

KLM Technology Group Project Engineering Standard	 www.klmtechgroup.com	Page : 1 of 55
		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)	

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TABLE OF CONTENT

SCOPE	3
REFERENCES	3
DEFINITIONS AND TERMINOLOGY	4
SYMBOLS AND ABBREVIATIONS	5
UNITS	8
PROCESS PIPE SIZING FOR PLANTS LOCATED ONSHORE-SINGLE PHASE	
GENERAL SIZING CRITERIA	9
FLUID FLOW	9
REYNOLDS NUMBER	10
FRICTION FACTOR	10
FLUID FLOW CALCULATIONS	10
SINGLE PHASE LIQUID FLOW	11

KLM Technology Group Project Engineering Standard	 www.klmtechgroup.com	Page : 2 of 55
		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)	

FITTINGS AND VALVES	11
SPECIAL CONDITIONS	12
SINGLE PHASE GAS FLOW	16

PROCESS PIPE SIZING FOR PLANTS LOCATED OFFSHORE

SCOPE	19
SIZING CRITERIA-GENERAL	19
SIZING CRITERIA FOR LIQUID LINES	20
PUMP PIPING	20
SIZING CRITERIA FOR SINGLE-PHASE GAS LINES	24
SIZING CRITERIA FOR GAS/LIQUID TWO-PHASE LINES	25

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING) (PROJECT STANDARDS AND SPECIFICATIONS)	Page 3 of 55
		Rev: 01
		April 2011

TRANSMISSION PIPELINES FOR LIQUID AND GAS

SCOPE	28
SIZING CRITERIA	28
CRUDE OIL PIPELINES	28
NATURAL GAS LIQUIDS (NGL) PIPELINES	30
NATURAL GAS PIPELINES	30
TWO PHASE FLOW	
TWO PHASE FLOW SIZING PROCESS PIPING	32
TWO-PHASE FLOW PATTERNS	36
VELOCITY LIMITATIONS	37
MAINTAIN THE PROPER REGIME	38
DESIGN CONSIDERATIONS	39
APPENDIX A	43
APPENDIX A.1	44
APPENDIX B	46
APPENDIX C	47
APPENDIX D	48
APPENDIX E	49
APPENDIX F	50
APPENDIX G	52

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING) (PROJECT STANDARDS AND SPECIFICATIONS)	Page 4 of 55
		Rev: 01
		April 2011

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"

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING) (PROJECT STANDARDS AND SPECIFICATIONS)	Page 5 of 55
		Rev: 01
		April 2011

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 - Decibels (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	1/2	400	16
20	3/4	450	18
25	1	500	20
40	1 1/2	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

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING) (PROJECT STANDARDS AND SPECIFICATIONS)	Page 6 of 55
		Rev: 01
		April 2011

ERW - Electric Resistance Welding

mmH₂O - 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 H₂O) is also used [9.80665 Pa = 1 mm H₂O (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.

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING) (PROJECT STANDARDS AND SPECIFICATIONS)	Page 7 of 55
		Rev: 01
		April 2011

SYMBOLS AND ABBREVIATIONS

<u>SYMBOL/ABBREVIATION</u>	<u>DESCRIPTION</u>
A	Area of cross-sectional of pipe, in (m ²)
A _m	Minimum pipe cross-sectional flow area required, in (mm per m ³ /h liquid flow)
A _{mm}	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, (dimensionless)
f _D	Darcy's friction factor = f _m , (dimensionless)
f _m	Moody friction factor, (dimensionless)
f _f or f _F	Fanning friction factor f _D = f _m = 4f _F , (dimensionless)
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)

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING) (PROJECT STANDARDS AND SPECIFICATIONS)	Page 8 of 55
		Rev: 01
		April 2011

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

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING) (PROJECT STANDARDS AND SPECIFICATIONS)	Page 9 of 55
		Rev: 01
		April 2011

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, (dimensionless)
X	L & M modulus for two-phase
Z	Gas compressibility factor

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING) (PROJECT STANDARDS AND SPECIFICATIONS)	Page 10 of 55
		Rev: 01
		April 2011

Greek Letters:

Δ (delta)	Differential between two points
ε (epsilon)	Absolute pipe roughness in (mm)
ν (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.

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING) (PROJECT STANDARDS AND SPECIFICATIONS)	Page 11 of 55
		Rev: 01
		April 2011

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.

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING) (PROJECT STANDARDS AND SPECIFICATIONS)	Page 12 of 55
		Rev: 01
		April 2011

REYNOLDS NUMBER

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

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

FRICTION FACTOR

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

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

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 \bar{n} is not required and either the downstream or upstream density can be used.

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING) (PROJECT STANDARDS AND SPECIFICATIONS)	Page 13 of 55
		Rev: 01
		April 2011

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):

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

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, therefore 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:

$$\Delta P_{100} = \frac{32\mu_2\mu}{d^2} = 4070 \times 10^4 \mu \cdot q_s / d^4 \text{ at flow condition} \quad \text{Eq. (4)}$$

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, P_{100} can be expressed:

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

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

$$\Delta P_{100} = 81055 \times 10^7 f_D \cdot q^2 / d^5 = \text{bar/100 meter}$$

at flowing conditions (temperature and pressure)

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING) (PROJECT STANDARDS AND SPECIFICATIONS)	Page 14 of 55
		Rev: 01
		April 2011

FITTINGS AND VALVES

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

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

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

Pressure drops " ΔP_f " in fittings can be calculated as follows:

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

Where:

ΔP_f is pressure drop in fitting (psi) or (kg/cm²);

K is coefficient of resistance;

V is velocity is pipe (ft/sec) or (m/s);

ρ is density (lb/ft³) or (kg/m³);

gc is gravity constant 32.17 (lb/ft/sec² . lb-force), 9.80 (kg.m/s² . kg-force).

As a result, following equation is obtained:

$$\Delta P_f = K. \rho . V^2 / 196120 = 5.1 \times 10^{-6} K. \rho.V^2 \text{ kg/cm}^2 \quad \text{Eq. (10)}$$

$$= 5 \times 10^{-4} K. \rho.V^2 \text{ kPa} \quad \text{Eq. (11)}$$

In cases where valves and fittings are to be handled as pipe equivalent lengths, the equivalent lengths shall be taken from Appendix G and added to the actual pipe lengths, from which the pressure drops shall be calculated.

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING)	Page 15 of 55
	(PROJECT STANDARDS AND SPECIFICATIONS)	Rev: 01
		April 2011

SPECIAL CONDITIONS

1. Water Flow

The pressure loss for water flow shall be calculated by Hazen- Williams's formula. The Hazen-William's relationship, is one of the most accurate formula for calculation pressure loss in water line (see Appendix C for Hazen-William's constant C). For the design of new water pipelines, constant "C" is taken as "100". The Hazen-s formula is as follows:

$$h_f = 2.25 \times 10^4 L_e \left(\frac{100}{C} \right)^{1.85} \left(\frac{Q_w^{1.85}}{d^{4.8655}} \right) \quad \text{Eq. (12)}$$

2. Pump Suction Lines

Generally the pressure drops in pump suction lines shall be held below 4.5 kPa/100 m; in the case of liquid at the boiling point and below 7.9 kPa/100 m in the case of liquid below the boiling point.

The maximum velocity of bubble point liquids shall be 1.2 m/s and for sub-cooled liquids shall be 2.4 m/s. For corrosive liquids these values may be reduced by fifty percent.

Allowable pressure drops can be determined by the following formula:

$$\Delta P = 9.835 S [H - (\text{NPSHR} + \alpha)] + (P_1 - P_v) \quad \text{Eq. (13)}$$

Where:

ΔP is friction loss in piping to pump inlet, in (kpa);

S is relative density (Water = 1);

H is height from datum to pump centre, in (m) (the term "Datum" refers to the bottom tangent line in the case of vertical vessels and to the bottom level in the case of horizontal vessels);

NPSHR is net positive suction head required, in (m);

α (alpha) is 0.305 m (1 ft) for liquid at boiling point and 0.2134 m for liquid below boiling point;

P_1 is pressure working on suction liquid surface, in (kPa);

P_v is vapor pressure of liquid at suction temperature, in (kPa).

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING) (PROJECT STANDARDS AND SPECIFICATIONS)	Page 16 of 55
		Rev: 01
		April 2011

In cases where permanent strainers are to be provided a minimum pressure drop of 3.45 kPa (0.5 psi) shall be added in the case of dirty service. No addition is required in the case of clean service.

The equivalent length to be used for pressure drop calculations shall be assumed to be 46 m (150 ft).

A suction liquid line to a centrifugal pump should be short and simple. Velocities are usually between 0.3 to 2.13 m/s. Higher velocities and unit losses can be allowed within this range when subcooled liquid is flowing than when the liquid is saturated.

Note that the longer payout times favor larger pipe diameters. Pipe smaller than pump discharge nozzle size is not used.

3. Cooling Water

Cooling water discharge headers are usually sized with unit pressure losses in decimals of 7 kPa (1 psi). An economical comparison is justified with large diameter piping, where most of the pump pressure is used for pipe and equipment resistance. Of course, piping costs increase with diameter while utility costs decrease. Between alternate design the best size can be determined by adding the total cost of utilities over the period of capital payout to the capital cost of each installation. The lowest over-all figure will give the most economical solution.

4. Limitations Owing to Erosion Preventive Measures

Velocity of the fluid plays an important role in erosion-corrosion. Velocity often strongly influences the mechanism of the corrosion reactions. Mechanical wear effects at high values and particularly when the solution contains solids in suspension.

a. Amine solution

The following limitations should be considered.

For carbon steel pipe:

- Liquid 3 m/s
- Vapor-liquid 30 m/s

For stainless steel pipe:

- Liquid 9 m/s
- Vapor-liquid 36 m/s

b. Ammonium bisulfate (NH₃-H₂S-H₂O) solution

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING)	Page 17 of 55
	(PROJECT STANDARDS AND SPECIFICATIONS)	Rev: 01
		April 2011

Aqueous solutions of ammonium bisulfate produced in the effluent line of hydrocracking, hydrotreating processes often cause rapid erosion- corrosion of carbon steel pipes, especially for nozzles, bend, tees, reducer and air cooler tube inlet parts after water injection points. Care must be taken not to exceed the highest fluid velocity in pipe tubes.

5. Other Matters

a. Gravity flow

i) Side cut draw-off

In cases where no controller is provided for the liquid level in the liquid draw-off tray, the flow velocity in the first 3 meters of the vertical line shall be less than 0.762 m/s. This value is intended for vapor-liquid separation based on the particle diameter 200 micrometers (1000 micron = 1 mm) in cases where the operating pressure is high or the difference between the vapor and liquid densities is small:

$$CV = \frac{Q}{\sqrt{\Delta P/S.G}} \quad \text{Eq. (14)}$$

Where:

CV = The flow coefficient or pressure loss coefficient

Q = flow rate, GPM

ΔP = pressure drop, psi

S.G = specific gravity of the fluid

The line size shall be also checked that the control valve size may not become larger than the line size.

ii) Determination of line sizes in cases where the liquid enters a control valve at the boiling point should be sized on the following basis:

With consideration given to the static head and length of the line from the liquid level to the control valve, the line size shall be determined so that no vaporization may occur at the inlet of control valve. In this case, the following should be satisfied;

$$0.1412 \rho.H > \Delta P (\text{flowmeter}) + \Delta P (\text{line friction}) \quad \text{Eq. (15)}$$

Or

$$2.26 Sh > \Delta P (\text{flowmeter}) + P (\text{line friction}) \quad \text{Eq. (16)}$$

Where:

ρ(rho) is relative density, in (kg/m³);

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING) (PROJECT STANDARDS AND SPECIFICATIONS)	Page 18 of 55
		Rev: 01
		April 2011

- H is static head, in (m);
 h is static head, in (mm);
 S is relative density;
 ΔP (flowmeter) = kPa pressure drop in flowmeter;
 ΔP (line friction) = kPa pressure drop due to friction.

b. Vacuum tower overhead line

- i) The line cost and steam and cooling water consumptions shall be calculated and the line size shall be decided so that the annual cost will become minimum.
- ii) Pre-condenser shall be provided in wet cases where the pressure loss in the pre-condenser shall be 4 mm Hg.

c. Steam condensate lines

- i) Line from heat exchanger to steam trap or control valve

The pressure drop in this line shall be smaller than 11.3 kPa/100 m (0.1 kg/cm²/100 m) and shall be checked that no condensate may vaporize therein.

- ii) Line from steam trap or control valve to following vessel

- Steam condensate return lines must be sized to avoid excessive pressure loss. Part of the hot condensate flashes into steam when it is discharged into the condensate return system.
- In this case, the flow velocity "V" must be limited to 1524 m/min to prevent erosion.
- The flow velocity shall be calculated by the following equation:

$$V = \frac{354 \cdot W_c \cdot V_R (h_c - h_R)}{d^2 \cdot L_R} \quad \text{Eq. (17)}$$

d. Flare headers

Flare headers shall be designed so that the maximum allowable velocity does not exceed 50 percent of critical velocity, a figure mostly practiced by design companies.

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING) (PROJECT STANDARDS AND SPECIFICATIONS)	Page 19 of 55
		Rev: 01
		April 2011

SINGLE PHASE GAS FLOW

1. In general when considering compressible flow, as pressure decreases along the line so does the density (assuming isothermal flow). A variation in density implies variation in Reynolds number on which the friction factor is dependent. A rigorous calculation of pressure loss for long pipeline involves dividing it into segments, performing the calculation for each segment (considering variable parameters) and integrating over the entire length. For process piping however, since pipe lengths are generally short, a rigorous calculation would not be necessary and the equation outline below are considered adequate.
2. As mentioned above for estimating pressure drop in shortrun of gas piping such as within plant or battery limit, a simplified formula for compressible fluids is accurate for fully turbulent flow, assuming the pressure drop through the line is not a significant fraction of the total pressure (i.e., no more than 10%).
3. The Darcy formula (Eq. 5) also can be used for calculation of pressure loss in process gas lines as follows:

$$\Delta P_{100} = \frac{62530 f_D \cdot W_g^2}{\rho_g \cdot d^5} \text{ bar/100 m} \quad \text{see Eq. (5)}$$

4. A Practical Way to Calculate Gas Flow in Pipeline

Here is a short cut way to calculate gas flow in pipelines. It is based on Weymouth formula. At 15.5°C and relative density (specific gravity) of 0.6, the answer will be accurate. For every 5.5°C (10°F) variation in temperature, the answer will be 1% error. For every 0.01 variation in relative density (specific gravity), the answer will be three-fourths percent in error:

Formula:

$$Q_g = \frac{10.73 \times 10^{-4} \cdot d^{8/3} \sqrt{P_1^2 - P_2^2}}{\sqrt{L}} \text{ m}^3/\text{h} \quad \text{Eq. (18)}$$

Where:

Q_g is cubic meter of gas per hour, (m³/h);

d is pipe ID in (mm);

P₁ is kPa (abs) at starting point;

P₂ is kPa (abs) at ending point;

L is length of line in (m).

KLM Technology Group Project Engineering Standard	PROCESS DESIGN OF PIPING SYSTEMS (PROCESS PIPING AND PIPELINE SIZING) (PROJECT STANDARDS AND SPECIFICATIONS)	Page 20 of 55
		Rev: 01
		April 2011

5. An important factor in handling compressible fluid flow is a phenomenon known as critical flow. As the pressure drop in a pipe (increases) so does the flow. But for compressible flow this increase is limited to the velocity of sound in the fluid at flowing conditions. This limit is called the critical velocity.

Sonic or critical velocity is the maximum velocity which a compressible fluid can attain in a pipe. For trouble-free operation maintain operable velocities at $0.5 V_c$ and V_c for ideal gas is given by:

$$V_c = \sqrt{\frac{K.R.T}{m}} \text{ m/s} \quad \text{Eq. (19)}$$

$$= 31.64 V_c \sqrt{\frac{K.P}{m}} \text{ m/s} \quad \text{Eq. (20)}$$

The maximum velocity in piping handling compressible shall be less than $\frac{1}{2}$ of the critical velocity.

6. System operating at pressure less than 7000 N/m^2 (7 kPa), the Spitzglass equation shall be used for pressure loss calculations:

$$Q = 0.00338 \left[\frac{\Delta h_w \cdot d^5}{G.L \left(1 + \frac{91.5}{d} + 0.00118d \right)} \right]^{0.5} \text{ m}^3/\text{h at } 115^\circ\text{C} \quad \text{Eq. (21)}$$

$$Q = \left[\frac{0.00108 \Delta \cdot d^5}{G.L \left(1 + \frac{91.5}{d} + 0.00118d \right)} \right]^{0.5} \text{ m}^3/\text{h at } 115^\circ\text{C} \quad \text{Eq. (22)}$$

Where:

ΔP is the pressure drop in Pa.

7. Steam Flow

Babcock formula shall be used to calculate pressure drop in steam lines:

$$\Delta P_f = 3.63 \cdot 10^{-8} \left(\frac{d + 3.6}{d^6} \right) \frac{W^2 L}{\rho} \quad \text{(Eq. 23)}$$

Where:

ΔP_f is frictional component of pressure drop, psi