

SPD0032ERN
PROCESS DESIGN MANUAL
LINE SIZING AND HYDRAULICS

REV. : [4](#)

DATE: [11 OCT 2013](#)



SAMSUNG
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1. GENERAL

1.1. [Purpose](#)

[This Basic Design Manual discusses guidelines, methods to calculate line sizes, and explains what economic evaluations to be made, and also discusses flow velocity limitations due to potential of erosion and requirements of gravity flow. With respect to calculation methods, this manual includes SECL's computer programs along with their sources.](#)

1.2. [Use Limitation](#)

[This manual is applicable to all engineering projects if there are no special requirements from the Customer and / or Licensor.](#)

1.3. [References](#)

- (1) [Peters and Timmerhaus, Plant design and economics for chemical engineers, 2nd edition, McGraw-Hill, 1963](#)
- (2) [Optimum pipeline diameters by nomogram, Pipes and Pipelines, April/May, 1971, Vol. 16, No. 4/5.](#)
- (3) [Larry Meador and Ashok Shah, Steam lines designed two-phase, Hydrocarbon Processing, January 1969, Vol.48, No. 1.](#)
- (4) [Frederik A. Zenz, Minimize manifold pressure drop, Hydrocarbon Processing, December 1962, Vol. 41, No. 12.](#)
- (5) [Bill Sisson, How to size condensate piping, Hydrocarbon Processing, April 1971](#)

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2. DESIGN CRITERIA FOR LINE SIZING

Optimum line sizes should minimize the total energy and piping cost. However, limitations due to erosion and corrosion must be taken into consideration.

Also, in case of two-phase flow, the line sizes must be determined in accordance of the flow regime. Sometimes, the line sizes must be determined to satisfy the process requirements, for instance, in the case of pump suction lines.

See Table 2-1 'Line Sizing Design Criteria' for the SECL approved Design Criteria for line sizing and hydraulics

2.1. Review of Optimum Flow Velocities

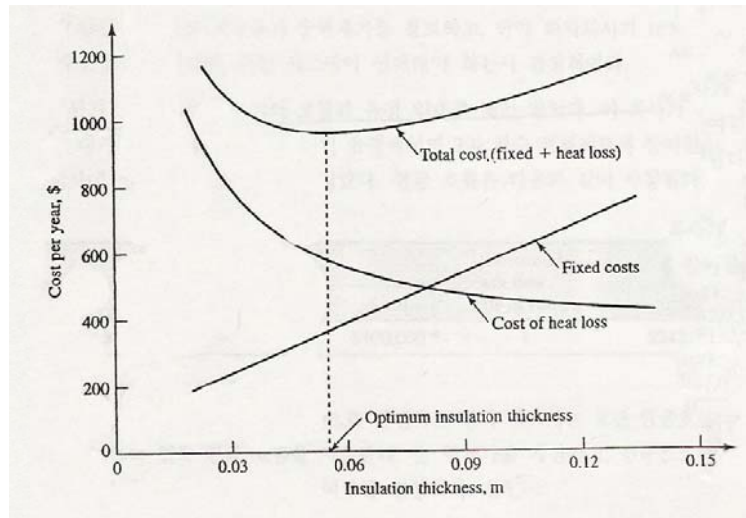
When determining the line sizes for pump or compressor heads, the sum of the utility cost and piping cost should be minimized.

Line sizes are to be determined from the economic flow velocities and pressure drop.

For an optimal line sizing, the sum of operating and fixed cost should be minimum. To achieve this, finding the optimal size of pipe is very important. But this method is hard and takes much time so the pressure drop or the velocity criteria is considered for line sizing.

These criteria are based on the experimental values so there are no gaps between the least annual cost and the expected cost from this method.

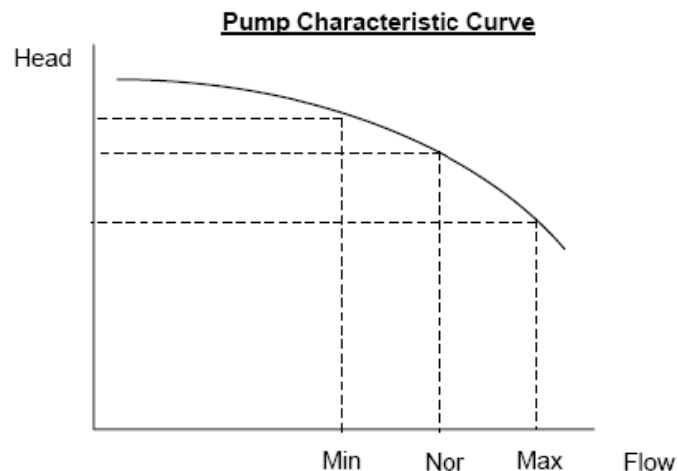
The main design criteria is Erosion & Corrosion / Noise Level / Minimum Velocity / Flow Pattern and etc.



2.2. Pump Suction/Discharge Line

After selection of pump head and line size, review the all case to each flowrate with pump performance curve

Case	Case1	Case2	Case3
Flowrate	Max	Nor	Min
Equip Press at starting point	Min	Nor	Max
Equip Press at destination point	Max	Nor	Min
Pump Diff. Head	@Max flow	@Nor flow	@Min flow
Control V/V DP	Min	Nor	Max



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2.2.1. Pump Suction Line

Generally, pressure drops in pump suction lines shall held below 0.20 psi/100 ft in the case of liquid at boiling point and below 0.35 psi/100 ft in the case of liquid below the boiling point.

The allowable pressure drops can be determined by the following formula:

$$\Delta P = \frac{\text{Sp.Gr.}}{2.3} (H - (\text{NPSH}_R + \alpha)) + (P_1 - P_2)$$

Where,

ΔP : Friction loss in piping to pump inlet (psi)

H : Height from datum to pump center (ft)

(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 : Net positive suction head required

α : 3 ft for liquid at boiling point 2 ft for liquid below boiling point

(NPSHa and r margin shall be based on client's specification if any)

P1 : Pressure above suction liquid surface (psi)

P2 : Vapor pressure of liquid at suction temperature (psi)

In cases where permanent strainers are to be provided, a pressure drop of 0.5 psi shall be added in dirty service. No addition is required in clean service. The equivalent length to be used for pressure drop calculations shall be assumed to be 150 ft.

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2.2.2. Pump Discharge Line

Generally, pressure drop in pump discharge lines shall be held below 4.0 psi/100 ft in the case of liquid below the boiling point. In case where orifice type flowmeter or integral type flowmeters are to be provided, a pressure drop of 3.0 psi or 10.0 psi shall be added, respectively.

Pressure drops can be determined by the following formula :

$$\Delta P = \Delta P_{LINE} + \Delta P_{H/E.F} + \Delta P_{PCV} + \Delta P_{Others}$$

$$\Delta P_{H/E.F} = \Delta P_{H/E \text{ Calc.}} \times K$$

Where,

ΔP_{LINE} : Pressure drop of lines from pump discharge to destination

$\Delta P_{H/E.F}$: ΔP of heat exchanger at fouled condition

$\Delta P_{H/E \text{ Calc.}}$: Calculated ΔP at heat exchanger

K: ΔP correction factor

$$r \text{ (ft}^2 \cdot \text{hr} \cdot ^\circ\text{F / Btu)} \leq 0.001 \quad K=1.05$$

$$r \text{ (ft}^2 \cdot \text{hr} \cdot ^\circ\text{F / Btu)} \leq 0.002 \quad K=1.10$$

$$r \text{ (ft}^2 \cdot \text{hr} \cdot ^\circ\text{F / Btu)} > 0.002 \quad K=1.20$$

ΔP_{PCV} : ΔP of control valves

ΔP_{Others} : ΔP of flow meter, furnace, etc.

r: Fouling Factor

(1) At the early basic design stage, the equivalent length to be used for pressure drop calculations shall be assumed as follows.

- Pump discharge to equipment : 300 ft

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- Equipment to equipment : 200 ft

- Equipment to battery limit : 500 ft

(2) In the case where plot plan is available, pump discharge equivalent length equals to three times of measured L.

Where L: Straight length measured with a rule on the plot plan plus elevation.

2.3. Limitations Owing to Erosion Preventive Measures

The velocity of the fluid plays an important role in corrosion caused by erosion. Velocity often strongly influences the mechanisms of corrosion reactions.

Velocity exhibits mechanical wear effects at high values and particularly, when the solution contains solids in suspension.

In many processes, licensors specify the velocity limitation, and basic design engineers should consider that limitation.

2.4. Limitations owing to Sonic Velocity

The maximum velocity shall be under 1/2 of the critical velocity.

Calculations shall be conducted by the following formula for ideal gas:

$$V_{\text{crit}} = \sqrt{\frac{g_c k R T}{M}} = 223 \sqrt{\frac{R T}{M}}$$

Where,

Vcrit : Critical velocity (ft/sec)

g_c : Gravity conversion factor, 32.17 (lb ft/sec²/lb-force)

k : Cp /Cv

R : Gas constant, 1546 (ft³ lb/ft² lb-mol °R)

T : Temperature (°R)

M : Molecular weight (lb/lb-mol)

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2.5. Condensate Lines

(1) Line from heat exchanger to steam trap or control valve.

The pressure drop in this line shall be smaller than 0.1 kg/cm²/100 m (0.50 psi/100 ft), so that no condensate may vaporize therein.

(2) Line from steam trap or control valve to following vessel.

Steam condensate return lines must be sized to avoid excessive pressure drop. Part of the hot condensate flashes into steam when it is discharge into the condensate return system.

The pressure drop in this line can be calculated by the method explained in Para. 3.2.3, as applicable.

In this case, the flow velocity V must be limited to 5,000 ft/min to prevent erosion.

(Refer to Ref. 5)

The flow velocity shall be calculated by the following equation:

$$V = \frac{3.06 W V_R (h_p - h_R)}{d^2 L R}$$

Where,

W : Condensate load (lb/hr)

d : Inside diameter of the pipe (in)

h_p : Enthalpy of the condensate, at inlet line pressure (Btu/lb)

h_R : Enthalpy of the condensate at return line pressure (Btu/lb)

V_R : Specific volume of steam at return line pressure (ft³/lb)

LR : Latent heat of steam at return line pressure (Btu/lb)

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2.6. Other Matters

2.6.1. Gravity Flow

(1) Side cut draw-off(See Fig. 2-2.)

In cases where no controller is provided for the liquid level in the liquid draw-off tray, the flow velocity in the first 10 feet of the vertical line shall be less than 2.5 ft/sec (0.762 m/sec). This value is intended for vapor-liquid separation based on the particle diameter 200 microns (200-micron size vapor bubbles in liquid) in atmospheric distillation towers.

The flow velocities shall be reviewed by using Newton's formula with 200 microns particle diameter in cases where the operating pressure is high or the difference between the vapor and liquid densities is small:

$$U_m = \sqrt{3.03 g (\rho_L - \rho_V) \frac{D_p}{\rho_V}}$$

Where,

U_m : Velocity ([ft/sec](#))

ρ_L : Liquid density ([lb/ft³](#))

ρ_V : Vapor density ([lb/ft³](#))

D_p : Particle diameter ([200 microns= 6.6×10⁻⁴ ft](#))

g : Gravity constant, [32.17 \(ft/sec²\)](#)

The flow velocities after the first 10 feet of the vertical shall be determined so the control valve size may not become larger than the line size.

In this case, the pressure drop in the line is permissible up to "Head difference×2/3".

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(2) Determination of line sizes in cases where the liquid enters a control valve at the boiling point. (See Fig. 2-3)

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 the control valve.

In this case, the following shall be satisfied:

$$0.1(\text{Sp.Gr.}) h > \Delta P_{\text{flow meter}} + \Delta P_{\text{line frict}}$$

Where,

[Sp.Gr.:](#) Specific gravity of fluid

h : Static head (meter,m)

$\Delta P_{\text{flow meter}}$: Pressure drop in flow meter (kg/cm²)

$\Delta P_{\text{line frict}}$: Pressure drop due to friction (kg/cm²)

2.6.2. Vacuum Tower overhead Line

The line cost and steam and cooling water consumptions shall be calculated and the line size shall be decided so that the annual cost is minimized.

Pre-condensers shall be provided in wet cases, where the pressure drop in the pre-condenser shall be 4 mmHg.

2.6.3. Limitations Required to Prevent Noise

The allowable maximum flow velocities, in cases where the maximum sound pressure levels of the piping noises must be kept 8 - 10 dB(A) under the sound pressure level of the background noise, are as follows:

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Normal Background Sound Pressure, dB(A)	Maximum Fluid Velocity to Prevent Noise, ft/sec
60	100
80	135
90	170

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3. PRESSURE DROP CALCULATION METHOD

3.1. SECL's Calculation Programs

The following computer programs are available for the pressure drop calculations of the line.

- Single and two phase flow
- Single flow
- #FLINE compressible flow
- Manifold flow distribution

- [HYTOS](#)

Calculation Method

3.1.1. [Incompressible](#) Flow

[Pressure drops can be calculated for each section by the Fanning equation.](#)

$$\Delta P_{fL} = \frac{4fL}{D} \left(\frac{m_l^2}{2\rho_l} \right) \quad \text{or} \quad h_f = \frac{\Delta P_s}{\rho} = 4f \frac{L}{D} \times \frac{V^2}{2}$$

[Where,](#)

[L : line length \(m\)](#)

[D : inside diameter \(m\)](#)

[m_L : Liquid mass flux\(kg/m²s\)](#)

[ρ_L : Liquid density\(kg/m³\)](#)

[V : Velocity \(m/s\)](#)

[f : Friction factors](#)

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SECL recommends Chen Friction Factor as below:

$$\frac{1}{\sqrt{f}} = -2 \log \left[\frac{\varepsilon / D}{3.7} - \frac{5.02}{\text{Re}} \log A \right]$$

$$A = \frac{\varepsilon / D}{3.7} + \left(\frac{6.7}{\text{Re}} \right)^{0.9}$$

ε = roughness factor(m)

Re = Reynolds Number

For Moody friction factor and relatives roughness, see Figs. 3-1 and 3-2.

3.1.2. Water Flow

Pressure drops shall be calculated by William and Hazen's formula.

$$h_f = 0.002083 \text{Le} \left(\frac{100}{C} \right)^{1.85} \times \frac{V_f^{1.85}}{d^{4.8655}}$$

Where,

d : Inside diameter of circular pipe (in)

Le : Length of pipe including equivalent length for loss through fittings (ft)

C : Friction factor for Hazen & Williams (See table 3-1)

VF : Flow of liquid (gpm)

hf : Head loss due to friction (ft of liquid)

Note: This formula is based on the viscosity of 1.13 cks (Centistokes) for water. This formula can be used for any liquid having a viscosity in the range of 1.13 cks.

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3.1.3. Compressible Flow

Vapor of which velocity is more than 200ft/s (=60m/s) or pressure drop is more than 10% of upstream pressure.

Typical example is the swelled vapor through valve, the high speed vapor in a small pipe and flows in a vacuum condition.

Actual properties of Compressible Flow are intermediate between isothermal and adiabatic flow.

- Adiabatic: $PV^\gamma = \text{Constant}$

- Isothermal: $PV = \text{Constant}$

⇒ In the isothermal case, the specific volume is larger and the velocity is faster than the adiabatic case.

According to theories and equations, the line sizing under the isothermal flow condition is safer than adiabatic flow condition. So the larger size pipe is needed and selected conservatively.

The initial pressure shall be taken as P_1 and the end pressure as P_n .

The line from P_1 and P_n shall be divided into proper sections, each of which the properties shall be calculated.

Pressure drops (ΔP_i) in the line shall be calculated from the properties in each section, and $l_i / \Delta P_i$ shall be computed when the equivalent length (l_i) for a specified or calculated ΔP_i needs to be known.

$l_i / \Delta P_i$ is shown in a curve or graph as the function of P_i , namely as $f(P_i)$ from which the pipe equivalent length L can be calculated as follows:

$$L = \int_{P_n}^{P_1} f(P_i) dp$$

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Otherwise, it shall be obtained by the following equation

$$\frac{M}{2RT}(p_a^2 - p_b^2) - \frac{G^2}{g_c} \ln \frac{\rho_a}{\rho_b} = \frac{G^2 f \Delta L}{2g_c r_H}$$

Where, F= friction factor

G= vapor mass flux(kg/m²s)

gc : Newton's law proportionality factor

L : length (m)

M : Molecular weight of fluid,

rH : Hydraulic radius of conduit (m)

R : Gas constant

f = Friction factors

SECL recommends Chen Friction Factor like incompressible flow,

but for long line, the following friction factor can be used:

$$\text{- Weymouth equation: } f = \frac{0.008}{d^{1/3}} \quad \text{- AGA equation: } f^{-0.5} = 4 \log\left(\frac{3.7}{\varepsilon/d}\right)$$

$$\text{- Panhandle A equation: } f^{-0.5} = 6.872(\text{Re})^{0.07305}$$

(Not applied if viscosity < 0.0105cP)

$$\text{- Panhandle B equation: } f^{-0.5} = 16.49(\text{Re})^{0.01961}$$

(Not applied if viscosity > 0.0105cP)

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[If a critical flow is expected, calculations should be performed by using either INPLANT® or VISUAL FLOW SUITE™. For details, see the operating manuals for each program.](#)

[Pressure Drop and Regime in Two-phase Flow](#)

[\(a\) Pressure Drop](#)

[The calculation procedure is very complex and the result is not exact. Under the proper condition, it has ±25% of the error rate. Furthermore there is ±50% potential error under the abnormal condition. For the result estimation of two phase flow, there is not only general academic but also experimental equation in a various case.](#)

[HTFS Commercial Report is officially used by SECL. HYTOS provides calculation module to analyze Flow Regime and Pressure drop.](#)

[Pressure drops in two-phase flows shall be calculated by using the following equation](#)

$$\frac{dP}{dL} = \Delta P_G + \Delta P_F + \Delta P_{Acc}$$

[Where,](#)

[ΔPG = pressure loss by gravity](#)

[ΔPF = pressure loss by friction](#)

[ΔPACC = pressure loss by acceleration \(momentum\)](#)

[The detail equation is;](#)

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$$\frac{dP}{dL} = \frac{g}{g_c} \rho^* \sin \theta + \left(\Delta P_L + \Delta P_G + C \sqrt{\Delta P_G \times \Delta P_L} \right) + \Delta P_m$$

Where,

ΔP_L = liquid phase pressure drop in pipe

ΔP_V = vapor phase pressure drop in pipe

ρ = two phase mean density

C = two phase multiplier factor

ΔP_m = momentum loss/gain ($\doteq$ Nil)

(b) Regime

The following maps are used.

- For horizontal: Taitel & Dukler

- For vertical upward: Hewitt & Robert

- For vertical downward: Golan

& Stenning

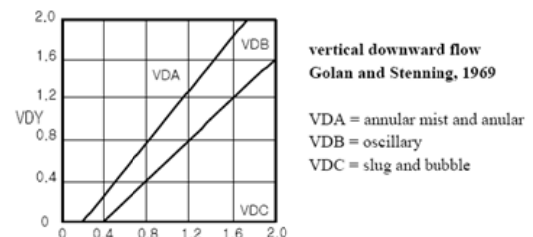
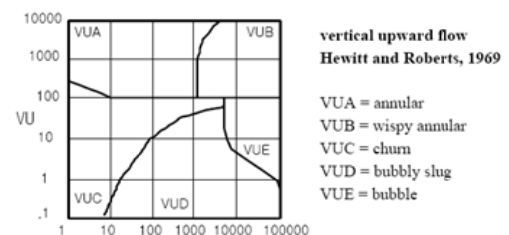
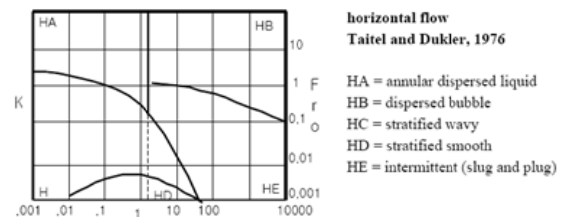
The following patterns should be acceptable.

- Bubble: Bubble is dispersed in Liquid.

- Stratified: Gas and Liquid flows parallel stably.

- Wavy: Similar to Stratified, but liquid is waving.

- Annular: Gas is very fast, so it flows in pipe



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center area and liquid flows ring pattern.

The following patterns should be avoided.

- Slug: Gas Bubble makes Slug on liquid phase.
- Plug: Gas Bubble makes Plug on liquid phase.
- Dispersed: Gas and Liquid mixed unstably flows irregularly.

Not admissible flow pattern could be avoided by following methods.

- By reducing line sizes to a minimum permitted due to erosion/corrosion considerations, and to the available pressure differentials.
- By designing parallel pipe runs.
- By modification of the pipe routing / of the location of control valves.
- By using valve auxiliary pipe runs to regulate alternative flow rates.
- By diameter adjustment coupled with gas injection.

(c) Velocity Limitation

Two phase velocity should be maintained below erosion velocity.

- Homogeneous Velocity:
$$V_h = V_g + V_l$$

- Two Phase Mean Velocity:
$$V_m = \dot{m} / \rho^*$$

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$$\text{- Maximum Velocity: } \frac{122}{(\rho_h)^{0.5}}$$

$$\text{- Erosion Velocity : } \frac{195}{(\rho_h)^{0.5}}$$

Where, V_g = Gas phase velocity in pipe (m/s)

V_l = Liquid phase velocity in pipe (m/s)

ρ_h = Two phase homogeneous density (kg/m³)

ρ_m = Two phase homogeneous density (kg/m³)

m = Mass flux (kg/m²/s)

3.1.4. Pressure Drops in Manifolds

Pressure drops in manifolds shall be calculated based on Reference 4.

SECL Program can be used for calculation of pressure drops in S-flow and U-flow.

3.1.5. Pressure Drops in Control Valves

Generally speaking, theoretical approaches of differential pressure for control valves are not practical.

Herein, the following method will be given for General service:

$$\Delta P = 0.33 \times \Delta P_{fric}$$

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Where, ΔP_{fric} = Variable Pressure drop excepting control valve pressure drop
(Pipeline, instrument, equipment which has pressure drop)

Therefore, the portion of control valve pressure drop is 25% of total variable pressure drop on loop.

Herein, the following method will be given for pumping service:

$$(1) \quad \Delta P = \left[\left(1.1135 \times \frac{\text{max. flow}}{\text{nor. flow}} \right)^2 - 1 \right] \times \Delta P_{fric}$$

Where, max/nor flow = can be defined "Control Valve Overdesign Factor"

ΔP_{fric} = Variable Pressure drop except for control valve pressure drop
(Pipeline, instrument, equipment which has pressure drop)

$$(2) \quad \Delta P = 0.33 \times \Delta P_{fric}$$

$$(3) \quad \Delta P = 0.7 \text{ kg / cm}^2 \quad (\text{As a minimum})$$

$$(4) \quad \Delta P = 0.08 \times \Delta P_{dis}$$

Where, ΔP_{dis} = Pump discharge pressure without control valve pressure drop

$$(5) \quad \Delta P = 1.1 \left[\left(\frac{\text{Max. flow}}{\text{Nor. flow}} \right)^2 - 1 \right] \times \Delta P_{fric} + 0.05 \times P_s + B$$

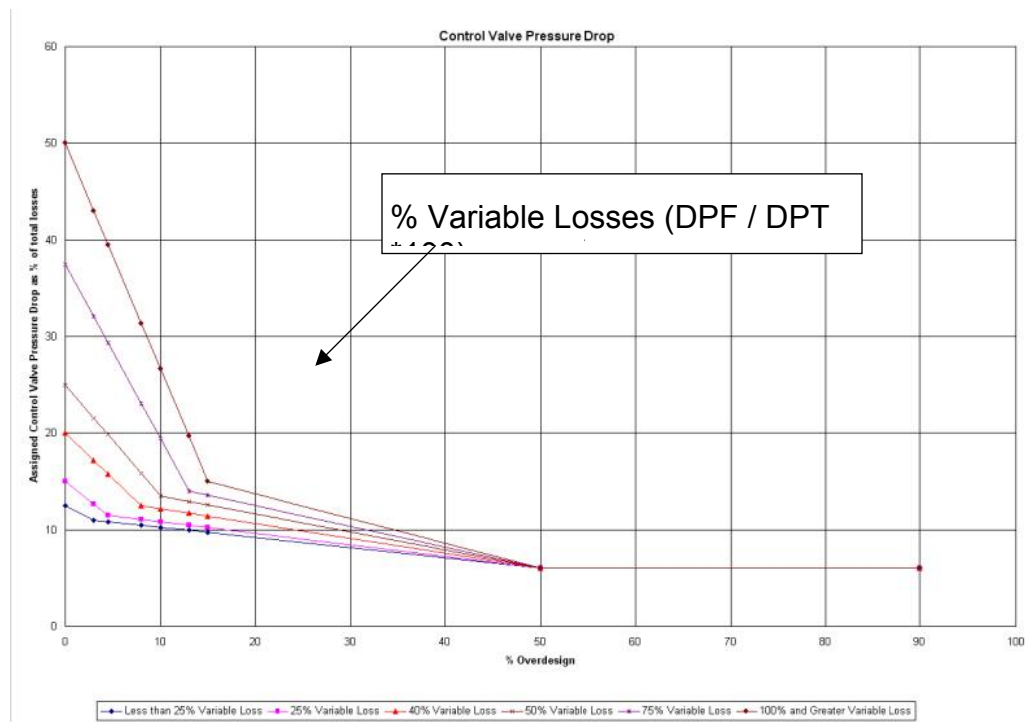
Where,

P_s : Suction Equipment Pressure

B : Base Pressure drop by valve type

<u>Control Valve type</u>	<u>B. (psi)</u>
<u>Single Plug</u>	<u>11</u>
<u>Double Plug</u>	<u>7</u>
<u>Cage Valve (unbalanced)</u>	<u>4</u>
<u>Cage Valve (balanced)</u>	<u>4</u>
<u>Butterfly</u>	<u>0</u>
<u>V-ball</u>	<u>1</u>

(6) Chart



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$$\% \text{Variable Losses} = \left(\frac{\text{Variable Losses at Rated Flow}}{\text{Total Pressure Drop}} \times 100 \right)$$

$$\% \text{Overdesign} = \left(\frac{\text{Rated Flow}}{\text{Normal Flow}} - 1 \right) \times 100$$

In case where large fluctuations in the static pressure are expected, it is necessary to provide sufficient pressure difference for the control valve to reduce the effects of external disturbances.

MIN. ΔP_{cv} : - Reflux & product = 15 psi

- Low press gas = 1 - 5 psi

-

3.1.6. Pressure Drops in Valves and Fittings

(1) In cases where the velocity heads K are to be used,

$K = K_{\text{valve}} + K_{\text{elbow}} + K_{\text{tee}}$shall be taken and calculated from

Figs. 4-3, 4-4 and 4-5.

The value K, is defined as follows:

$$\Delta P = \frac{4 f L}{D} \left(\frac{\rho V^2}{2 g_c} \right) \quad \text{.....Fanning Equation}$$

$$K = \frac{4 f L}{D}$$

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Pressure drops ΔP_f in fittings can be calculated as follows:

$$\Delta P = K \left(\frac{\rho V^2}{2 g_c} \right)$$

Where,

ΔP_f : Pressure drop in fittings (psi) or (kg/cm²)

K : Velocity heads

V : Velocity in Pipe (ft/sec) or (m/sec)

ρ : Density (lb/ft³) or (kg/m³)

g_c : Gravity constant, 32.17 (lb/ft/sec² lb-force) or 9.80 (kg m/sec² kg-force)

As a result, following equations are obtained.

$$\Delta P_f = K \rho V^2 / (9.266 \times 10^3) \text{ (psi)}$$

$$\Delta P_f = K \rho V^2 / (196.120 \times 10^3) \text{ (kg/cm}^2\text{)}$$

(2) In cases where valves and fittings are to be handled as pipe equivalent lengths, the equivalent lengths shall be taken from Table 3-2 and added to the actual pipe lengths, from which the pressure drops shall be calculated.

[\(3\) To define K value, Equivalent Length, Crane and 2K Method is officially used by SECL.](#)

[In general pipe line, it could be got as straight length from a plot plan times the factor by geometry.](#)

[- Process Line : straight length x 3](#)

[- Rack Line : straight length x 1.5](#)

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This assumption is based on the experimental method. Because at the early design stage of each project, there is no isometric drawing. So it could not get the detailed geometric information about a pipe and fitting.

The following cases have to calculate exactly after the issue of isometric drawing according to it.

- Pump suction
- Reboiler circuit
- Compressor loop
- Vacuum tower overhead

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4. REVISION HISTORY

Rev. No.	Rev. Date	Rev. Page	Reason for Revision
0	17 APR 1998	All	First Issue Written at Proces & System Eng'g Dept. -Prepared by: J.H.Park, J.E.Lim -Checked by: B.I.Lee, S.B.Jo, J.C.Ro -Approved by: S.G.Oh
1	31 DOC 2005	4,6,8,9	Revision Written at Proces & System Eng'g Dept. -Prepared by: C.S.Song -Checked by: E.D.Lee -Approved by: C.S.Jeong
2	28 MAY 2009		Revision Written at Proces & System Eng'g Dept. -Prepared by: S.Y.Lee -Checked by: Henry. Sung, J.C.Ro, E.D.Lee -Approved by: C.S. Jeong

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3	20 NOV 2010		Document Number change due to new numbering system Written at Proces & System Eng'g Dept. -Prepared by: D.S.Song -Checked by: Henry. Sung, J.C.Ro, H.H.Kwak, M.H.Oh, S.U.Hong -Approved by: E.D.Lee
4	11 OCT 2013	All	Revision Written at Proces & System Eng'g Dept. -Prepared by: M.H.Lee -Checked by: J.H.Park, S.D.Kim, I.H.HWANG -Approved by: S.B.Lee

APPENDIX : Table and Figures

Table 2-1. SECL Design Criteria

1. Liquid

	<u>Velocity</u>	<u>Pressure drop</u>
	<u>(m/s)</u>	<u>(kg/cm2/100m)</u>
<u>A. Pumped Fluids</u>		
<u>1. Suction lines</u>		
<u>a. Equilibrium fluid or suction pressure less than 0.7 kg/cm2,g</u>		<u>0.023 ~ 0.115</u>
<u>b. Vacuum tower bottoms</u>		<u>0.023</u>
<u>c. Side draw-offs and sub-cooled liquid</u>		<u>Max. 0.46</u>
<u>d. From storage tanks</u>		<u>Max. 0.12</u>
<u>(Note: Suction line velocity, in general, may not be important, but in the case of slurry lines to be checked if velocity is less than 1.2m/s)</u>		
<u>2. Discharge lines</u>		
<u>a. Lines with 150# rating</u>		
<u>- C.S material</u>	<u>2.0 ~ 2.1</u>	
<u>- S.S material</u>	<u>2.2 ~ 2.3</u>	
<u>- Alloy material</u>	<u>2.7 ~ 3.0</u>	
<u>b. Lines with 300# rating</u>		
<u>- C.S material</u>	<u>1.9 ~ 2.2</u>	
<u>- S.S material</u>	<u>2.3 ~ 2.4</u>	
<u>- Alloy material</u>	<u>3.0 ~ 3.2</u>	
<u>c. Lines with 600# rating</u>		
<u>- C.S material</u>	<u>2.1 ~ 2.6</u>	

<u>B. Cooling and Tempered Water</u>		
<u>1. For headers</u>		<u>0.07 ~ 0.16</u>
<u>2. For leads</u>		<u>0.12 ~ 0.35</u>
<u>C. Caustic and Concentrated H2SO4</u>	<u>1.2</u>	
<u>D. General Process Liquid</u>	<u>1.2 ~ 3.0</u>	<u>0.23 ~ 0.46</u>
<u>E. Boiler Feed Water</u>	<u>1.5 ~ 3.7</u>	<u>0.12 ~ 0.23</u>
<u>F. Phenolic Water (1% or more)</u>	<u>0.91</u>	
<u>G. MEA, DEA</u>	<u>3.0</u>	
<u>H. Reboiler Downcomer</u>		
<u>1. Horizontal Reboilers</u>		
<u>a. Lines</u>	<u>0.91 ~ 2.1</u>	
<u>b. Lead</u>	<u>Max. 0.91</u>	
<u>2. Vertical Reboilers</u>		
<u>a. Lines</u>	<u>0.91 ~ 2.1</u>	
<u>b. Lead</u>	<u>0.91 ~ 2.1</u>	
<u>I. Fuel Oil</u>	<u>0.23 ~ 0.46</u>	
<u>J. Slurry</u>	<u>1.2 ~ 2.4</u>	

2. Vapor

	<u>Velocity</u>	<u>Pressure drop</u>
	<u>(m/s)</u>	<u>(kg/cm2/100m)</u>
<u>A. Steam</u>		
<u>1. Supply</u>		
<u>a. To drivers, HEX, heating coil</u>		
<u>- Steam mains under 35 kg/cm2.g</u>		<u>0.12 ~ 0.35</u>
<u>- Steam mains above 35 kg/cm2.g</u>		<u>0.23 ~ 0.46</u>
<u>- Steam leads under 35 kg/cm2.g</u>		<u>0.23 ~ 0.46</u>
<u>- Steam leads above 35 kg/cm2.g</u>		<u>0.23 ~ 0.69</u>
<u>- Velocities limitations for steam</u>		
<u>0 ~ 1.0 kg/cm2.g (saturated)</u>	<u>Max. 18.3</u>	
<u>1.0 ~ 14.0 kg/cm2.g (saturated)</u>	<u>Max. 39.6</u>	
<u>1.0 ~ 14.0 kg/cm2.g (superheated)</u>	<u>Max. 61.0</u>	
<u>(Note: 14.0 kg/cm2.g (superheated) velocity less than or equal 0.3 MACH number with pressure drop as primary criteria)</u>		
<u>b. Steam lines for stripping, aeration, leads to towers, drums, etc. shall be sized for available pressure drop. However, piping shall not be sized for velocities producing excessive noise.</u> <u>(Downstream MACH number shall be < 0.3 or less than approximately 106.7 m/s). Vessel analytical must be advised of high velocities.</u>		
<u>(Note: Overall criteria for steam headers must be that pressure from one end of the plant to the other should not vary by more than 0.35 kg/cm2 for headers less than or equal to 17.6 kg/cm2.g or 0.7 kg/cm2 for headers less than or equal to 42.2 kg/cm2.g</u>		
<u>2. Exhaust</u>		
<u>a. Exhaust steam lines shall be sized for a unit pressure drop of approximately 0.046 to 0.12 kg/cm2/100m, as a guide, unless the turbine is condensing</u>		

<u>b. In vacuum exhaust steam for condensing turbines use approximately 1 /2 inHg or 0.0176 kg/cm2/100m total loss in line.</u>		
<u>3. Inlet to steam turbine</u>		
<u>Designer cannot allow the inlet pressure to go below that given by Machinery on the turbine datasheet.</u>		
<u>B. Compressors</u>		
<u>1. Suction lines</u>	<u>22.9 ~ 60</u>	
<u>a. less than 1000 HP</u>		<u>0.023 ~ 0.23</u>
<u>b. more than 1000 HP</u>		<u>0.018 ~ 0.09</u>
<u>2. Discharge lines</u>	<u>30.5 ~ 76.2</u>	<u>0.046 ~ 0.23</u>
<u>(Note: The total drop must be based on available pressure drop)</u>		
<u>3. kickback lines</u>	<u>1 / 3 sonic</u>	
<u>C. Tower Overheads</u>	<u>7.62 ~ 30.5</u>	<u>0.023 ~ 0.12</u>
<u>D. Vacuum Service</u>		<u>0.005 ~ 0.07</u>
<u>E. Nitrogen, Air Headers</u>		
<u>2" min for flows less than 510 Nm3/h</u>		
<u>4" min for flows equal to 1700 Nm3/h</u>		

<u>F. Inlet to Gas Turbine</u>	<u>45.7 ~ 106.7</u>	
<u>G. Fuel Gas</u>		<u>0.023 ~ 0.23</u>
<u>H. General Process</u>		
<u>The following criteria is velocity limit (m/s)</u>		
<u>NPS</u>	<u>Saturated</u>	<u>Superheated</u>
	<u>Low Pressure</u>	<u>Medium Pressure</u> <u>High Pressure</u>
<u>3/4" ~ 2"</u>	<u>13.7 ~ 30.5</u>	<u>12.2 ~ 24.4</u> <u>9.1 ~ 18.3</u>
<u>3" ~ 4"</u>	<u>15.2 ~ 33.5</u>	<u>13.7 ~ 27.4</u> <u>10.7 ~ 21.3</u>
<u>6"</u>	<u>18.3 ~ 36.6</u>	<u>15.2 ~ 36.6</u> <u>13.7 ~ 27.4</u>
<u>8" ~ 10"</u>	<u>19.8 ~ 38.1</u>	<u>24.4 ~ 48.8</u> <u>19.8 ~ 38.1</u>
<u>12" ~ 14"</u>	<u>21.3 ~ 39.6</u>	<u>30.5 ~ 57.9</u> <u>24.4 ~ 44.2</u>
<u>16" ~ 18"</u>	<u>22.9 ~ 41.1</u>	<u>33.5 ~ 64.0</u> <u>27.4 ~ 48.8</u>
<u>20"</u>	<u>24.4 ~ 42.7</u>	<u>36.6 ~ 67.1</u> <u>30.5 ~ 51.8</u>

3. Two Phase Flow

A. In general

As available for pressure drop with no slug flow in general with velocity > 4.6 m/s (10.7 ~ 22.9 m/s) with 30.5 m/s max.

B. Reboiler Riser (L/V)

1. Vertical Reboilers

a. $V_{min} \text{ (ft/s)} = 3.33 \text{ (Liquid density / Vapor density)}^{0.5}$

<u>b. Pressure</u> <u>(kg/cm2.g)</u>	<u>V_V / V_L Ratio</u> <u>Usual / Minimum</u>	<u>Riser velocity</u> <u>(m/s)</u>
<u>21.1</u>	<u>5 : 1</u>	<u>4.6 or 1.5 x V_{min}</u>
<u>14.1 ~ 21.1</u>	<u>5 : 1 ~ 10 : 1</u>	<u>4.6 ~ 6.1 (note)</u>
<u>7.0 ~ 14.1</u>	<u>10 : 1</u>	<u>4.6 ~ 6.1 (note)</u>
<u>2.8 ~ 7.0</u>	<u>10 : 1</u>	<u>6.1 (note)</u>
<u>1.1 ~ 2.8</u>	<u>10 : 1</u>	<u>9.1</u>
<u>0.7</u>	<u>10 : 1</u>	<u>12.2</u>

(Note: Generally higher velocities at lower pressures)

c. Outlet connections are generally sized such that 0.02 kg/cm2 is the maximum loss. (using the homogeneous density)

$$D_{min} \equiv \frac{W_{conn}^{1/2}}{\rho_h^{1/4}} / 29.1$$

2. Horizontal Reboilers

a. Outlet connections are generally sized such that 0.018 kg/cm2 is the maximum loss (using the homogeneous density)

$$D_{min} \equiv \frac{W_{conn}^{1/2}}{\rho_h^{1/4}} / 27.8$$

<Liquid>

<Vapor>

SECL criteria in HYTOS:

Type	Velocity	ΔP
	m/s	kg/cm ² /100m
General Service	4.5	0.9
- Pump Suction Lines		
Boiling Liquids	1.8	0.081
Non-boiling Liquids	2.4	0.2
- Pump Discharge Lines		
0 ~ 56 m ³ /h	2.4	1.4
56 ~ 155 m ³ /h	3	0.9
155 m ³ /h ~	4.5	0.5
- Process Lines		
Reboiler Trapout	1.2	0.03
To Control Valve	-	0.2
Gravity Flow Service	2.4	0.09
Boiler Feed Water Service	4.5	-
From Condenser	1.5	-
Liquid Feed to Tower	1.8	-
Refrigerant Lines	1.2	-
- Process Fluids		
Cooling Water (header)	4.8	0.5
Cooling Water (branch)	3	0.5
Phenolic Water	0.9	-
Concentrated H ₂ SO ₄	1.2	-
Salt Water	1.8	-
Caustic Solution	1.2	-
CO ₂ Rich Amine Liquid	3	-

Type	Velocity	ΔP
	m/s	kg/cm ² /100m
- General Service		
~ 4.55 kg/cm ² (g)	-	0.023
4.55 ~ 15.1 kg/cm ² (g)	-	0.138
15.1 ~ 36.2 kg/cm ² (g)	-	0.346
36.2 kg/cm ² (g) ~	-	1.461
Air Service	18.3	0.557
- Compressor Lines		
Suction (Reciprocating Type)	12.2	-
Suction (Centrifugal Type)	24.4	-
Discharge	13	0.231
- Tower Overhead		
~ 0.7 kg/cm ² (g)	61	0.023
Atm.	30.5	0.115
3.5 kg/cm ² (g) ~	15.2	0.115
- Steam Lines		
~ 4.55 kg/cm ² (g)	50	0.058
4.55 ~ 15.1 kg/cm ² (g)	40	0.231
21 kg/cm ² (g) ~	30	0.346
High Pressure Steam	20	0.115
- Flare		
Header	-	0.115
Branch	10.7	-

Table 3-1. Hazen and Williams-Friction Factor C*

TYPE OF PIPE	Values of C		
	Range - High = best smooth, well laid - Low = poor or corroded	Average value for clean, new pipe	Commonly used value for design purpose
Cement-Asbestos	160-140	150	140
Fibre	-	150	140
Bitumastic-enamel-lined iron or steel centrifugally applied	160-130	148	140
Cement-lined iron or steel centrifugally applied	-	150	140
Copper, brass, lead, tin or glass pipe and tubing	150-120	140	130
Wood-stave	145-110	120	110
Welded and seamless steel	150-80	130	100
Interior riveted steel (no projecting rivets)	-	139	100
Wrought-iron, Cast-iron	150-80	130	100
Tar-coated cast-iron	145-50	130	100
Girth-riveted steel (projecting rivets in girth)	-	130	100

th seams only)										
Concrete					152-85		120		100	
Full-riveted steel(projecting rivets in girth and horizontal seams)					-		115		100	
Vitrified, Spiral-riveted steel(flow with lap)					-		110		100	
Spiral-riveted steel(flow against lap)					-		100		90	
Corrugated steel					-		60		60	
Values of C	150	140	130	120	110	100	90	80	70	60
*Multiplier(Basis C=100)	.47	.54	.62	.71	.84	1.00	1.22	1.50	1.93	2.57

*Multiplier to correct friction loss tables(in previous editions-14th Edition and earlier); cannot be used with tables in this book which are based on the Darcy-Weisbach-Colebrook formula

**Note : the Hazen Williams friction factor "C" must not be confused with the Darcy-Weisbach-Colebrook friction factor "f"; these two friction factors are not in any way related to each other

CAMERON HYDRAULIC DATA 16th Edition, 1979

Table 4-2 Representative Equivalent Length in Pipe Diameters (L/D) of Various Valves and Fittings

Description of product				Equivalent Length In Pipe Diameter (L/D)
Globe Valve	Conventional	With no obstruction in flat, bevel, or plug type seat With wing or pin guided disc	Fully open Fully open	340 450
	Y-Pattern	(No obstruction in flat, bevel, or plug type seat) - With stem 60 degrees from run of plug line - With stem 45 degree from run of pipe line	Fully open Fully open	175 145
Angle valve	Conventional	With no obstruction in flat, bevel, or plug type seat With wing or pin guided disc	Fully open Fully open	145 200
Gate Valves	Conventional Wedge Disc, Double Disc or Plug Disc	Fully open Three-quarters open One-half open One-quarter open		13 35 160 900
	Pulp Stock	Fully open Three-quarters open One-half open One-quarter open		17 50 260 1200
	Conduit Pipe Line	Fully open		6
Check Valves	Conventional Swing Clearway Swing Globe Lift or stop Angle Lift or stop In-Line Ball	0.5†...Fully open 0.5†...Fully open 2.0†...Fully open 2.0†...Fully open 2.5 vertical and 0.25 horizontal †...Fully open		135 50 Same as Globe Same as Angle 150
Foot Valves with Strainer		With poppet lift-type disc With leather-hinged disc	0.3†...Fully open 0.4†...Fully open	420 75
Butterfly Valves(6-inch and larger) Fully open				20
Cocks	Straight-Through	Rectangular plug port area equal to 100% of pipe area	Fully open	18
	Three-Way	Rectangular plug port area equal to 80% of pipe area(fully open)	Flow straight through Flow through branch	44 140
Fittings	90 Degree Standard Elbow 45 Degree Standard Elbow 90 Degree Long Radius Elbow			60 16 20
	90 Degree Street Elbow 45 Degree Street Elbow Square Corner Elbow			50 26 57
	Standard Tee	With flow through run with flow through branch		20 60
	Close Pattern Return Bend			50

Exact Equivalent length is equal to the length between flange faces or welding ends.

Minimum calculated pressure drop(psi) across valve to provide sufficient flow to lift disc fully.

For limitations and effect of end concentrations.

Crane Co. Engineering Data

(1960)

Fig.2-1. Condensate line Typical Flow

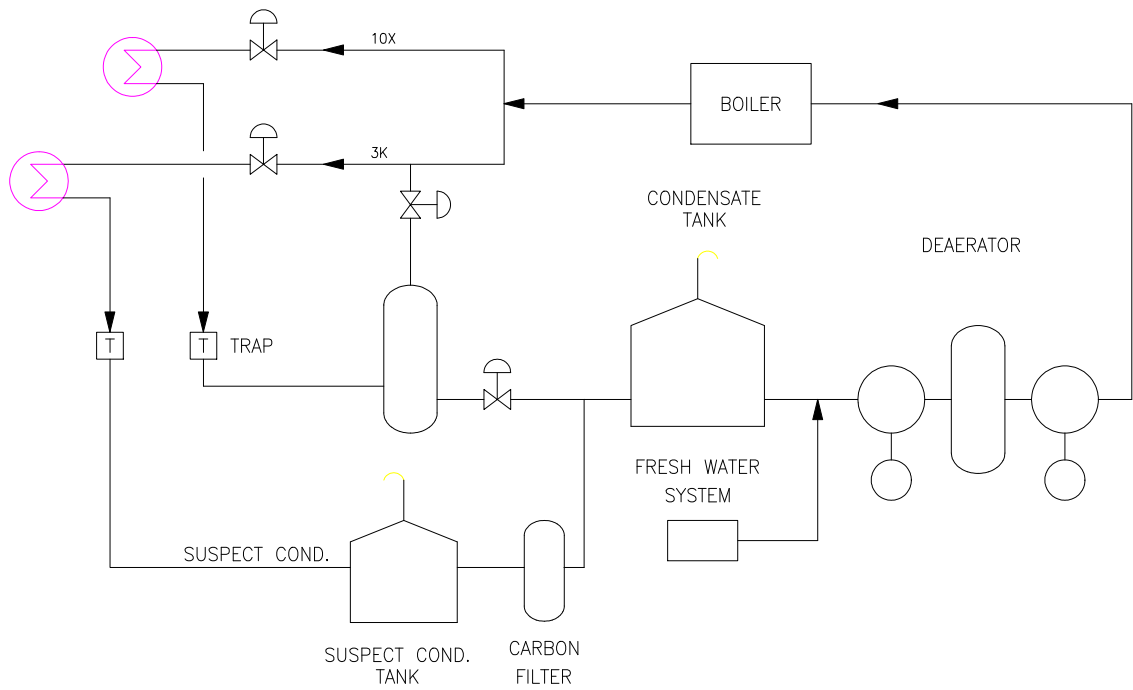


Fig.2-2 Gravity Flow Line 1

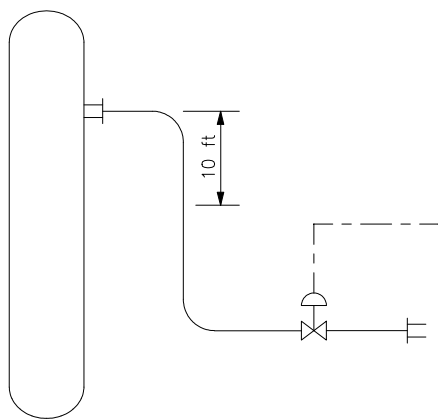


Fig. 2-3 Gravity Flow Line 2

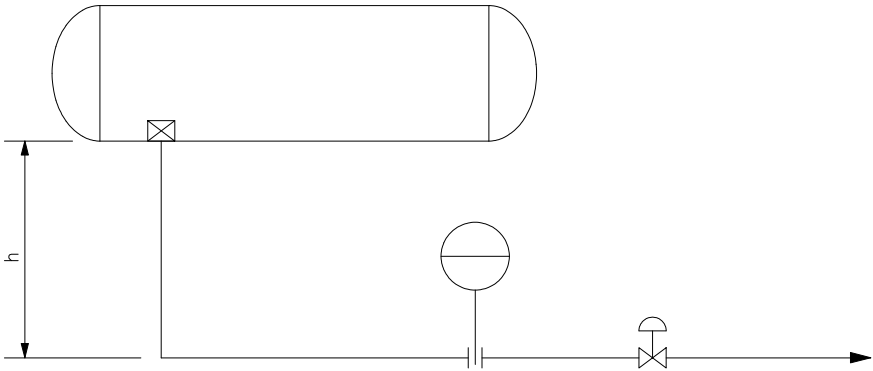
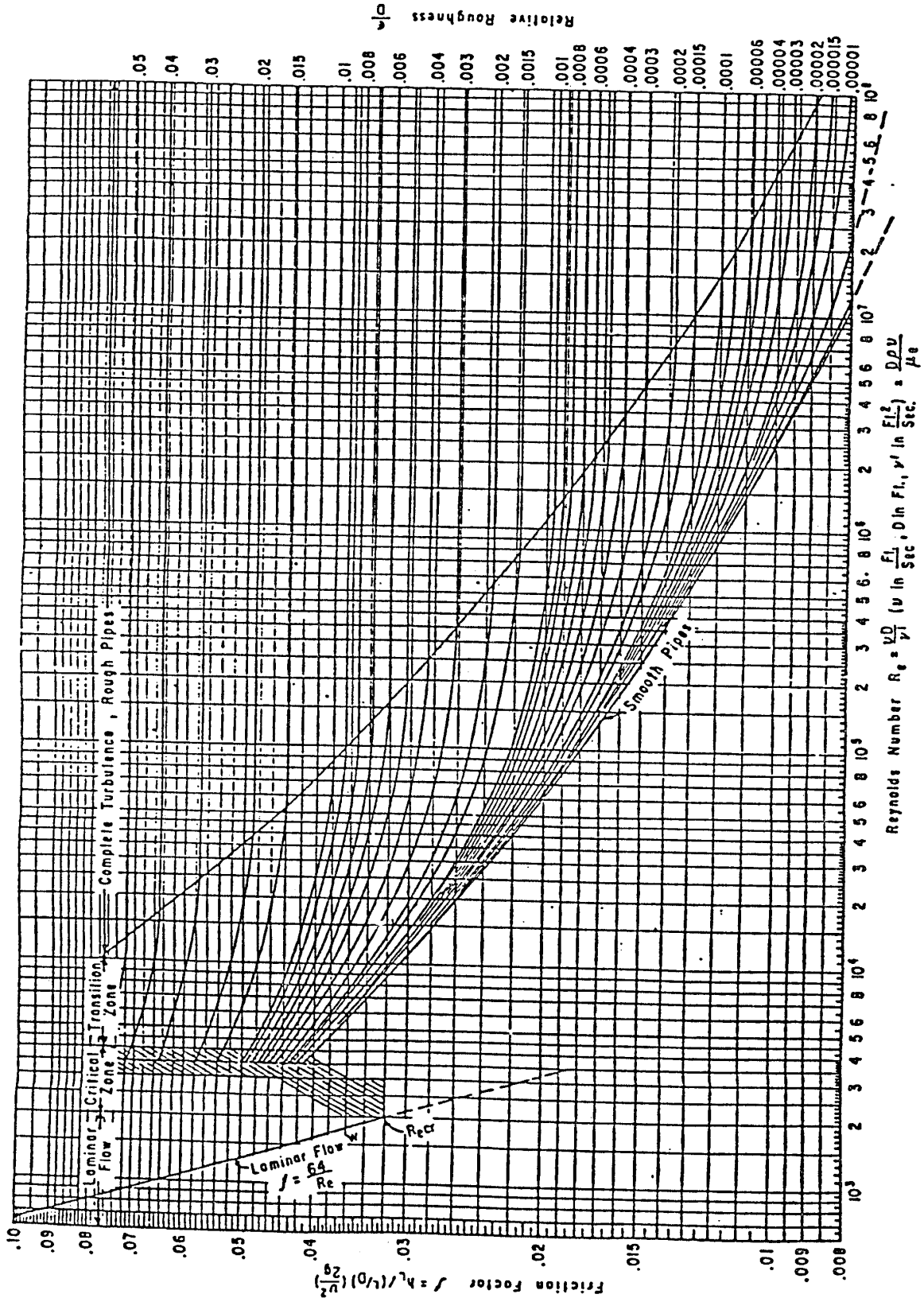


Fig. 3-1. Moody Chart



Friction factors for any kind and size of pipe. (Reprinted from "Pipe Friction Manual" copyright 1954 by the Hydraulic Institute, 122 E. 42nd St., New York 17, N. Y.)

Fig. 3-2. Relative Roughness

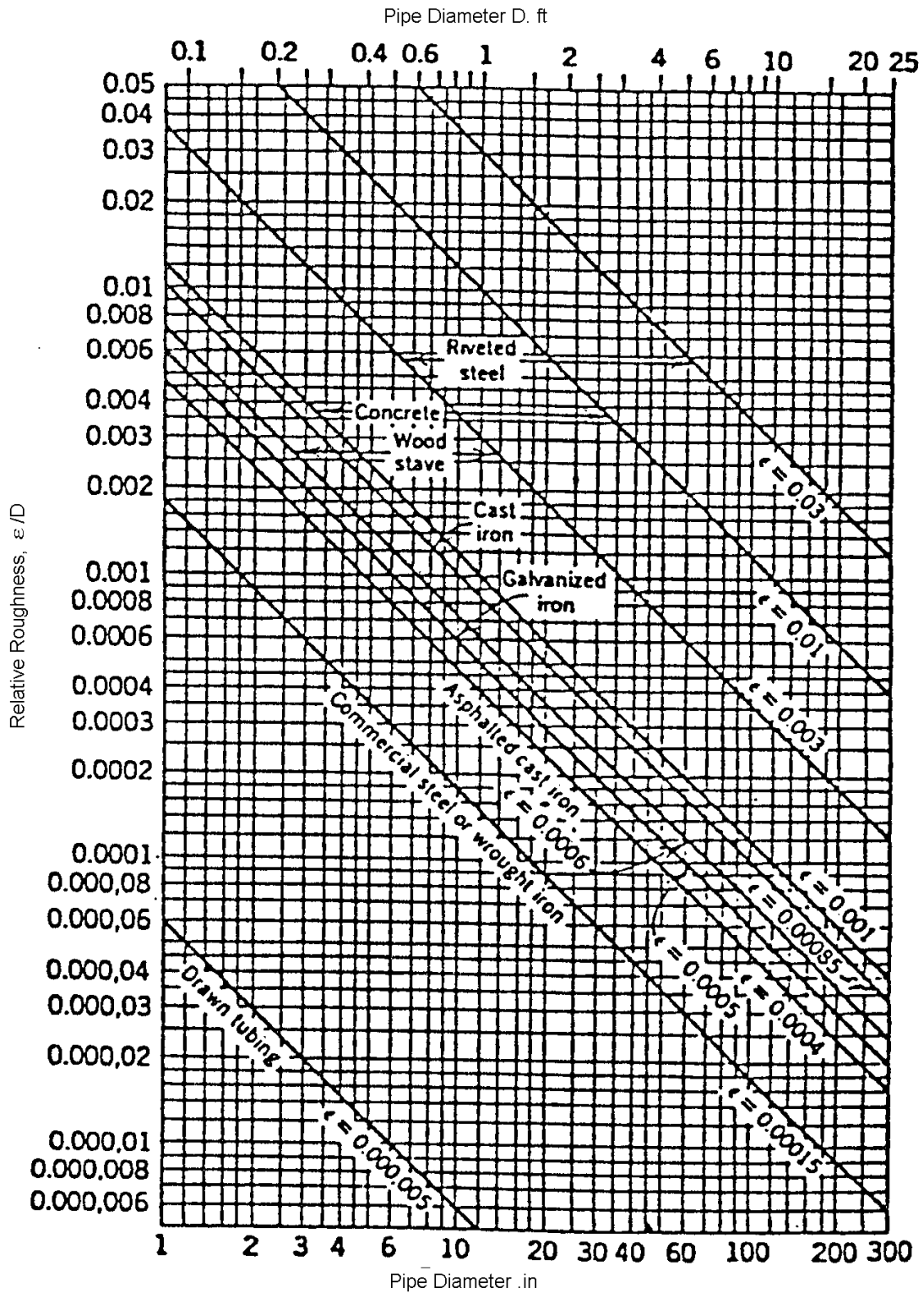
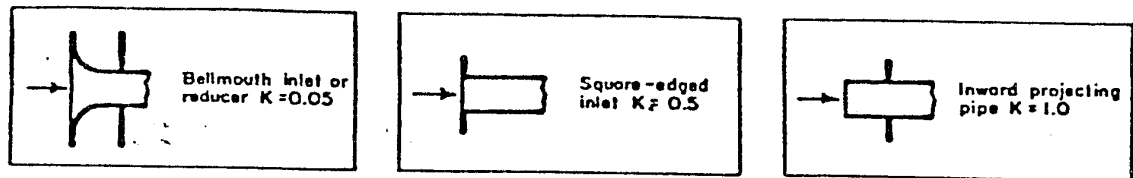
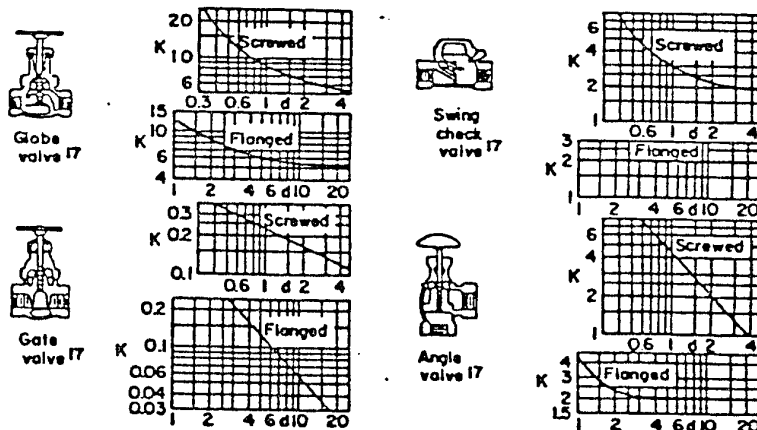
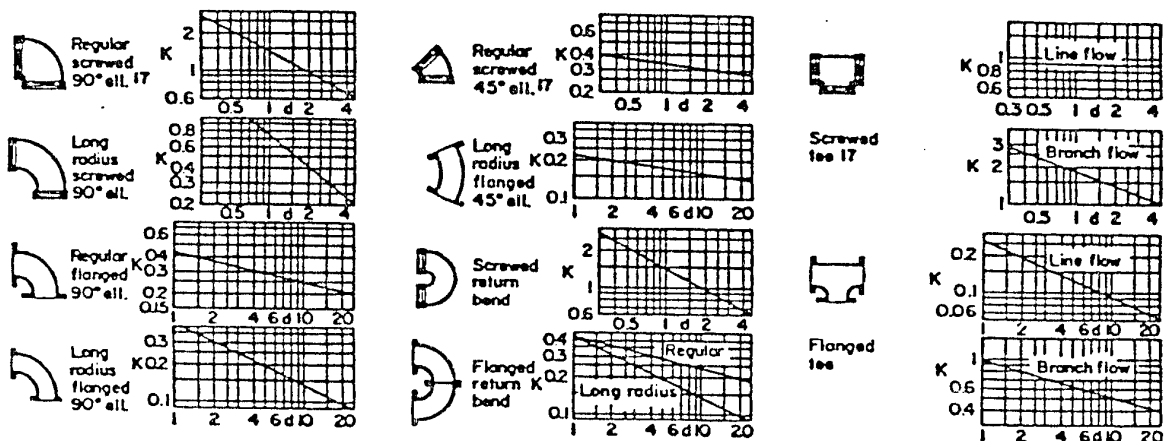


Fig. 3-3. Resistance Coefficients for Valves and Fitting 1



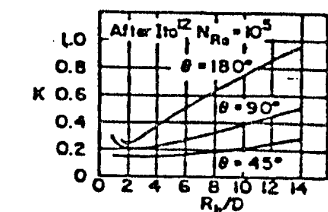
Note: K decreases with increasing wall thickness of pipe and rounding of edges



Smooth pipe bends



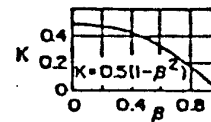
Reynolds no.	Multiplier for K
10^4	1.48
10^5	1.00
10^6	0.676



Length of pipe in bend is included in K as additional loss. Elsewhere, length contribution is excluded from K.



Contraction



Orifice

$$K = 2.8(1 - \beta^2) \left[\left(\frac{1}{\beta} \right)^4 - 1 \right]$$

β = small diameter / large diameter
K based on velocity in smaller pipe; based on main pipe for orifice.



Enlargement

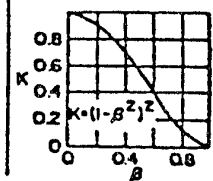
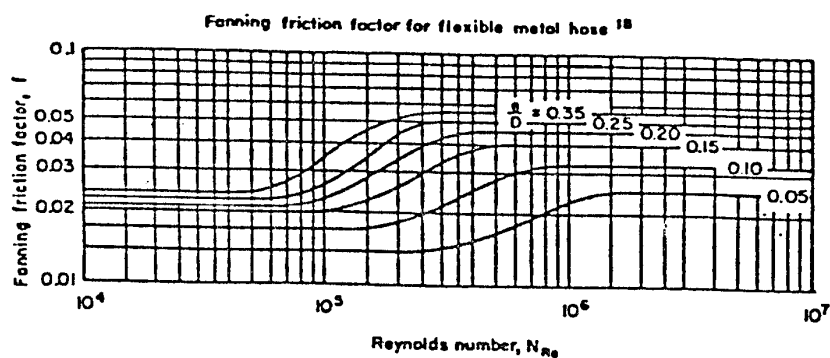
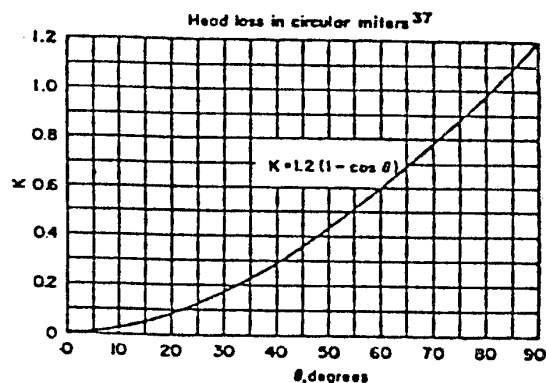
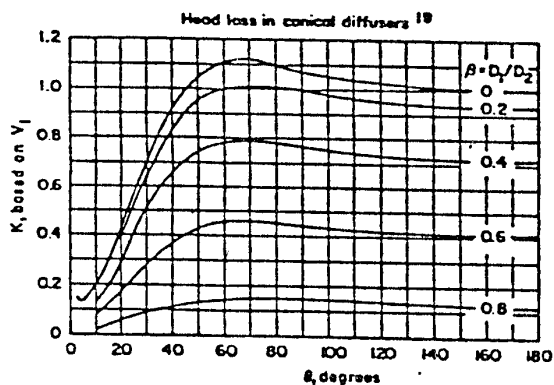
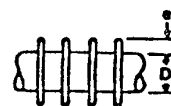


Fig. 3-4. Resistance Coefficients for Valves and Fitting 2



Typical dimensions

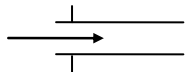
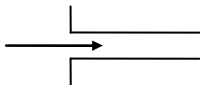
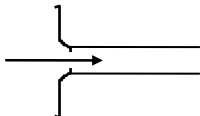
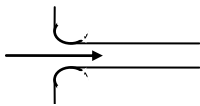
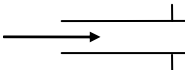
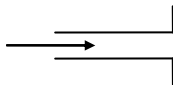
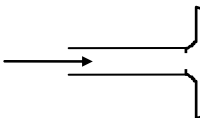
Nominal size (in.)	I.D. (in.)	$\frac{e}{D}$
1/2	0.520	0.250
3/4	0.750	0.275
1	1.000	0.187
1-1/2	1.500	0.200
2	2.000	0.161
3	2.962	0.143
4	4.000	0.081



Plug cock valve 18, $\theta = 5^\circ$	K	θ is angle between pipe axis and plug cock axis
10°	0.05	
20°	0.29	
40°	1.56	
60°	17.3	
	206.0	

Butterfly valve 19, $\theta = 5^\circ$	K	θ is angle between pipe axis and flapper plate
10°	0.24	
20°	0.52	
40°	1.54	
60°	10.8	
	118.0	

Fig. 3-5. Resistance Due to Pipe Entrance and Exit

	K	Service
	0.78	Inward Projecting Pipe Entrance
	0.5	Sharp Edges Entrance
	0.23	Slightly Rounded Entrance
	0.04	Rounded Entrance
	1	Projecting Pipe Exit
	1	Sharp Edged Exit
	1	Rounded Exit