KLM Technology Group

Project Engineering Standard

KLM Technology Group

Engineering Solutions

www.klmtechgroup.com

Page : 1 of 62

Rev: 01

April 2011

KLM Technology Group
#03-12 Block Aronia,
Jalan Sri Perkasa 2
Taman Tampoi Utama
81200 Johor Bahru
Malaysia

PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING)

(PROJECT STANDARDS AND SPECIFICATIONS)

KLM Technology Group has developed; 1) Process Engineering Equipment Design Guidelines, 2) Equipment Design Software, 3) Project Engineering Standards and Specifications, 4) Petrochemcial Manufactuing Reports and 5) Unit Operations Manuals. Each has many hours of engineering development.

KLM is providing the introduction to this standard for free on the internet. Please go to our website to order the complete document.

www.klmtechgroup.com

KLM Technology Group with their key partners specialize in;

1) Process Engineering Equipment Design Guidelines
2) Training for Refining, Chemicals, Ethylene and Equipment Design
3) Process Engineering Consulting Studies
4) Process Safety Management Consulting
5) HAZOP Facilitation
6) Distillation Equipment Supply (Random and Structured Packing, Trays)
7) Commissioning Assistance

TABLE OF CONTENT

PROCESS PIPE SIZING FOR PLANTS LOCATED ONSHORE-SINGLE PHASE

PROCESS PIPE SIZING FOR PLANTS LOCATED OFFSHORE

TRANSMISSION PIPELINES FOR LIQUID AND GAS

TWO PHASE FLOW

SCOPE

This Project Standards and Specifications covers process piping design and pipeline sizing, in addition to presenting most popular pressure drop equations and fluid velocity.

The subject of this Standard is to present mathematical relationships, based on which pipe size is calculated. The relationships presented cover Newtonian fluids which include most useful process piping application.

Unless noted otherwise, the methods suggested here do not contain any built-in safety factors. These should be included, but only to the extent justified by the problem at hand.

REFERENCES

Throughout this Standard the following dated and undated standards/codes are referred to. These referenced documents shall, to the extent specified herein, form a part of this standard. For dated references, the edition cited applies. The applicability of changes in dated references that occur after the cited date shall be mutually agreed upon by the Company and the Vendor. For undated references, the latest edition of the referenced documents (including any supplements and amendments) applies.

1. API (American Petroleum Institute) API Publication 2564

Third Ed., December 2001,	"Manual of Petroleum Measurement Standards; Chapter 15 Guidelines for the Use of International System of Units (SI) in the Petroleum and Allied Industries"

2. NACE (National Association of Corrosion Engineers)

NACE MR 0175-2002,	"Standard Material Requirements Sulfide Stress Cracking Resistant Metallic”

3. GPSA (Gas Processors Suppliers Association)
   "Engineering Data Book", Vol. II, Section 17, 10th. Ed., 1987

4. Hydraulic Institute Standard
   "Centrifugal, Rotary and Reciprocating Pumps", 14th. Ed., January 1982

DEFINITIONS AND TERMINOLOGY

AGA - American Gas Association

BBM - Begg's-Brill-Moody

dB - Decibles (unit of sound pressure level)

DN - Diameter Nominal, in (mm). The Nominal Pipe Size (NPS) will be designated by "DN" although in calculations the diameter generally has the units of millimeters (mm). The following table gives equivalents of Nominal Pipe Size in DN and Nominal Pipe Size (NPS) in inches:

DN (mm)	NPS (inches)	DN (mm)	NPS (inches)
15	½	400	16
20	¾	450	18
25	1	500	20
40	1½	600	24
50	2	650	26
80	3	700	28
100	4	750	30
150	6	800	32
200	8	900	36
250	10	1000	40
300	12		
350	14		

Eq. – Equation

ERW - Electric Resistance Welding

mmH_2O - In adopting the SI System of Units in this Standard it has been tried to satisfy the requirements of API Publication 2564. To this end, kilopascal (kPa) is adopted as the unit of pressure in calculations. But in cases where the pressure drop is expected to be small, millimeters of water column (mm H_2O) is also used [9.80665 Pa = 1 mm H_2O (Conventional)].

MSC - The Metric Standard Conditions. For measuring gases and liquids as referred to in the Standard is defined as 101.325 kPa and 15°C.

NGL - Natural Gas Liquids

NPS - Nominal Pipe Size, in (inch)

NPSHA - Net Positive Suction Head Available

NPSHR - Net Positive Suction Head Required

Re - Reynolds number

r/min - Rotations (revolutions) per minute (RPM)

s - second.

SYMBOLS AND ABBREVIATIONS

SYMBOL/ABBREVIATION	DESCRIPTION
A	Area of cross-sectional of pipe, in (m^2)
Am	Minimum pipe cross-sectional flow area required, in (mm per m^3/h liquid flow)
Amm	Cross-section of pipe, in (mm^2)
B_d	Rate of flow in barrels (42 U.S gallons)per day
B_h	Rate of flow in barrels (42 U.S gallons) per hour
B_X & B_Y	Baker parameters
C	Hazen-Williams constant
D	Inside diameter of pipe, in (m)
D_p	Particle diameter, in (mm)
d_i	Inside diameter of pipe, in (mm)
E	Efficiency factor
f	Friction factor of pipe, (dimenssionless)
f_D	Darcy's friction factor = f_m, (dimensionless)
f_m	Moody friction factor, (dimenssionless)
f_f or f_F	Fanning friction factor $f_D = f_m = 4f_F$, (dimenssionless)
g	Gravitational acceleration (usually is equal to 9.81 m/s^2)
G	Relative density of gas at the prevailing temperature and pressure relative to air, G =M(gas)/M(air), at 20°C and 760 mm of mercury.
h_f	Head loss due to friction, in (mm)
h_c	Head loss due to friction, in (mm)
h_R	Enthalpy of condensate at supply pressure, in (J/kg)
H	Enthalpy of condensate at return line pressure, in (J/kg)
h_1	Static head, in (m)

h_2	Initial elevation of pipeline, in (m)
K	Final elevation of pipeline, in (m)
K_e	Ratio of specific heat at constant pressure to the specific heat at constant volume cp/cv, (dimensionless)
L	Coefficient of resistance in pipe, fitting, valves and etc., in (m)
L_{km}	Length of pipe, in (m)
L_e	Equivalent length of pipe, in (m)
L_R	Latent heat of steam at return line pressure, in (J/kg)
M	Molecular mass, in (kg/mol)
P	Operating pressure, in [kPa (absolute)]
P_{ave}	Average gas pressure = $\frac{2}{3}\left(P_1+P_2-\frac{P_1 P_2}{P_1+P_2}\right)$
P_f	Operating pressure in fittings, in [kPa (absolute)]
P_v	Vapor pressure of liquid in suction temperature of pump, in [kPa (absolute)]
P_o	Base pressure, in [101.325 kPa (absolute)]
P_1	Initial or inlet pressure, in [kPa (absolute)]
P_2	Final or outlet pressure, in [kPa (absolute)]
ΔP_{100}	Operating pressure, along 100 m of pipe, in kPa/100 (absolute) or [P_1-P_2/100 (absolute)]
ΔP_{100}	Pressure loss, in (kPa/100 m)
ΔP_{TP100}	Two-phase pressure, loss, in (kPa/100 m)
Q_L	Liquid flow rate, in (m^3/h)
Q_{sc}	Gas flow rate at P_o, T_o, in (m^3/h)
Q_v	Vapor flow rate, in (m^3/h)
q	Rate of flow at flowing conditions, in (m^3/s)
q_l	Liquid flow rate, in litre/minute (L/min)

q_s	Liquid flow rate, in (m^3/s)
R	Universal gas constant, in 8314.3/M (J/kg. mol. K)
R_e	Reynolds number
R_{em}	Modified Reynolds number
R_{gl}	Gas/liquid ratio in m^3 (gas)/m^3 (liquid) at MSC
S	Relative liquid density (water = 1)
T	Flowing temperature, in kelvin (K)
T_o	Base temperature = (273 + 15) = 288 K
V	Fluid velocity, in (m/s)
V_{ave}	Average fluid velocity, in (m/s)
V	Specific volume, in (m^3/kg)
V_c	Critical velocity with respect to sound velocity, in (m/s)
V_e	Fluid erosional velocity, in (m/s)
V_R	Specific volume of steam at return line pressure, in (m^3/kg)
W	Mass flow rate, in (kg/h)
W_T	Total fluid mass flow rate, in (kg/h), (liquid+vapor)
W_c	Condensate load, in (kg/h)
W_L	Liquid mass flow rate, in (kg/h)
W_g	Gas mass flow rate, in (kg/h)
x	mass (weight) fraction of vapor, (dimenssionless)
X	L & M modulus for two-phase
Z	Gas compressibility factor

Greek Letters:

Δ (delta)	Differential between two points
ε (epsilon)	Absolute pipe roughness in (mm)
γ(nu)	Kinematic viscosity, in (m^2/s) = $\frac{\text{absolute viscosity}}{\text{relative density}}$
μ (mu)	Absolute viscosity at flowing temperature and pressure, in (cP)
μ_g (mu)	Gas viscosity at flowing temperature and pressure, in (Pa.s)
ρ(rho)	Density, in (kg/m^3)
ρ_L (rho)	Liquid density, in (kg/m^3)
ρ_g (rho)	Gas density, in (kg/m^3)
ρ_V (rho)	Vapor density, in (kg/m^3)
ρ_m (rho)	Mixture density, in (kg/m^3)
ρ_{TP} (rho)	Two-phase flow density, in (kg/m^3)
λ(lambda)	Liquid volumetric fraction
φ(phi)	A fraction of L & M modules
δ(sigma)	Surface tension of liquid, in (dyne/cm = mN/m)

Subscripts:

1-	Refer to initial, or upstream conditions
2-	Refer to second, downstream or outlet
g-	Refers to gas
L-	Refers to liquid

UNITS

This Standard is based on International System of Units (SI) except where otherwise specified.

PROCESS PIPE SIZING FOR PLANTS LOCATED ONSHORE-SINGLE PHASE

GENERAL SIZING CRITERIA

The optimum pipe size should be based on minimizing the sum of energy cost and piping cost. However, velocity limitations causing erosion or aggravating corrosion must be taken into consideration. Sometimes, the line size must satisfy process requirements such as pump suction line. Although pipe sizing is mainly concerned with pressure drop, sometimes for preliminary design purposes when pressure loss is not a concern, process piping is sized on the basis of allowable velocity.

When there is an abrupt change in the direction of flow (as in elbow or tees), the local pressure on the surface perpendicular to the direction of flow increases dramatically. This increase is a function of fluid velocity, density and initial pressure. Since velocity is inversely proportional to the square of diameter, high velocity fluids require special attention with respect to the size selection.

FLUID FLOW

In vapor systems, the use of rule of thumb or approximate sizing methods can lead to critical flow and subsequent vibration and whistling. With two-phase systems, improper sizing can lead to slug flow with its well known vibration and pressure pulsations.

With both vapor and two-phase systems, approximate calculations often neglect the importance of momentum on total pressure drop; the result being that, pressure drop available for controllability, is reduced; and rigorous calculations to determine pressure drop involving trial and error should be performed by computers. The problem is further complicated when a diameter is to be found which will produce a specified pressure drop or outlet velocity for a given flow.

In this situation additional trial and error is required to determine the proper diameter. The design problem as described above is correctly defined as line sizing. The opposite problem, that of calculating velocity and pressure loss for a given diameter is very frequently encountered during hydraulic or "spool" checks. In general an evaluation of the total system equivalent length must be made based on fittings, valves, and straight line in the system. In addition, fitting and valve losses are not constant, but are functions of diameter. A preliminary line sizes must often be selected before an accurate knowledge of the system equivalent length is available, spool check calculations are required before final specifications for prime movers can be written on final diameter, chosen.

REYNOLDS NUMBER

The relationship between pipe diameter, fluid density, fluid viscosity and velocity of flow according to Reynolds number is as follows:

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

FRICTION FACTOR

The basis of the Moody friction factor chart (see Appendix A, and B) is the Colebrook equation.

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left[\frac{\varepsilon}{3.7D} + \frac{2.51}{R_e\sqrt{f}}\right] \qquad \text{Eq. (2)}$$

For reference chart and method of solution see Appendix A, and B.

FLUID FLOW CALCULATIONS

For calculation pressure loss for a single phase (liquid-gas-vapor) fluid at isothermal condition when flow rate and system characteristics are given; presented in this Standard through the application of Darcy-Weisbach (often referred to as simply Darcy) and Fanning principles

For compressible (gas and vapor lines, where the pressure losses are small relative to line pressure) reasonable accuracy can often be predicted providing the following conditions are met.

The average gas density of flow in uses i.e., $\rho = \frac{(\rho_1 + \rho_2)}{2}$

The pressure drop is less or equal 40% of up stream pressure
i.e., $(P_1 – P_2) \leq 0.4 P_1$

This is because energy losses due to acceleration and density variations can be neglected up to this limit. In cases where the pressure loss is less than 10% of the upstream pressure, an average value of ñ is not required and either the downstream or upstream density can be used.

SINGLE PHASE LIQUID FLOW

For the calculation of pressure loss in liquid lines, the Darcy-Weisbach or Fanning methods shall be used. The calculation is simplified for liquid flows since the density can reasonably be assumed to be constant.

As a result the Darcy-Weisbach calculation can be applied to a long run of pipe rather than segmentally as directed by the variable density in gas flow. Elevation pressure drops must be calculated separately, using Equation (3):

$$\Delta P_e = \frac{h_L . \rho}{10200} \text{ kg/m}^2 \qquad \text{Eq. (3)}$$

The elevation pressures gains or losses are added algebraically to the frictional pressure drops.

Flow is considered to be laminar at Reynolds number of 2000 or less, therefor before using the formula for pressure drop, Reynolds number should be determined for regime of flow. The following formula is for pressure loss of laminar flow:

$$\Delta P_{100} = \frac{32\mu 2\mu}{d^2} = 4070x10^4 \mu . q_s/d^4 \text{ at flow condition} \qquad \text{Eq. (4)}$$

Where:

ΔP_{100} is the pressure drop in bar per 100 meters.

For a given mass flow rate and physical properties of a single phase fluid in turbulent conditions, P100 can be expressed:

$$\Delta P_{100} = 6253 \frac{f_p.W^2}{d^5.\rho} \qquad \text{Eq. (5)}$$

Alternatively, for a given volumetric rate, ΔP_{100} can be expressed as:

ΔP_{100} = 81055 x 10^7 f_D . q^2/d^5 = bar/100 meter

at flowing conditions (temperature and pressure)

FITTINGS AND VALVES

In case where the coefficient of resistance "K" are to be used, K = K valve + K elbow + K tee...... shall be taken and calculated from Appendices D, E and F. The value "K" is defined as follows:

$$\Delta P = n \frac{4.f.L}{d} \left(\frac{\rho.V_2}{2gc} \right) \text{ (Fanning equation)} \qquad \text{Eq. (7)}$$

$$K = \frac{4.f.L}{d} \qquad \text{Eq. (8)}$$

Pressure drops "$P\Delta_f$" in fittings can be calculated as follows:

$$\Delta P = K \left(\frac{\rho.V^2}{2gc} \right) \qquad \text{Eq. (9)}$$

Where:

ΔP_f is pressure drop in fitting (psi) or (kg/cm^2);
K is coefficient of resistance;
V is velocity is pipe (ft/sec) or (m/s);
P is density (lb/ft^3) or (kg/m^3);