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TABLE OF CONTENTS

List of Figure

INTRODUCTION

The purpose of this pocket handbook is to make readily available in a limited number of pages some of the more important understanding of how gasses and fluids flow in equipment that are fundamental to the practice of the chemical engineering profession. The pocket handbook covers the basic elements in the field of Piping Fluid Flow Material Selection and Line Sizing in sufficient detail to design a pipeline and / or other piping classes. This pocket handbook includes single phase liquid flow, single phase gas flow for hydrocarbon, water, steam and natural gases.

The proper pipe sizing and the principles of fluid flow are discussed in this pocket handbook which is very critical to understand before designing equipment. The principles are not complex, but neither are they simple due to the interdependence of pressure drop and friction

Proper pipe sizing is determined by the length of the pipe and the allowable pressure drop in the line. The allowable pressure drop may be influenced by factors, including process requirements, economics, safety, and noise or vibration limitations. This pocket handbook also covers other piping related equipment, such as valve, fittings and orifices. Pressure drop calculations in these fitting are discussed in detail to help the design of piping systems.

Process Equipment Design Flaws

Many groups of process equipment follow the “Kolmetz Universal Law of Project Stupidity”. A law strictly followed by most engineering and non-engineering projects.

“Save money and poorly design the process equipment by awarding it to the low-cost bidder. Loose money for the next twenty years on plant capacity, maintenance reliability, and excess energy.”

According to this law, awarding a process equipment contract to the lowest bidder may save you money in the short term, but it can cost you heavily in the long run. You may end up losing money for the next twenty years on plant capacity, maintenance reliability, and excess energy. So, next time you are tempted to cut corners, remember the Kolmetz Law of Project Stupidity.

Typically, process equipment is awarded to the lowest bidder with very low standards of guarantees. Typical guarantees by the manufacturers are hydraulic capacity only, and this test must be carried out within three to six months, while the process equipment is still clean and new. Typical process guarantees are by the process engineering company which includes capacity and purities, again the performance test must be carried out within three to six months.

Imagine buying a car and receiving a three-to-six-month warranty and only good gas milage for the first six months. You would think the car manufacturer was taking advantage of you, yet this is what we do for heat exchangers, and cars are much more complex than heat exchangers.

Kolmetz Law in action – we saved USD 50,000 on trays and spend USD 1.0 million on larger vessels, foundations and piping. Also add the higher energy cost and lower purities over 20 years maybe another USD 1.0 million. We saved USD 50,000 and lost 2.0 million.

What are things that should be included in process equipment design that are not being utilized because of the sweetheart guarantees and low-cost bidders.

1. KLM is a recognized expert in Process Equipment Design, only utilize groups with technical expertise. This guideline has sizing examples in the document and then in an excel spreadsheet.

2. KLM only partners with high quality suppliers, often from the same factories as the Original Equipment Manufacturers (OEM) and has senior inspectors to ensure your equipment is installed correctly

3. Ensure correct metallurgy. Do not use Stainless Steel in Acid or Caustic Solution Servies as some Stainless Steel is not resistant to attack. Many vendors only supply stainless steel even though they know that this might be the wrong metallurgy for your application.

4. Review Galvanic Corrosion Potential for extended life. If you have polar liquids (water, acids, caustics) and a carbon steel vessel, stainless steel will experience bi-metallic corrosion with reduced life.

5. Review the failures of the non-technical suppliers.

KLM can assist your team in providing Senior Engineering and Operations Staff to provide support for your local team in many areas including demister pads, distillation towers, heat exchanger and pump design.

GENERAL FLUID FLOW THEORY

In designing the piping fluid flow there are many factors have to be considered for the suitability of the material selection for the application codes and standards, environmental requirements, safety, performance of the requirements, and the economics of the design and other parameters which may constrain the work.

They should be included engineering calculations for the piping system design. Combined with the piping design criteria, calculations define the process flow rates, system pressure and temperature, pipe wall thickness, and stress and pipe support requirements.

The service conditions should be the consideration as well because the piping system is designed to accommodate all combinations of loading situations such as pressure changes, temperature changes, thermal expansion and contraction and other forces or moments that may occur simultaneously and they are used to set the stress limit of the design.

Design code and the standards are reviewed for the project of the design for the safety purposes and the verification of the applicability. In this design guideline generally follows the codes and the standards of the American Society of Mechanical Engineers (ASME) Code for Pressure Piping, B31. ASME B31 includes the minimum design requirements for various pressure piping applications.[4]

Normal environmental factors that have the potential for damage due to corrosion must be addressed in the design of process piping. Physical damage may also occur due to credible operational and natural phenomena, such as fires, earthquakes, winds, snow or ice loading, and subsidence. Two instances of temperature changes must be considered as a minimum.

First, there are daily and seasonal changes. Second, thermal expansion where elevated liquid temperatures are used must be accommodated. Compensation for the resulting expansions contractions are made in both the piping system and support systems. Internal wear and erosion also pose unseen hazards that can result in system failures.

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 equipment 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. That is, 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 catholic protection requirements. The highest ranked material of construction is then selected.

The design proceeds with pipe sizing, pressure integrity calculations and stress analyses. If the selected piping material does not meet those requirements, then second ranked material is used to sizing, pressure integrity calculation and stress analyses are repeated.

For the pressure drop calculation: the primary requirement of the design is to find an inside diameter with system design flow rates and pressure drops. The design flow rates are based on system demands that are normally established in the process design phase of a project. This will involves trial and error procedure to find the suitable inside diameter.

Basically service conditions must be reviewed to determine operational requirements such as recommended fluid velocity for the application and liquid characteristics such as 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.

Normal liquid service applications, 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. This velocity range is considered reasonable for normal applications.[4]

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.

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.

Normally for the line sizing the following rules should be follow

1) Calculate the Pressure drop with expressed in the term "psi/100 ft of pipe".
2) 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.
3) 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)
4) 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.
5) Determine the roughness of pipe, the more rough the pipe, the larger the friction factor; the larger the friction factor, the more pressure drop.
6) Incompressible flow- liquids; actual pressure is not a factor in pressure drop calculation.
7) 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; but there are 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 do not save on header sizing to allow for future increase in capacity without changing out piping. Pipeline holdup of process liquids may be a factor; smaller pipe may be desired to limit holdup even though pressure drop goes up.

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.

Reynolds Number, Re - A dimensionless number which expresses the ratio of inertial to viscous forces in fluid flow

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.

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 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 (mm)
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) – $32.2 ft/s^2$ – $9.8 m/s^2$
GPM	Volume flow rate, gpm (m^3/hr)
ΔH	Surge pressure, ft-liq (m-liq)
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)
M	Molecular weight
P	Pressure drop in pipe, lbf/in^2(kg/cm^2)
P_i	Internal design pressure, psig (kg/cm^2 gage)
Pwr	power, hp (kW)
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 (m^3/min)
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)
Tv	Valve stroking time (s)
Te	Effective valve stroking time (s)
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)
$\overline{V}$	Specific volume, ft^3/lbm (m^3/kg)
$\overline{V_1}$	Inlet specific volume, ft^3/lb (m^3/kg)
V_{max}	The bigger velocity for enlargement / contraction, ft/s (m/s)
ΔV	Change of linear flow velocity, ft/s (m/s)

v_s	Sonic velocity, ft/s (kg/s)
W	Mass flow rate, Ibm/hr (kg/hr)
w	Mass flow rate, Ibm/s (kg/s)
Y	Expansion factor (dimensionless)
z	Elevation of pipe, ft (m)

Greek letters

ρ	Weight density of fluid, Ibm/ft^3 (kg/m^3)
μ_e	Absolute viscosity, Ibm.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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