTRODUCTION

Scope

This design guideline covers basic considerations in Piping Fluid Flow Material Selection and Line Sizing to allow an engineer to design a pipeline with the correct material selection and suitable size. Process requirements, type of fluid to be used, and its flow characteristic will determine material selection for pipeline. Process requirements might be pressure and temperature changes. There are two phases of fluids: liquid and gas. Herewith several fluids tend to be used in industries, such as hydrocarbon and water for liquid phase; also steam and natural gas for gas phase. This fluid flows through inside a pipeline with different flow characteristics; either it is laminar or turbulent flow. These substances of fluid and their flow characteristic result in different design procedures, which are included in this guideline.

Besides material selection, pipe sizing should be considered in process system. It is important to make sure that substance will flow through optimally and so increase the process efficiency. Pipe size is determined by pipe length and allowable pressure drop in the line. Pipe length will reduce in pipe sizing for constant fluid flow rate, and so the inverse. Meanwhile, allowable pressure drop is influenced by factors such as process requirement, economics, safety, and noise or vibration limitations.

Pressure drop is a term to describe the decrease in pressure along the pipeline as a result of force friction due to resistance to flow. Large pressure drop is not desired since it means there is more resistance to flow and reduces the process efficiency. However it is important to understand pressure drop calculation in pipeline to maintain process stability.

Good consideration in material selection and pipe sizing will not develop proper pipeline design without good calculation methods. There might be different calculation methods for each industry based on their necessity, but generally it's all derived based on commonly used piping design theory. Commonly used theories are often preferable and easier to understand. For pipeline calculation, some commonly used theories are Bernoulli's Theorem and Darcy's Formula, which are also used for piping calculation in this guideline. Bernoulli's Theorem is used for general energy equation and pressure measurement. Meanwhile, Darcy's Formula is used for friction loss in fluid flow general equation and also as basic principle for compressible flow in pipe equation.

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There are another interconnect points need to be considered as well. They are usually includes in piping calculation. Hence this guideline also covers calculation in those piping-related equipments; such as valve, fittings and orifices.

Since it is important to get piping design calculation concept, herewith some applications and sample calculations, which is generally used in industrial, is attached in this guideline to make an engineer easier to learn and calculate an actual design of pipeline. Also there is Calculation Data Spreadsheet included to make the calculation even easier.

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INTRODUCTION

General Design Consideration

Detail and proper equipment selection is needed to build process systems. Large equipments usually need more consideration since its installation would require extra cost. But it is also important to notice on small equipments such as pipeline since its failure might result great damage in process system. Most failures of fluid process systems occur at or within interconnect points the piping, flanges, valves, fittings, etc. It is, therefore, vital to select interconnecting equipments and materials that are compatible with each other and the expected environment.

Materials selection is an optimization process, and the material selected for an application must be chosen for the sum of its properties. Many factors have to be considered in pipeline material selection, such as its suitability with valid application codes and standards; environment of pipeline; safety factors; pipeline performance and economic design; and the other parameters which might constrain its work.

Suitability of material selection with valid application codes and standards has to be reviewed for safety purposes and verification of applicability. The commonly used code and standard is American Society of Mechanical Engineering (ASME) Code for Pressure Piping, B31. This ASME Code is also being used in this guideline as it includes the minimum design requirements for various pressure piping applications.

Environmental considerations of a pipeline describe conditions where the pipeline is installed; whether the pipeline is on land or offshore, whether the climate is warm or cold. This environmental of pipeline needs to be considered since it might have potential damage in process piping design due to corrosion; either buried pipeline, offshore pipeline, or pipeline in warmer climate tend to get more corrosion challenges. Corrosion causing pipeline is easier to be ruptured and damaged process system.

Besides the conditions mentioned above, other physical damage might also occur due to operational failure and natural phenomena; such as fires, earthquakes, winds, snows or ice loadings. It is the temperature which is generally important to be maintained here. A small change in temperature might change an environmental of pipeline and process condition, so it affects the pipeline design. There are two instances of temperature changes must be considered as a minimum; first, the diurnal and seasonal changes, and second is thermal expansion. Thermal expansion of fluids in a pipeline

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might cause expansion contraction both in piping system and support system, which is undesirable in process. Also, there is internal erosion which might cause unseen hazard resulting system to be failure.

Safety factor or safety margin as a function of resistance (strength) and load (applied stress) is made large enough than compensate for uncertainties. Failure then occurs if the factor safety is less than one or becomes negative; or in other word: pipe strength is less than applied stress. For larger applied stress, pipeline material with better quality is needed.

The other term to be considered is pipeline performance and economic design, related to its durability and service life. It is better to design pipeline equipment based on based on performance, not economics. But it is also important to consider the economic aspect in order to minimizing process cost. Sometimes pipeline design with best performance might need an extra cost, so it is needed to find a proper design with suitable cost.

The selected material may not rank first in each evaluation category; it should, however, be the best overall choice. Considerations include cost and availability. Key evaluation factors are strength, ductility, toughness, and corrosion resistance. Piping material is selected by optimizing the basis of design. The remaining materials are evaluated for advantages and disadvantages such as capital, fabrication and installation costs; support system complexity; compatibility to handle thermal cycling; and protection requirements. The highest ranked material of construction is then selected.

In line with those design criteria mentioned above, it is also needed to define process flow rates, system pressure and temperature, pipe wall thickness, stress and pipe support requirements. This design and data then proceed with pipe sizing calculations, pressure integrity calculations, and stress analyses. Material trial might be needed if the selected piping material does not meet those requirements. Combination of these selective design criteria and correct calculation are required to result in proper pipeline design in order to support effective industrial process.

Several basic service conditions must also be reviewed to determine operational requirements; such as recommended fluid velocity for the application, and liquid characteristics (viscosity, temperature, suspended solids concentration, solids density and settling velocity, abrasiveness and corrosively). This information is useful to determine the minimum internal diameter of the pipe for the whole system network. Besides, the service condition should be considered as well because the piping system

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is designed to support various loading situation, such as pressure and temperature changes; thermal expansion and contraction; and other forces that may occur simultaneously. Combination of various loading situations is then used to set the stress limit design. Normal liquid service applications, as example, the acceptable velocity in pipes is 2.1 ± 0.9 m/s (7 ± 3 ft/s) with a maximum velocity limited to 2.1 m/s (7 ft/s) at piping discharge points including pump suction lines and drains. This velocity range is considered reasonable for normal applications.⁽⁴⁾

The primary requirement of the design is to get a suitable inside diameter with system design flow rates, basic service conditions, and pressure drops. The design flow rates and basic service conditions are based on system demands that are normally established in the process design project. But then it will involve trial and error procedure to find the suitable inside diameter with minimum pressure drop. Pressure drop, or head loss, is caused by friction between the pipe wall and the fluid, and by minor losses such as flow obstructions, changes in direction, changes in flow area, etc. Fluid head loss is added to elevation changes to determine pump requirements.

A common method for calculating pressure drop is the Darcy-Weisbach equation. Pressure drops throughout the piping network are designed to provide an optimum balance between the installed cost of the piping system and operating costs of the system pumps. Primary factors that will impact these costs and system operating performance are internal pipe diameter (and the resulting fluid velocity), materials of construction and pipe routing.

Generally pressure drop calculation for pipeline following these rules below:

- 1) Select the suitable Velocity which expressed in ft/sec; there is standard for general liquid flow the range of the velocity should be in the suitable range for the basic design.
- 2) Calculate the Reynolds number to determine the fluid flow. Reynolds number is a factor of pipe diameter, flow rate, density, and viscosity of the liquid; allows analysis of flow characteristics (slug, laminar, transition, turbulent); sanitary systems always require full turbulence (Reynolds number > 10,000).
- 3) Determine the suitable of pipe diameter - the inside pipe or tube diameter is used in the several equations to determine the pressure drops, Reynolds number, velocity and etc.

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- 4) Determine the roughness of pipe, the more rough the pipe, the larger the friction factor; the larger the friction factor, the more pressure drop.
- 5) Calculate the Pressure drop with expressed in the term “psi/100 ft of pipe”.
 - a. Incompressible flow - liquids; actual pressure is not a factor in pressure drop calculation.
 - b. Compressible flow - gases and vapors; actual pressure is a direct factor in pressure drop calculation.

Liquids (Incompressible Flow):

Size longer lines for less pressure drop than shorter lines.

Most water-like liquids, long lines should be sized for 0.5 to 1.0 psi/100 ft;

short lines should be sized for 1.0 to 2.0 psi/100 ft; no hard and fast rules.

For liquids with viscosities 10 cp or less consider just like water;

Above 10 cp, check Reynolds number to see what equations to use for pressure drop calculation.

Careful with sizing lines in the fractional line size range; It may cost more to install ¾” pipe and smaller than 1” pipe due to support requirements.

Usually don’t save on header sizing to allow for future increase in capacity without changing out pipe.

Pipeline holdup of process liquids may be a factor; smaller pipe may be desired to limit holdup even though pressure drop goes up.

Gases and Vapors (Compressible Flow):

Supply pressure is a major factor in line sizing calculations; also, overall pressure drop by means of typical calculation methods should not exceed 10% of the supply pressure, otherwise, alternative calculation methods must be used.

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Typically, consider all gases and vapors (including saturated steam) to behave gases in order to calculate vapor densities ($PV = nRT$).

DEFINITIONS

Compressible Fluid - Molecules in a fluid to be compacted and the density is varies. Energy is exchanged not only among the kinetic energy and the potential energies due to gravity and pressure, but also with the internal energy⁽⁷⁾.

Darcy Friction Factor, f - 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.

In-Compressible Fluid - An incompressible flow is one in which the density of the fluid is constant or nearly constant. Liquid flows are normally treated as incompressible⁽⁶⁾. Molecules in a fluid to be cannot be compacted. Generally the flow energy is converted to friction, kinetic and potential energy if available and not the internal energy.

Laminar 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 - A fluid characterized by a linear relationship between shear rate (rate of angular deformation) and shear stress.

Non-Newtonian Liquids - Fluids may be broadly classified by their ability to retain the memory of a past deformation (which is usually reflected in a time dependence of the material properties). Fluids that display memory effects usually exhibit elasticity.⁽⁸⁾ Fluids in which viscosity depends on shear rate and/or time. Examples are some slurries, emulsions, and polymer melts and solutions.

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

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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.

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 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.

Specific gravity - Is a relative measure of weight density. Normally pressure has not significant effect for the weight density of liquid, temperature is only condition must be considered in designating the basis for specific gravity.

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

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 - Turbulence is characterized by velocity fluctuations that transport momentum across streamlines; there is no simple relationship between shear stress and strain rate in turbulent flow. Instantaneous properties cannot be predicted in a turbulent flow field; only average values can be calculated. For engineering analyses, turbulent flow is handled empirically using curve-fits to velocity profiles and experimentally determinate loss coefficients. This flow type occurs in pipes in industrial situations when $Re > 4,000$. Under very controlled laboratory situations, laminar flow may persist at $Re > 4,000$.

Viscosity- Defined as the shear stress per unit area at any point in a confined fluid divided by the velocity gradient in the direction perpendicular to the direction of flow, if

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the ratio is constant with time at a given temperature and pressure for any species, the fluid is called a Newtonian fluid.

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.

NOMENCLATURE

A	Radius-sectional area, ft ² (m ²)
a	Sum of mechanical allowances plus corrosion allowance plus erosion allowance, in(mm)
C	Flow coefficient for the nozzles and orifices
c	Compressible factor, for perfect gas c =1.0
D	Internal diameter of pipe, ft (m)
d	Internal diameter of pipe, in
d ₁	Pipe with smaller diameter in enlargements or contractions in pipes
d ₂	Pipe with smaller diameter in enlargements or contractions in pipes
d _e	Equivalent hydraulic diameter, in (mm)
D _o	Outside diameter of pipe, in. (mm)
E	Weld joint efficiency or quality factor from ASME B31.3
f	Dancy's friction factor, dimensionless
f _t	Friction factor for fitting
g	Acceleration of gravity, ft/s ² (m/s ²) – 32.2ft/s ²
h _L	Head loss, ft (m)
k	Ratio of specific heat at constant pressure to specific heat at constant volume = c _p /c _v
K	Resistance coefficient, dimensionless
K ₁	Resistance coefficient for enlargement/contraction, dimensionless
L	Length of pipe, ft (m)
L _{eq}	Equivalent length, ft (m)
L _m	Length of pipe, miles
M	Molecular weight
P	Pressure drop in pipe, lbf/in ² (Pa)
P _i	Internal design pressure, psig (kPa gage)
Q	Volumetric flow rate, ft ³ /s (m ³ /s)
q	Volumetric flow rate, ft ³ /hr (m ³ /hr)
Q ₁	Rate of flow, gal/min

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R	Individual gas constant, MR =1544
R_e	Reynolds Number, dimensionless
S	Specific gravity of a liquid, dimensionless (hydrocarbon in API)
S_g	Specific gravity of a gas, dimensionless
S_m	Allowable stress, from ASME B31.3, psi (MPa)
T	Absolute temperature, R (460+°F)
t	Pressure design minimum thickness, in. (mm)
t_m	Total minimum wall thickness required for pressure integrity, in. (mm)
t_{nom}	Wall thickness, in. (mm)
V	Mean velocity, ft/s (m/s)
\bar{V}	Specific volume, ft ³ /lbm (m ³ /kg)
\bar{V}_1	Inlet specific volume, ft ³ /lb
V_{max}	The bigger velocity for enlargement / contraction, ft/s (m/s)
v_s	Sonic velocity, ft/s (kg/s)
W	Mass flow rate, lbm/hr (kg/hr)
w	Mass flow rate, lbm/s (kg/s)
Y	Expansion factor (dimensionless)
z	Elevation of pipe, ft (m)

Greek letters

ρ	Weight density of fluid, lbm/ft ³ (kg/m ³)
μ_c	Absolute viscosity, lbm.s /ft (kg.s/m)
μ	Absolute (dynamic) viscosity, cp
ε	Absolute roughness, in (mm)
θ	Angle of convergence or divergence in enlargements or contractions in pipes
Δ	Differential between two points

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THEORY

A) General Fluid Flow Theory

I) Physical Properties of Fluids

Physical properties of fluid are important for any flow problem and the accuracy of the values it affect the flow of fluids. If was the input of the engineering design of the piping and it will determine the pipe material selection and sizing.

Viscosity

A fluid viscosity can be described by its Dynamic viscosity (sometimes called Absolute viscosity), or its Kinematics viscosity. These two expressions of viscosity are not the same, but are linked via the fluid density.

Kinematics viscosity = Dynamic viscosity / fluid density

Density, Specific Volume and Specific Gravity

The weight density or specific weight of a substance is its weight per unit volume.

The specific volume \bar{V} is the reciprocal of the weight density, is expressed in the SI system as the number of cubic meter of space occupied by one kilogram of the substance.

The specific gravity of a liquid is the ratio of its weight density at specified temperature to that of water at standard temperature, 60F

$$S = \frac{\rho\{\text{any liquid at specific temperature}\}}{\rho(\text{water at 60F})} \quad \text{Eq (1a)}$$

For hydrocarbon like oil, the API unit is used.

$$S (60 F / 60 F) = \frac{141.5}{131.5 + \text{deg}.API} \quad \text{Eq(1b)}$$

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Normal water deg. API unit is 10, that mean water $S = 1.00$

For gas the specific gravity S_g is expressed as

$$S_g = \frac{M(\text{gas})}{M(\text{air})} \quad \text{Eq (1c)}$$

Mean Velocity

Mean velocity is the average velocity in flow across the given cross section as determined by the continuity equation for steady state flow. It normally express as ratio of the volumetric flow rate (Q) to sectional area (A) of the pipe.

$$\text{Mean Velocity, } V = \frac{Q}{A} \quad \text{Eq (2)}$$

which,

- V = mean velocity, ft/s (m/s)
- Q = volumetric flow rate, ft³/s (m³/s)
- A = radius-sectional area, ft² (m²)

Which, Volumetric flow rate in the pipe line is the ratio of the mass flow rate to density of the fluid.

$$\text{Volumetric flow rate, } Q = \frac{w}{\rho} \quad \text{Eq (3)}$$

which,

- w = mass flow rate, lbm/s (kg/s)
- ρ = weight density of fluid, lbm/ft³ (kg/m³)

and the Sectional Area in pipe formula is expressed as

$$\text{Sectional area, } A = \frac{\pi D^2}{4} \quad \text{Eq (4)}$$

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II) Flow Characteristic in Pipe

Three differences kind of flow in pipe which determines the pipe sizing. There are laminar flow, between laminar and transition zones flow, and turbulent flow. This mean is very important for the designer to determine the type of flow of the fluid before proceed the next stage calculation.

Reynolds Number

The Reynolds Number is used to determine the nature of flow in pipe whether is the laminar flow or turbulent flow. Reynolds Number with symbol R_e , which depend with pipe diameter (D), the density (ρ) and absolute viscosity (μ) of the flowing fluid and it velocity (V) of the flow. This number is a dimensionless group with combination of these four variables which expressed as

$$R_e = \frac{DV\rho}{\mu_e} \quad \text{Eq (5a)}$$

$$R_e = \frac{50.6 Q_1 \rho}{d\mu} \quad \text{Eq (5b)}$$

which,

- D = internal diameter of pipe, ft (m)
- V = mean velocity of flow, ft/s (m/s)
- ρ = weight density of fluid, lbm/ft³ (kg/m³)
- μ_e = absolute viscosity, lbm /ft.s (kg /m.s)
- d = internal diameter of pipe, in
- Q_1 = Mass flow, gal/min
- μ = absolute (dynamic) viscosity, cp

Fluid Flow Equations for the Friction Loss/Pressure Drop in Pipe

Bernoulli's equation is useful in calculation of the fluid flow. It was following the first law of the Thermodynamic and there it applies to calculate the energy balance in steady state and incompressible flow. The formula for the friction term in pipe line is expressed as

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$$\Delta \left(\frac{P}{\rho} + z + \frac{V^2}{2g} \right) = h_L \quad \text{Eq (6)}$$

which,

- P = pressure drop in pipe, lbf/in²(Pa – For the SI unit remember to divide the pressure head with the acceleration of gravity.)
- z = elevation of pipe, ft (m)
- g = acceleration of gravity, ft/s² (m/s²) – 32.2ft/s²
- h_L = Head loss, ft (m)

Dancy's formula of the friction in pipe line is expressed as

$$h_L = f \frac{L}{D} \cdot \frac{V^2}{2g} \quad \text{Eq (7)}$$

which,

- f = friction factor, dimensionless
- L = length of pipe, ft (m)

Dancy's friction factor, f is determined experimentally. Normally friction factor for the laminar flow conditions ($Re < 2100$) is simple calculated with just function of the Reynolds number only, which can be expressed as

$$f = \frac{64}{R_e} \quad \text{Eq (8)}$$

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