



ENGINEERING DESIGN SEMINAR

SEPTEMBER 6, 1994 - NOVEMBER 11, 1994

LINE SIZING

Presented by

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A. General Line Sizing Comments

- 1. Guides and Approximations**
- 2. Reduce Time Required for Line Sizing**
- 3. Good Judgement and Experience**

1. **Use "NORMAL" Flow Rates and "NORMAL" pressures from Process Design**
2. **Consider the effects of:**
 - a. **Design Case Flow Rates**
 - b. **Maximum Flow rates**
 - c. **Startup Conditions**
 - d. **Shutdown Conditions**
 - e. **Upset Conditions**
3. **Use Flow Sketch to summarize Hydraulics and Line Sizing Data**
4. **Flow Sketch especially helpful to visualize effects of static head.**

Principle Criteria

- 1. Pressure Drop in psi/100 ft of pipe**
- 2. Velocity in feet per minute (fpm)**

Required Physical Properties

- 1. Flowing Specific Gravity (Sp.Gr.)**
**Ratio of the liquid density at its flowing temperature
to the density of water at 60°F**
- 2. Vapor Density (lb/ft³)**
- 3. Vapor Specific Volume (ft³/lb)**



SONIC VELOCITY - of a vapor

1. **Maximum velocity that the fluid cannot exceed**
2. **Usually occurs at end of a pipe or system**
(at a discontinuity in cross-sectional area)
3. **Examples of common occurrence:**
 - a. **Vacuum Heater Transfer Line**
 - b. **Pressure Relief Piping**
 - c. **High Pressure Drop systems**

$$V_s = \sqrt{\gamma g R T}$$

Specific Volume Change

- 1. If total line $\Delta P < 10\%$ of upstream absolute pressure, either upstream or downstream specific volume is acceptable for line ΔP calculation.**
- 2. If total line $\Delta P < 40\%$, but $> 10\%$ of upstream absolute pressure, use average specific volume.**
- 3. If total line $\Delta P > 40\%$ of upstream pressure, design the line in sections.**

Mechanical Considerations

- 1. Minimum Size for Pipe Rack is 1"**
- 2. Avoid nonstandard sizes**
(1 1/4", 2 1/2", 3 1/2" and 5")
- 3. For 2" and smaller pipe size, Schedule 80 minimum is recommended.**

Pipe Wall Thickness

- 1. Constant O.D.**
- 2. Pipe I.D. changes as wall thickness changes**
- 3. Wall thickness tolerance is $\pm 12 \frac{1}{2} \%$ for seamless pipe up to 24" O.D.**
- 4. Wall thickness tolerance is $\pm 0.01"$ for pipe fabricated from rolled plate.**

Revamp Projects

- 1. Economics and decision factors are different.**
- 2. Line sizes can often be smaller than for a new plant.**

PRESSURE DROP FOR LIQUID FLOWS

The general equation for pressure drop of a liquid in a pipe can be expressed as the Darcy Equation in the form:

$$\Delta P = \frac{f \times \rho \times L \times V^2}{144 \times D \times 2 \times g}$$

where:

ΔP	=	Pressure Drop	(psi)
ρ	=	Density	(lb/ft ³)
f	=	Darcy Friction Factor	
	=	four times the Fanning Friction Factor	
L	=	Length of pipe	(ft)
V	=	Velocity	(ft/sec)
D	=	Internal Diameter	(ft)
d	=	Internal diameter	(in)
g	=	Gravitational constant	(32.2 ft/sec ²)
Q	=	Flow	(gpm)

By rearrangement of the equation we can obtain:

$$\Delta P = \frac{0.000216 \times f \times L \times \rho \times Q^2}{d^5}$$

Pressure Drop for Liquid Flows (Continued)

Assume $L = 100$ ft

Define $\Delta P_{(100)} = 100 \Delta P$

and since $\rho = 62.4 \times SG$

where SG = Specific Gravity of fluid

Substitution and re-arrangement yields:

$$\frac{\Delta P_{100}}{SG} = \frac{1.348 f \times Q^2}{d^5}$$

Define:

$$\Delta P_{0(100)} = \frac{\Delta P_{100}}{SG}$$

By Substitution:

$$\Delta P_{0(100)} = \frac{1.348 f \times Q^2}{d^5}$$

For small changes in flow, Q , assume Fanning Friction Factor remains constant.

Thus we can define a constant K as follows:

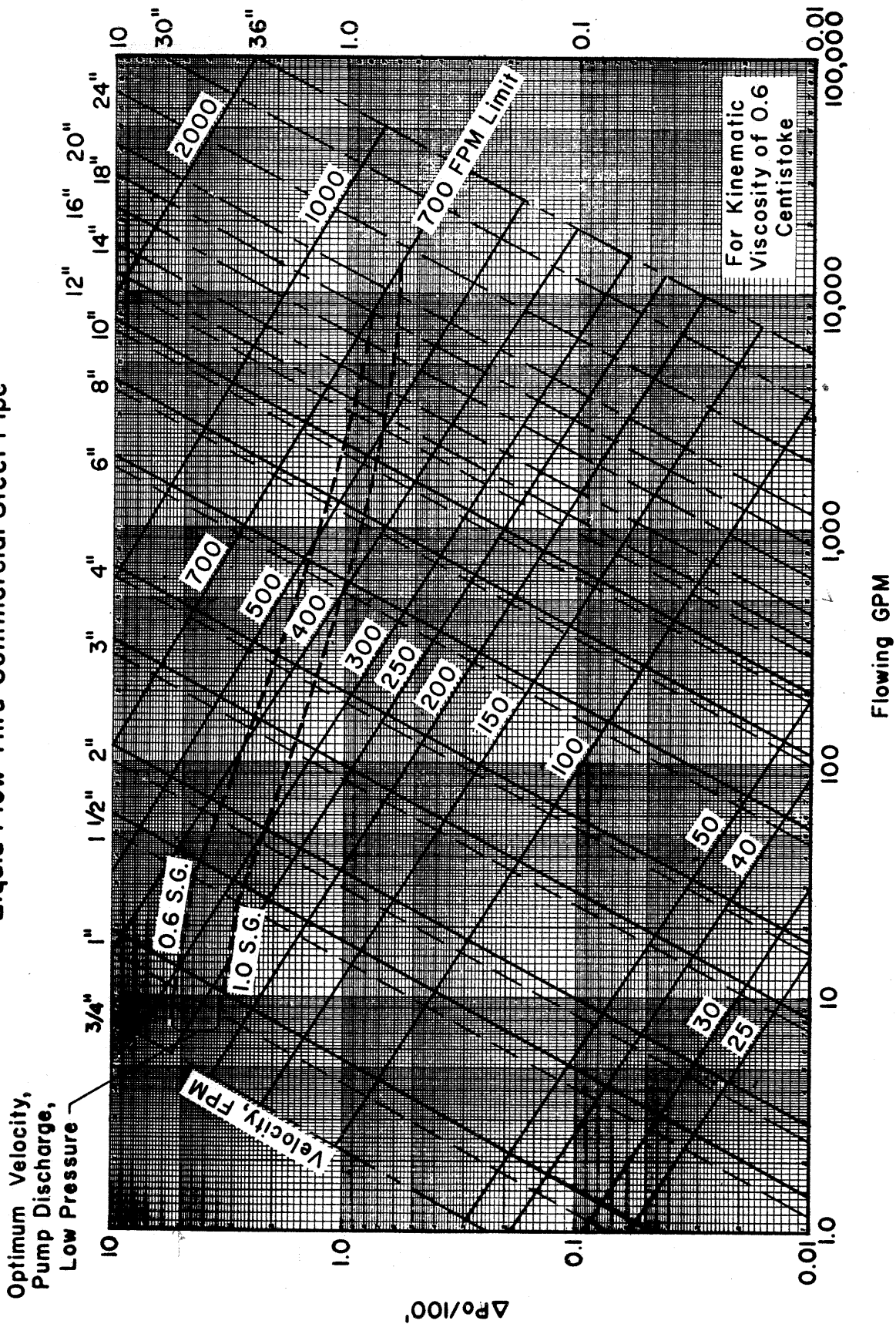
$$\frac{1.348 f}{d^5} = \text{Constant}, K$$

The equation then becomes:

$$\Delta P_{0(100)} = K Q^2$$

Which plots as a straight line on a Log-Log Graph.

Liquid Flow Thru Commercial Steel Pipe



--- Sch. 80
 --- Sch. 40
 --- 3/8" Wall

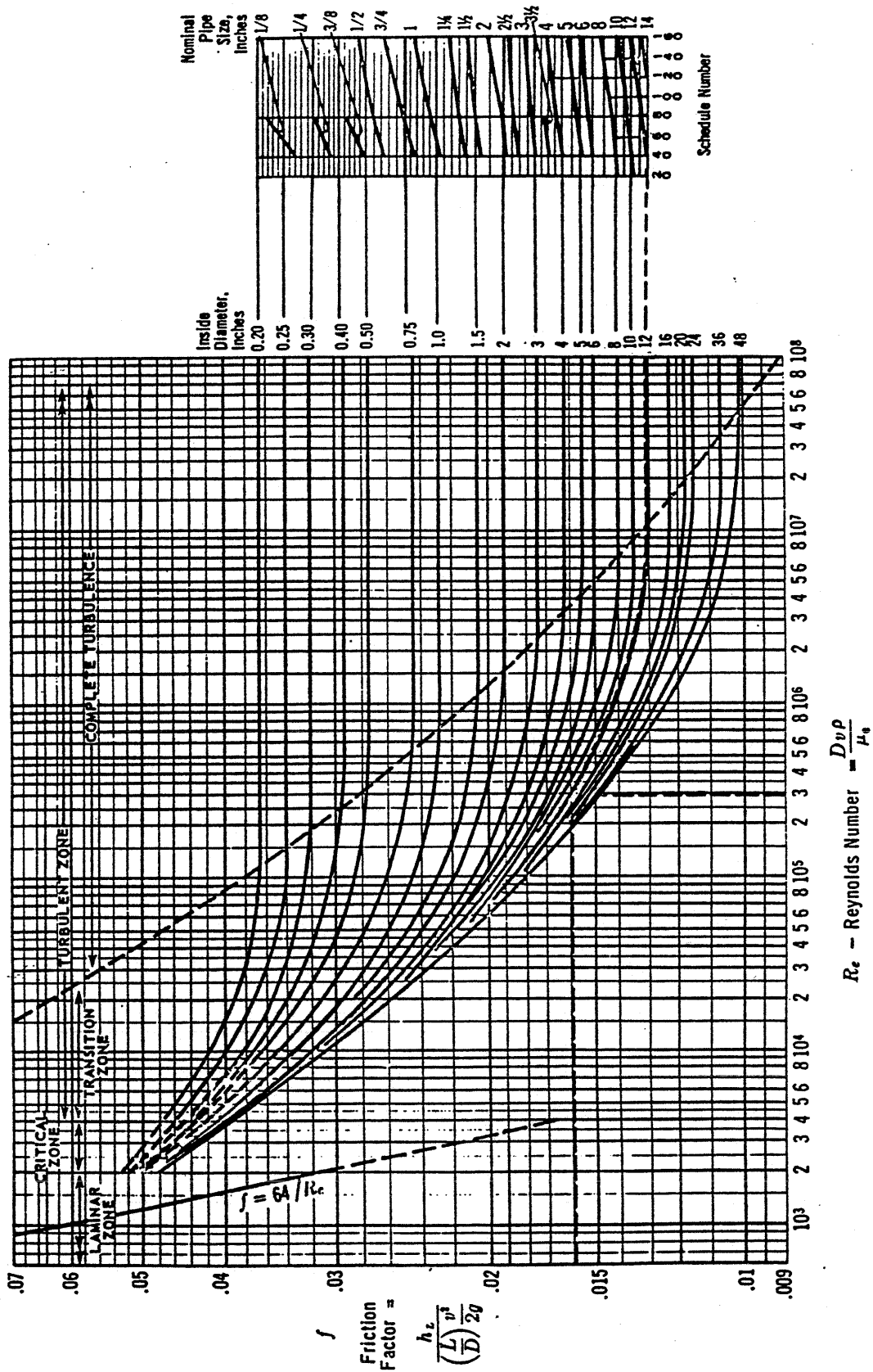
Note:

To Find ΔP in PSI per 100 ft. of Pipe,
 Multiply ΔPo/100' by Specific Gravity.

5-3-75 REJ

PD 435-C
 (Supersedes PD 435-B)

Friction Factors for Clean Commercial Steel and Wrought Iron Pipe¹⁸



Crane Co. "Flow of Fluids through Valves, Fittings, and Pipe",
Technical Paper 410, page A-25.

PD-903
7-20-75
RES

VISCOSITY CORRECTION:

The chart ΔP is based on a liquid having a kinematic viscosity of 0.6 centistoke.

For more viscous materials, multiply the chart ΔP by the correction factor:

$$\left(\frac{\nu}{0.6}\right)^{0.2}$$

where: ν is in centistoke.

Example:

For $\nu = 20$ centistoke, the correction factor = 2.016

$$\left(\frac{\nu}{0.6}\right)^{0.2} = \left(\frac{20}{0.6}\right)^{0.2} = 2.016$$

(Note: correction is for turbulent flow $Re > 2000$)

ν	Kinematic viscosity in centistoke
μ	Absolute viscosity in centipoise
ρ	Density, grams/cc @ 4°C
ν	μ/ρ

- ① From Chart
 ΔP_0 uncorrected
- ② Correct for specific Gravity
 $\Delta P_1 = \Delta P_0 \times Sp Gr.$
- ③ Correct for Viscosity
 $\Delta P_c = \Delta P_1 \left(\frac{\nu}{0.6}\right)^{0.2}$

Liquid Flow Line Sizing / ΔP Calculation

1. Flow Rate 500 gpm
 Flowing Sp.Gr. 0.75
 Viscosity 0.6 centistoke

- a. Find $\Delta P/100'$ in 6" Sch 80 Pipe

$$\frac{(1.0 \text{ (corr.)}) (500 \text{ gpm})^2}{(6 \text{ in})^5} = 0.28 \text{ psi/100 ft}$$

- b. Find $\Delta P/100'$ in 8" Sch 40 Pipe

$$\frac{(1.0 \text{ (corr.)}) (500 \text{ gpm})^2}{(8 \text{ in})^5} = 0.1215 \text{ psi/100 ft}$$

- c. Find Velocity in 8" Sch 40 Pipe

$$\approx 160 \text{ ft/min}$$

- d. Find Corrected $\Delta P/100'$ in 6" Sch 80 Pipe if $\nu = 50$ centistoke

$$\frac{(1.0 \text{ (corr.)}) (500 \text{ gpm})^2}{(6 \text{ in})^5} \times \frac{0.6}{50} = 0.0034 \text{ psi/100 ft}$$

- e. What size pipe would result in a $\Delta P/100' = 0.28$ psi if flow is 4000 gpm, Sp. Gr. = 0.8 and $\nu = 0.6$ centistoke?

$$16''$$

PRESSURE DROP FOR VAPOR FLOWS

The general equation for pressure drop of a vapor in a pipe can be expressed as the Darcy Equation in the form:

$$\Delta P = \frac{3.36 \times 10^{-6} \times f \times L \times W^2 \times \bar{V}}{d^5}$$

Where:

ΔP	=	Pressure drop	(psi)
ρ	=	Density	(lb/ft ³)
f	=	Darcy Friction Factor	
	=	four times the Fanning Friction Factor	
L	=	Length of pipe	(ft)
V	=	Specific Volume	(ft ³ /lb)
d	=	Internal diameter	(in)
W	=	Mass Flow Rate	(lb/h)

Pressure Drop for Vapor Flows (Continued)

Assume $L = 100$ ft

Define $\Delta P_{(100)} = 100 \Delta P/V$

By substitution and re-arrangement we obtain:

$$\Delta P_{100} = \frac{336f}{d^5} \left(\frac{W}{1000} \right)^2$$

For small changes in flow, W , assume the fanning friction factor, f , remains constant. Thus:

$$\frac{336f}{d^5} = \text{Constant}, K$$

$$\Delta P_{0(100)} = K \left(\frac{W}{1000} \right)^2$$

This plots as a straight line on a Log - Log graph.

VAPOR

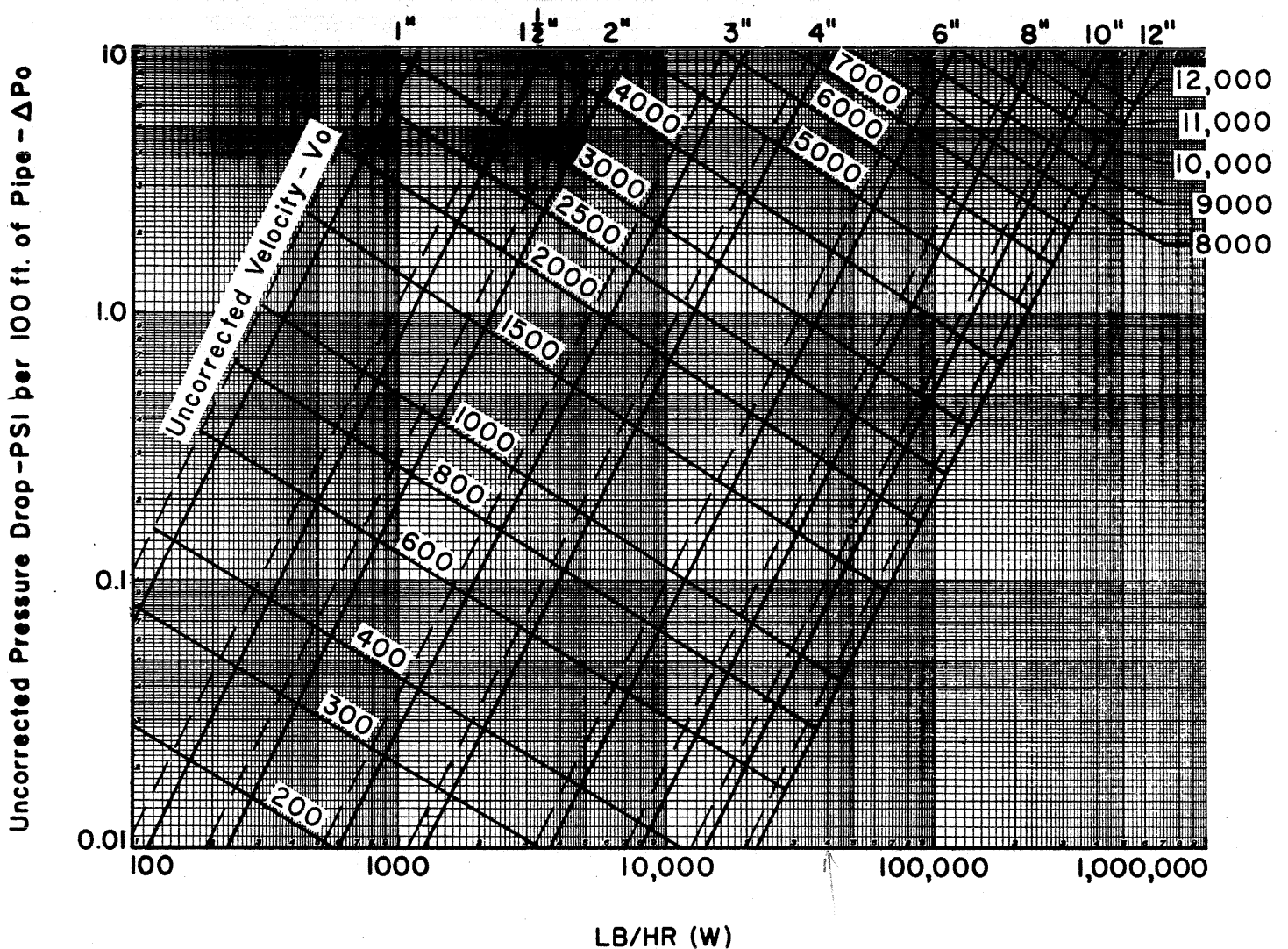
① From CHART
 $\Delta P_0 / 100$

② Correct for SPECIFIC VOLUME

$$\Delta P_e = \Delta P_0 (SV)$$

$$SV = 1/\rho$$

Vapor Flow Thru Commercial Steel Pipe



$$\Delta P_o = (f) \left(\frac{336}{d^5} \right) \left(\frac{W}{1000} \right)^2$$

Where

d = ID, inches

W = LB/HR

f =

0.027	for	1" Pipe
0.025	for	1½" Pipe
0.023	for	2" Pipe
0.022	for	3" Pipe
0.020	for	4" Pipe
0.018	for	6" Pipe
0.016	for	8" Pipe
0.015	for	10" Pipe
0.015	for	12" Pipe

Based on Viscosity
of 0.015 Centipoise.
Extrapolation Off Chart
May Give Erroneous "f".

LEGEND

Sch. 80 — — —
Sch. 40 — — —

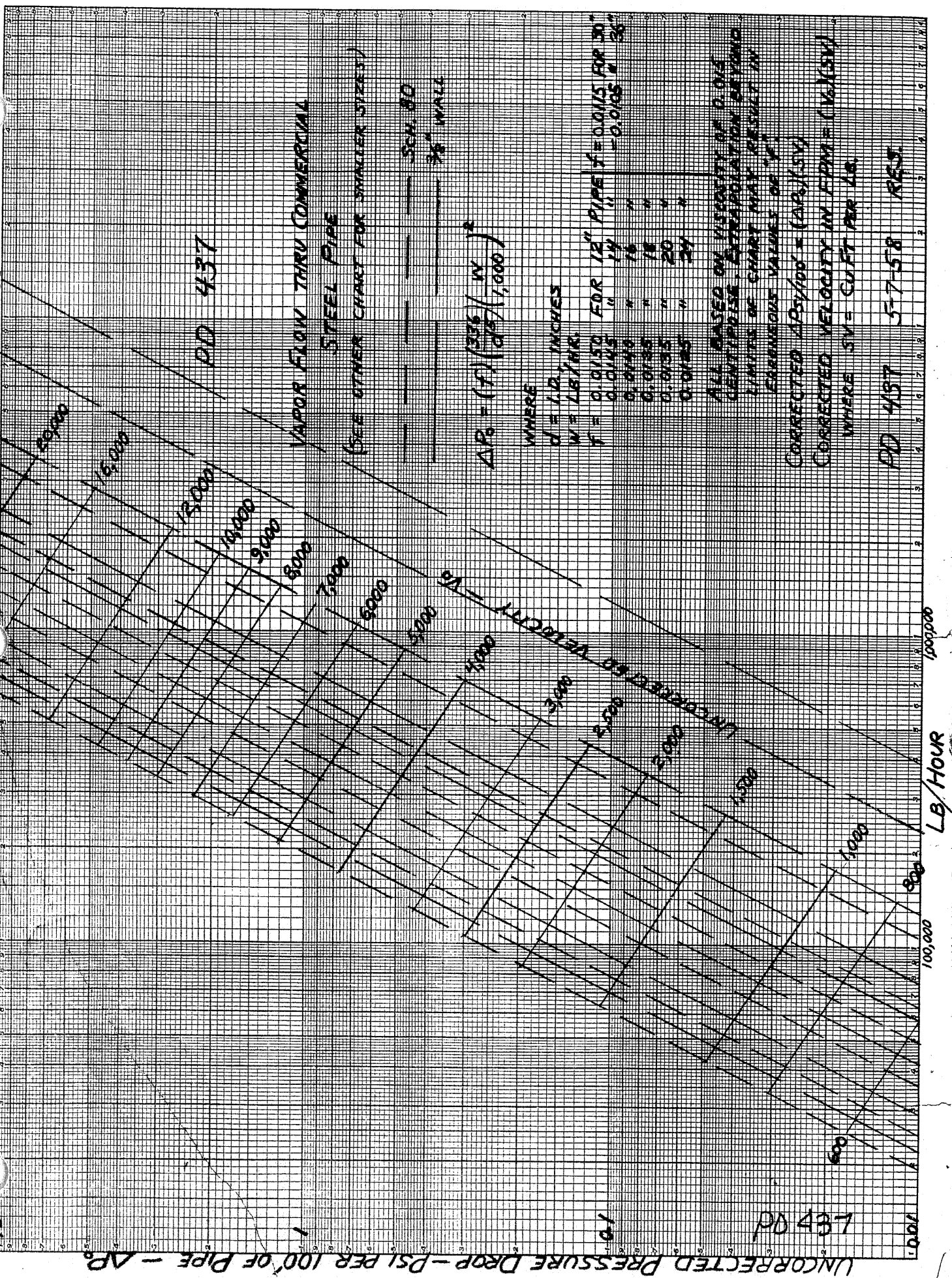
$$\text{Corrected } \frac{\Delta \text{PSI}}{100'} = (\Delta P_o)(SV)$$

$$\text{Corrected Vel. in FPM} = (V_o)(SV)$$

Where

SV = Cu. Ft./Lb.

PD 436
Redrawn 5-3-73



DD 437 5-7-58 RES

DD 437 5-7-58 RES.

Two-Phase Flow Pressure Drop

1. Calculate fictitious all vapor pressure drop, ΔP^*_G using total mass flow and flowing vapor properties
2. Calculate fictitious all liquid pressure drop, ΔP^*_L by converting total mass flow to liquid, gpm, and use the flowing properties of the liquid phase.
3. Calculate the ratio $\Delta P^*_G / \Delta P^*_L$
4. Calculate the actual liquid volume fraction

$$\frac{V_L}{V_L + V_G} = \text{LiquidVolumeFraction}$$

5. Using these last two values and chart determine factor, f

Where:

$$f = \Delta P_{TP} / \Delta P^*_L$$

6. Calculate two-phase pressure drop, ΔP_{TP}

$$\Delta P_{TP} = f \times \Delta P^*_L$$

Two Phase Flow Line Sizing / ΔP Calculation

Find a Schedule 80 Pipe Size that will result in approximately a pressure drop of 0.5 psi/100' as a result of Two-Phase flow having the following parameters:

Liquid Flow:

Rate = 500 gpm

Sp. Gr. = 0.75

Vapor Flow:

Rate = 40,000 lb/h

Sp. Vol. = 0.9 ft³/lb

Liquid Flow Line Sizing / ΔP Calculation

1. Flow Rate 500 gpm
 Flowing Sp.Gr. 0.75

- a. Find $\Delta P/100'$ in 6" Sch 80 Pipe

$$\Delta P/100' = 0.91 (\Delta P_s/100') \times 0.75 = 0.68 \text{ psi}$$

- b. Find $\Delta P/100'$ in 8" Sch 40 Pipe

$$\Delta P/100' = 0.17 (\Delta P_s/100') \times 0.75 = 0.13 \text{ psi}$$

- c. Find Velocity in 8" Sch 40 Pipe

$$\text{velocity} \sim 190 \text{ fpm}$$

- d. Find Corrected $\Delta P/100'$ in 6" Sch 80 Pipe if $\nu = 50$ centistoke

$$\Delta P/100' = 0.68 (50 / 0.6)^{0.2} = 0.68 \times 2.42 = 1.65 \text{ psi}$$

- e. What size pipe would result in a $\Delta P/100' = 0.28$ psi if flow is 4000 gpm, Sp. Gr. = 0.8 and $\nu = 0.6$ centistoke ?

$$\Delta P_s/100' = 0.28 / 0.8 = 0.35 \text{ psi}$$

$$\text{Line size} = 16" \text{ (} 3/8" \text{ wall)}$$

Vapor Flow Line Sizing / ΔP Calculation

1. **Flowing Quantity** **= 40,000 lb/h**
 Specific Volume **= 0.9 ft³/lb**

- a. **Find $\Delta P/100'$ in 6" Sch 80 pipe**

$$\Delta P/100' = 1.6 (\Delta P_s/100') \times 0.9 = 1.44 \text{ psi}$$

- b. **Find $\Delta P/100'$ in 8" Sch 40 pipe**

$$\Delta P/100' = 0.27 (\Delta P_s/100') \times 0.9 = 0.24 \text{ psi}$$

- c. **Find Velocity in 8" Sch 40 pipe**

$$\text{velocity} \sim 1900 (v_s) \times 0.9 \sim 1710 \text{ fpm}$$

- d. **What Sch 40 size pipe is required to obtain a $\Delta P/100'$ equal to or less than 0.4 psi, if the flow is 100,000 lb/h and density is 2 lb/ft³ ?**

What is the velocity in the line?

$$\text{Specific Volume} = 1/\text{density} = 1/2 = 0.5 \text{ ft}^3/\text{lb}$$

$$\Delta P_s/100' = 0.4/0.5 = 0.8 \text{ psi}$$

$$\text{Line size} = 10"$$

$$\Delta P/100' = 0.5 (\Delta P_s/100') \times 0.5 = 0.25 \text{ psi} < 0.4 \text{ psi}$$

$$\text{velocity} \sim 3100 \times 0.5 = 1550 \text{ fpm}$$

Check for Slug Flow in 10" Schedule 80 Pipe

Annular or mist flow is usually assured if the velocity in ft/sec is approximately equal to (or greater than) 60 divided by the square root of the mixed phase density in lbs/ft³.

$$V_c \geq \frac{60}{\sqrt{\rho_{mp}}} \quad \text{in ft/sec}$$

$$\rho_{mp} = \frac{227,500}{40,000} = 5.69 \text{ lbs/ft}^3$$

$$V_c = \frac{60}{\sqrt{5.69}} = 25.2 \text{ ft/sec}$$

$$V_{10"} = \frac{40,000}{3600 \times 0.4989} = 22.3 < 25.2 \text{ ft/sec}$$

Check further by use of chart

LOCKHART - MARTINELLI

CHENOWETH - MARTIN

↑
Thermosyphon Reboilers

Slug Flow Chart Coordinates

$$\text{Mass Velocity} = \frac{227,500}{3600 \times 0.4989} = 127$$

$$\frac{1}{\left(\frac{W_L}{W_G}\right)^{0.9} \left(\frac{\rho_G}{\rho_L}\right)^{0.5} \left(\frac{\mu_L}{\mu_G}\right)^{0.1}} = \frac{1}{4.02 \times 0.15 \times 1.41} = 1.18$$

$$(W_L/W_G)^{0.9} = (187,500/40,000)^{0.9} = 4.02$$

$$(\rho_G/\rho_L)^{0.5} = (1.11/46.9)^{0.5} = 0.15$$

$$(\mu_L/\mu_G)^{0.1} = (0.6 \times 0.75/0.015)^{0.1} = 1.41$$

Chart Indicates Annular Flow

Nomenclature

Unless otherwise stated, all symbols used in this book are defined as follows:

A = cross sectional area of pipe or orifice, in square feet
 a = cross sectional area of pipe or orifice, or flow area in valve, in square inches
 B = rate of flow in barrels (42 gallons) per hour
 C = flow coefficient for orifices and nozzles = discharge coefficient corrected for velocity of approach = $C_d / \sqrt{1 - \beta^4}$
 C_d = discharge coefficient for orifices and nozzles
 C_v = flow coefficient for valves; expresses flow rate in gallons per minute of 60 F water with 1.0 psi pressure drop across valve
 D = internal diameter of pipe, in feet
 d = internal diameter of pipe, in inches
 e = base of natural logarithm = 2.718
 f = friction factor in formula $h_L = f L v^2 / D 2g$
 f_T = friction factor in zone of complete turbulence
 g = acceleration of gravity = 32.2 feet per second per second
 H = total head, in feet of fluid
 h = static pressure head existing at a point, in feet of fluid
 h_g = total heat of steam, in Btu per pound
 h_L = loss of static pressure head due to fluid flow, in feet of fluid
 h_w = static pressure head, in inches of water
 K = resistance coefficient or velocity head loss in the formula, $h_L = K v^2 / 2g$
 k = ratio of specific heat at constant pressure to specific heat at constant volume = c_p / c_v
 L = length of pipe, in feet
 L/D = equivalent length of a resistance to flow, in pipe diameters
 L_m = length of pipe, in miles
 M = molecular weight
 MR = universal gas constant = 1545
 n = exponent in equation for polytropic change ($p' V^n = \text{constant}$)
 P = pressure, in pounds per square inch gauge
 P' = pressure, pounds per square inch absolute (see page 1-5 for diagram showing relationship between gauge and absolute pressure)
 p' = pressure, in pounds per square foot absolute
 Q = rate of flow, in gallons per minute
 q = rate of flow, in cubic feet per second at flowing conditions
 q' = rate of flow, in cubic feet per second at standard conditions (14.7 psia and 60F)
 q'_a = rate of flow, in millions of standard cubic feet per day, MMscfd
 q'_h = rate of flow, in cubic feet per hour at standard conditions (14.7 psia and 60F), scfh
 q_m = rate of flow, in cubic feet per minute at flowing conditions
 q'_m = rate of flow, in cubic feet per minute at std. conditions (14.7 psia and 60F), scfm
 R = individual gas constant = $MR/M = 1545/M$
 R_e = Reynolds number

R_H = hydraulic radius, in feet
 r_c = critical pressure ratio for compressible flow
 S = specific gravity of liquids at specified temperature relative to water at standard temperature (60 F)
 S_g = specific gravity of a gas relative to air = the ratio of the molecular weight of the gas to that of air
 T = absolute temperature, in degrees Rankine ($460 + t$)
 t = temperature, in degrees Fahrenheit
 $\bar{V}$ = specific volume of fluid, in cubic feet per pound
 V = mean velocity of flow, in feet per minute
 V_a = volume, in cubic feet
 v = mean velocity of flow, in feet per second
 v_s = sonic (or critical) velocity of flow of a gas, in feet per second
 W = rate of flow, in pounds per hour
 w = rate of flow, in pounds per second
 w_a = weight, in pounds
 x = percent quality of steam = 100 minus per cent of moisture
 Y = net expansion factor for compressible flow through orifices, nozzles, or pipe
 Z = potential head or elevation above reference level, in feet

Greek Letters

Beta

β = ratio of small to large diameter in orifices and nozzles, and contractions or enlargements in pipes

Delta

Δ = differential between two points

Epsilon

ϵ = absolute roughness or effective height of pipe wall irregularities, in feet

Mu

μ = absolute (dynamic) viscosity, in centipoise
 μ_c = absolute viscosity, in pound mass per foot second or poundal seconds per sq foot
 μ'_c = absolute viscosity, in slugs per foot second or pound force seconds per square foot

Nu

ν = kinematic viscosity, in centistokes
 ν' = kinematic viscosity, square feet per second

Rho

ρ = weight density of fluid, pounds per cubic ft
 ρ' = density of fluid, grams per cubic centimeter

Theta

θ = angle of convergence or divergence in enlargements or contractions in pipes

Subscripts for Diameter

- (1) ... defines smaller diameter
- (2) ... defines larger diameter

Subscripts for Fluid Property

- (1) ... defines inlet (upstream) condition
- (2) ... defines outlet (downstream) condition

Schedule (Thickness) of Steel Pipe Used in Obtaining Resistance Of Valves and Fittings of Various Pressure Classes by Test*

Valve or Fitting ASA Pressure Classification		Schedule No. of Pipe Thickness
Steam Rating	Cold Rating	
250-Pound and Lower	500 psig	Schedule 40
300-Pound to 600-Pound	1440 psig	Schedule 80
900-Pound	2160 psig	Schedule 120
1500-Pound	3600 psig	Schedule 160
2500-Pound	1/2 to 6" and larger	6000 psig 3600 psig xx (Double Extra Strong) Schedule 160

*These schedule numbers have been arbitrarily selected only for the purpose of identifying the various pressure classes of valves and fittings with specific pipe dimensions for the interpretation of flow test data; they should not be construed as a recommendation for installation purposes.

Representative Equivalent Length[†] in Pipe Diameters (L/D) Of Various Valves and Fittings

Description of Product				Equivalent Length In Pipe Diameters (L/D)
Globe Valves	Stem Perpendicular to Run	With no obstruction in flat, bevel, or plug type seat	Fully open	340
		With wing or pin guided disc	Fully open	450
	Y-Pattern	(No obstruction in flat, bevel, or plug type seat)	Fully open	175
		- With stem 60 degrees from run of pipe line - With stem 45 degrees from run of pipe line	Fully open Fully open	145
Angle Valves		With no obstruction in flat, bevel, or plug type seat	Fully open	145
		With wing or pin guided disc	Fully open	200
Gate Valves	Wedge, Disc, Double Disc, or Plug Disc		Fully open	13
			Three-quarters open	35
			One-half open	160
			One-quarter open	900
	Pulp Stock		Fully open	17
			Three-quarters open	50
			One-half open	260
			One-quarter open	1200
Conduit Pipe Line Gate, Ball, and Plug Valves			Fully open	3**
Check Valves	Conventional Swing	0.5†... Fully open	135	
	Clearway Swing	0.5†... Fully open	50	
	Globe Lift or Stop; Stem Perpendicular to Run or Y-Pattern	2.0†... Fully open	Same as Globe	
	Angle Lift or Stop	2.0†... Fully open	Same as Angle	
	In-Line Ball	2.5 vertical and 0.25 horizontal†... Fully open	150	
Foot Valves with Strainer		With poppet lift-type disc	0.3†... Fully open	420
		With leather-hinged disc	0.4†... Fully open	75
Butterfly Valves (8-inch and larger)			Fully open	40
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			30
	45 Degree Standard Elbow			16
	90 Degree Long Radius Elbow			20
	90 Degree Street Elbow			50
	45 Degree Street Elbow			26
	Square Corner Elbow			57
	Standard Tee	With flow through run		20
		With flow through branch		60
Close Pattern Return Bend			50	
Pipe	90 Degree Pipe Bends			See Page A-27
	Miter Bends			See Page A-27
	Sudden Enlargements and Contractions			See Page A-26
	Entrance and Exit Losses			See Page A-26

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

For resistance factor "K", equivalent length in feet of pipe

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

‡For limitations, see page 2-11. For effect of end connections, see page 2-10.

see pages A-31

Crane Co. "Flow of Fluids through Valves, Fittings, and Pipe",
Technical Paper 410, page A-30.

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Resistance of Bends

Resistance of 90 Degree Bends²¹

The chart at the right shows the resistance of 90 degree bends to the flow of fluids in terms of equivalent lengths of straight pipe.

Resistance of bends greater than 90 degrees is found using the formula:

$$\frac{L}{D} = R_t + (n - 1) \left(R_l + \frac{R_b}{2} \right)$$

n = total number of 90° bends in coil

R_t = total resistance due to one 90° bend, in L/D

R_l = resistance due to length of one 90° bend, in L/D

R_b = bend resistance due to one 90° bend, in L/D

Problem: Determine the equivalent lengths in pipe diameters of a 90 degree bend and a 270 degree bend having a relative radius of 12.

Solution: Referring to the "Total Resistance" curve, the equivalent length for a 90 degree bend is 34.5 pipe diameters.

The equivalent length of a 270 degree bend is:

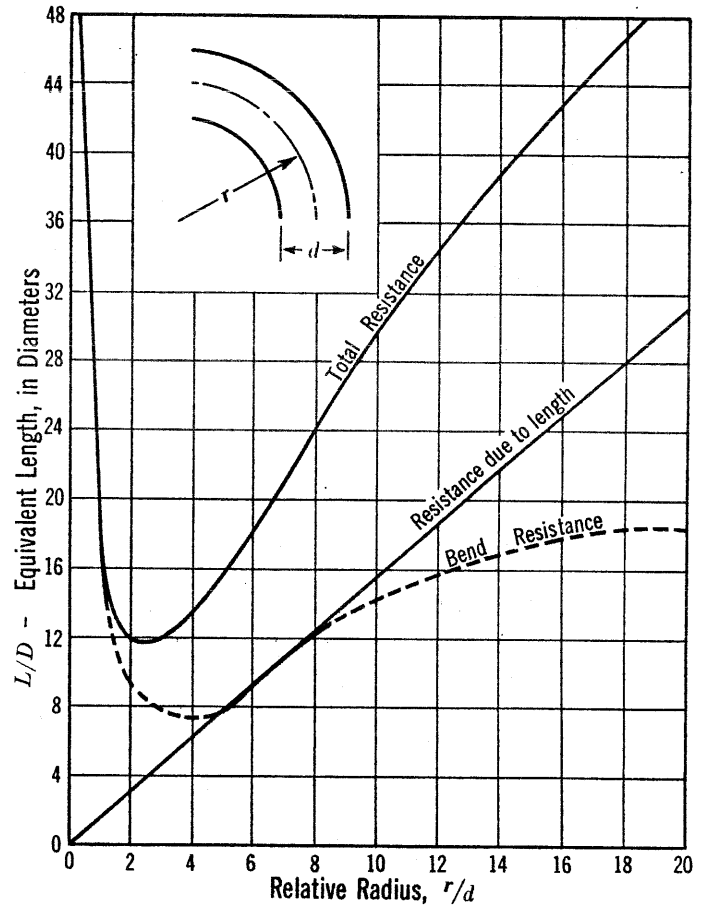
$$L/D = 34.5 + (3 - 1) [18.7 + (15.8 + 2)]$$

$$L/D = 87.7 \text{ pipe diameters}$$

Note: This loss is less than the sum of losses through three 90 degree bends separated by tangents. For "resistance of bends theory", see page 2-12.

Chart for Resistance of 90 Degree Bends

From *Pressure Losses for Fluid Flow in 90 Degree Pipe Bends* by K. H. Beij. Courtesy of *Journal of Research of National Bureau of Standards*, Vol. 21, July, 1938.



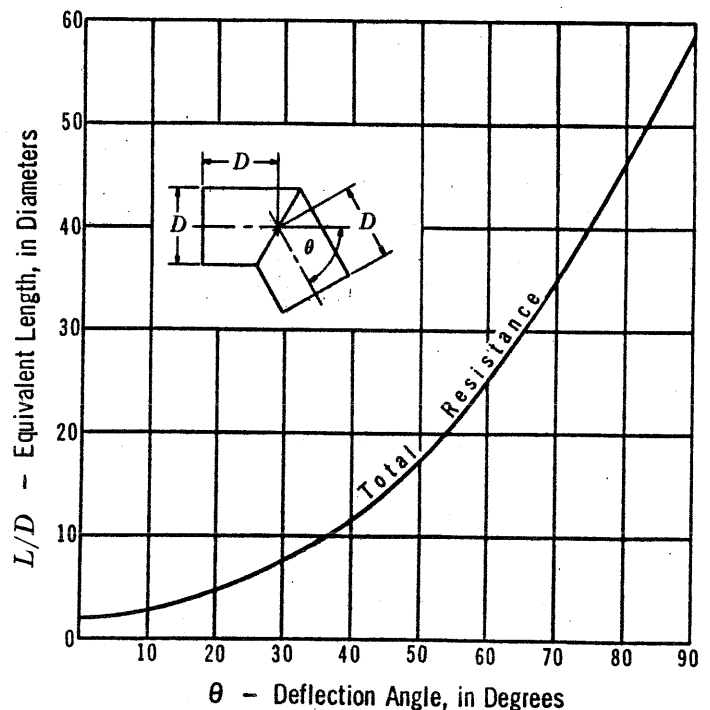
Resistance of Miter Bends⁴

The chart at the lower right shows the resistance of miter bends to the flow of fluids. The chart is based on data published by the American Society of Mechanical Engineers (ASME).

Problem: Determine the equivalent length in pipe diameters of a 40 degree miter bend.

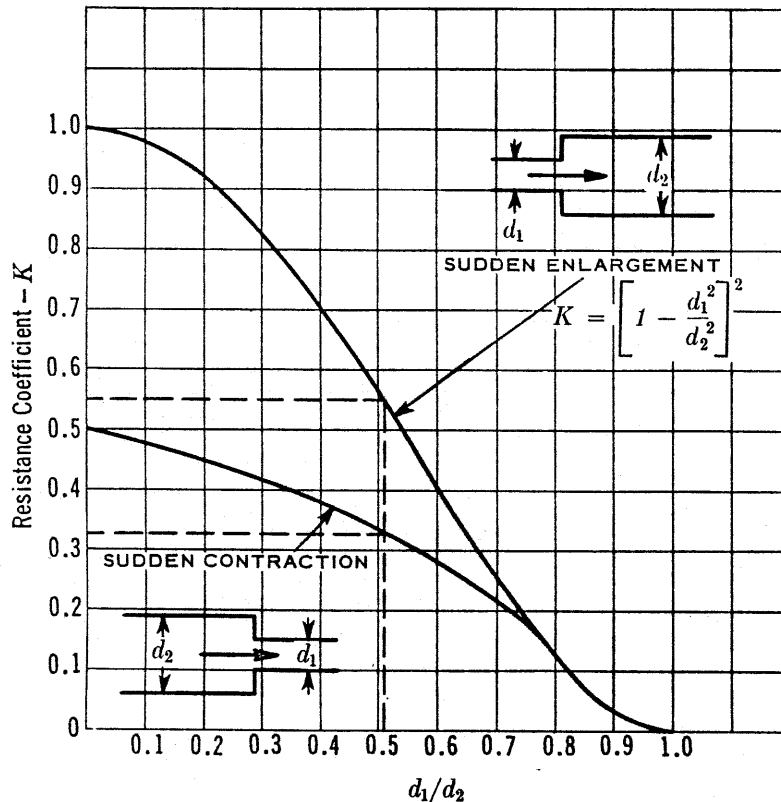
Solution: Referring to the "Total Resistance" curve in the chart, the equivalent length is 12 pipe diameters.

Chart for Resistance of Miter Bends



Resistance in Pipe

Resistance Due to Sudden Enlargements and Contractions²⁰



Sudden enlargement: The resistance coefficient K for a sudden enlargement from 6-inch Schedule 40 pipe to 12-inch Schedule 40 pipe is 0.55, based on the 6-inch pipe size.

$$\frac{d_1}{d_2} = \frac{6.065}{11.938} = 0.51$$

Sudden contraction: The resistance coefficient K for a sudden contraction from 12-inch Schedule 40 pipe to 6-inch Schedule 40 pipe is 0.33, based on the 6-inch pipe size.

$$\frac{d_1}{d_2} = \frac{6.065}{11.938} = 0.51$$

Note: The values for the resistance coefficient, K , are based on velocity in the small pipe. To determine K values in terms of the greater diameter, multiply the chart values by $(d_2/d_1)^4$.

Resistance Due to Pipe Entrance and Exit

$K = 0.78$
Inward
Projecting
Pipe
Entrance

$K = 0.50$
Sharp
Edged
Entrance

$K = 0.23$
Slightly
Rounded
Entrance

$K = 0.04$
Well
Rounded
Entrance

Problem: Determine the total resistance coefficient for a pipe one diameter long having a sharp edged entrance and a sharp edged exit.

Solution: The resistance of pipe one diameter long is small and can be neglected ($K = fL/D$).

$K = 1.0$
Projecting
Pipe
Exit

$K = 1.0$
Sharp
Edged
Exit

$K = 1.0$
Rounded
Exit

From the diagrams, note:

Resistance for a sharp edged entrance = 0.5

Resistance for a sharp edged exit = 1.0

Then,
the total resistance, K , for the pipe = 1.5

PIPE DATA **Carbon and Alloy Steel — Stainless Steel**

(also see next three pages)

Nom- inal Pipe Size Inches	Outside Diam. Inches	Identification			Wall Thick- ness (t) Inches	Inside Diam- eter (d) Inches	Area of Metal Square Inches	Transverse		Moment of Inertia (I) Inches ⁴	Weight Pipe Pounds per foot	Weight Water Pounds per foot of pipe	External Surface Sq. Ft. per foot of pipe	Section Modulus ($2\frac{I}{O.D.}$)
		Steel		Stain- less Steel Sched. No.				Internal Area						
		Iron Pipe Size	Sched. No.					(a) Square Inches	(A) Square Feet					
1/8	0.405	... STD XS	... 40 80	10S 40S 80S	.049 .068 .095	.307 .269 .215	.0548 .0720 .0925	.0740 .0568 .0364	.00051 .00040 .00025	.00088 .00106 .00122	.19 .24 .31	.032 .025 .016	.106 .106 .106	.00437 .00523 .00602
1/4	0.540	... STD XS	... 40 80	10S 40S 80S	.065 .088 .119	.410 .364 .302	.0970 .1250 .1574	.1320 .1041 .0716	.00091 .00072 .00050	.00279 .00331 .00377	.33 .42 .54	.057 .045 .031	.141 .141 .141	.01032 .01227 .01395
3/8	0.675	... STD XS	... 40 80	10S 40S 80S	.065 .091 .126	.545 .493 .423	.1246 .1670 .2173	.2333 .1910 .1405	.00162 .00133 .00098	.00586 .00729 .00862	.42 .57 .74	.101 .083 .061	.178 .178 .178	.01736 .02160 .02554
1/2	0.840	 STD XS ... XXS	 40 80 160 ...	5S 10S 40S 80S	.065 .083 .109 .147 .187 .294	.710 .674 .622 .546 .466 .252	.1583 .1974 .2503 .3200 .3836 .5043	.3959 .3568 .3040 .2340 .1706 .050	.00275 .00248 .00211 .00163 .00118 .00035	.01197 .01431 .01709 .02008 .02212 .02424	.54 .67 .85 1.09 1.31 1.71	.172 .155 .132 .102 .074 .022	.220 .220 .220 .220 .220 .220	.02849 .03407 .04069 .04780 .05267 .05772
3/4	1.050	... STD XS ... XXS	 40 80 160 ...	5S 10S 40S 80S	.065 .083 .113 .154 .219 .308	.920 .884 .824 .742 .612 .434	.2011 .2521 .3326 .4335 .5698 .7180	.6648 .6138 .5330 .4330 .2961 .148	.00462 .00426 .00371 .00300 .00206 .00103	.02450 .02969 .03704 .04479 .05269 .05792	.69 .86 1.13 1.47 1.94 2.44	.288 .266 .231 .188 .128 .064	.275 .275 .275 .275 .275 .275	.04667 .05655 .07055 .08531 .10036 .11032
1	1.315	 STD XS ... XXS	 40 80 160 ...	5S 10S 40S 80S	.065 .109 .133 .179 .250 .358	1.185 1.097 1.049 .957 .815 .599	.2553 .4130 .4939 .6388 .8365 1.0760	1.1029 .9452 .8640 .7190 .5217 .282	.00766 .00656 .00600 .00499 .00362 .00196	.04999 .07569 .08734 .1056 .1251 .1405	.87 1.40 1.68 2.17 2.84 3.66	.478 .409 .375 .312 .230 .122	.344 .344 .344 .344 .344 .344	.07603 .11512 .1328 .1606 .1903 .2136
1¼	1.660	... STD XS ... XXS	 40 80 160 ...	5S 10S 40S 80S	.065 .109 .140 .191 .250 .382	1.530 1.442 1.380 1.278 1.160 .896	.3257 .4717 .6685 .8815 1.1070 1.534	1.839 1.633 1.495 1.283 1.057 .630	.01277 .01134 .01040 .00891 .00734 .00438	.1038 .1605 .1947 .2418 .2839 .3411	1.11 1.81 2.27 3.00 3.76 5.21	.797 .708 .649 .555 .458 .273	.435 .435 .435 .435 .435 .435	.1250 .1934 .2346 .2913 .3421 .4110
1½	1.900	 STD XS ... XXS	 40 80 160 ...	5S 10S 40S 80S	.065 .109 .145 .200 .281 .400	1.770 1.682 1.610 1.500 1.338 1.100	.3747 .6133 .7995 1.068 1.429 1.885	2.461 2.222 2.036 1.767 1.406 .950	.01709 .01543 .01414 .01225 .00976 .00660	.1579 .2468 .3099 .3912 .4824 .5678	1.28 2.09 2.72 3.63 4.86 6.41	1.066 .963 .882 .765 .608 .42	.497 .497 .497 .497 .497 .497	.1662 .2598 .3262 .4118 .5078 .5977
2	2.375	... STD XS ... XXS	 40 80 160 ...	5S 10S 40S 80S	.065 .109 .154 .218 .344 .436	2.245 2.157 2.067 1.939 1.687 1.503	.4717 .7760 1.075 1.477 2.190 2.656	3.958 3.654 3.355 2.953 2.241 1.774	.02749 .02538 .02330 .02050 .01556 .01232	.3149 .4992 .6657 .8679 1.162 1.311	1.61 2.64 3.65 5.02 7.46 9.03	1.72 1.58 1.45 1.28 .97 .77	.622 .622 .622 .622 .622 .622	.2652 .4204 .5606 .7309 .979 1.104
2½	2.875	... STD XS ... XXS	 40 80 160 ...	5S 10S 40S 80S	.083 .120 .203 .276 .375 .552	2.709 2.635 2.469 2.323 2.125 1.771	.7280 1.039 1.704 2.254 2.945 4.028	5.764 5.453 4.788 4.238 3.546 2.464	.04002 .03787 .03322 .02942 .02463 .01710	.7100 .9873 1.530 1.924 2.353 2.871	2.48 3.53 5.79 7.66 10.01 13.69	2.50 2.36 2.07 1.87 1.54 1.07	.753 .753 .753 .753 .753 .753	.4939 .6868 1.064 1.339 1.638 1.997
3	3.500	... STD XS ... XXS	 40 80 160 ...	5S 10S 40S 80S	.083 .120 .216 .300 .438 .600	3.334 3.260 3.068 2.900 2.624 2.300	.8910 1.274 2.228 3.016 4.205 5.466	8.730 8.347 7.393 6.605 5.408 4.155	.06063 .05796 .05130 .04587 .03755 .02885	1.301 1.822 3.017 3.894 5.032 5.993	3.03 4.33 7.58 10.25 14.32 18.58	3.78 3.62 3.20 2.86 2.35 1.80	.916 .916 .916 .916 .916 .916	.7435 1.041 1.724 2.225 2.876 3.424

Identification, wall thickness and weights are extracted from ANSI B36.10 and B36.19. The notations STD, XS, and XXS indicate Standard, Extra Strong, and Double Extra Strong pipe respectively.

Transverse internal area values listed in "square feet" also represent volume in cubic feet per foot of pipe length.

PIPE DATA — cont.

Nom- inal Pipe Size Inches	Outside Diam. Inches	Identification			Wall Thick- ness (t) Inches	Inside Diam- eter (d) Inches	Area of Metal Square Inches	Transverse Internal Area		Moment of Inertia (I) Inches ⁴	Weight Pipe Pounds per foot	Weight Water Pounds per foot of pipe	External Surface Sq. Ft. per foot of pipe	Section Modulus ($\frac{I}{O.D.}$)
		Steel		Stain- less Steel Sched. No.				(a) Square Inches	(A) Square Feet					
		Iron Pipe Size	Sched. No.											
3½	4.000	...	...	5S	.083	3.834	1.021	11.545	.08017	1.960	3.48	5.00	1.047	.9799
		...	...	10S	.120	3.760	1.463	11.104	.07711	2.755	4.97	4.81	1.047	1.378
		STD	40	40S	.226	3.548	2.680	9.886	.06870	4.788	9.11	4.29	1.047	2.394
		XS	80	80S	.318	3.364	3.678	8.888	.06170	6.280	12.50	3.84	1.047	3.140
		...	...	...	...	...	...	...	...	...	...	...	...	...
4	4.500	...	...	5S	.083	4.334	1.152	14.75	.10245	2.810	3.92	6.39	1.178	1.249
		...	...	10S	.120	4.260	1.651	14.25	.09898	3.963	5.61	6.18	1.178	1.761
		STD	40	40S	.237	4.026	3.174	12.73	.08840	7.233	10.79	5.50	1.178	3.214
		XS	80	80S	.337	3.826	4.407	11.50	.07986	9.610	14.98	4.98	1.178	4.271
		...	120	...	.438	3.624	5.595	10.31	.0716	11.65	19.00	4.47	1.178	5.178
		...	160	...	.531	3.438	6.621	9.28	.0645	13.27	22.51	4.02	1.178	5.898
		XXS	...	...	.674	3.152	8.101	7.80	.0542	15.28	27.54	3.38	1.178	6.791
5	5.563	...	...	5S	.109	5.345	1.868	22.44	.1558	6.947	6.36	9.72	1.456	2.498
		...	...	10S	.134	5.295	2.285	22.02	.1529	8.425	7.77	9.54	1.456	3.029
		STD	40	40S	.258	5.047	4.300	20.01	.1390	15.16	14.62	8.67	1.456	5.451
		XS	80	80S	.375	4.813	6.112	18.19	.1263	20.67	20.78	7.88	1.456	7.431
		...	120	...	.500	4.563	7.953	16.35	.1136	25.73	27.04	7.09	1.456	9.250
		...	160	...	.625	4.313	9.696	14.61	.1015	30.03	32.96	6.33	1.456	10.796
		XXS	...	...	.750	4.063	11.340	12.97	.0901	33.63	38.55	5.61	1.456	12.090
6	6.625	...	...	5S	.109	6.407	2.231	32.24	.2239	11.85	7.60	13.97	1.734	3.576
		...	...	10S	.134	6.357	2.733	31.74	.2204	14.40	9.29	13.75	1.734	4.346
		STD	40	40S	.280	6.065	5.581	28.89	.2006	28.14	18.97	12.51	1.734	8.496
		XS	80	80S	.432	5.761	8.405	26.07	.1810	40.49	28.57	11.29	1.734	12.22
		...	120	...	.562	5.501	10.70	23.77	.1650	49.61	36.39	10.30	1.734	14.98
		...	160	...	.719	5.187	13.32	21.15	.1469	58.97	45.35	9.16	1.734	17.81
		XXS	...	...	.864	4.897	15.64	18.84	.1308	66.33	53.16	8.16	1.734	20.02
8	8.625	...	...	5S	.109	8.407	2.916	55.51	.3855	26.44	9.93	24.06	2.258	6.131
		...	...	10S	.148	8.329	3.941	54.48	.3784	35.41	13.40	23.61	2.258	8.212
		...	20	...	.250	8.125	6.57	51.85	.3601	57.72	22.36	22.47	2.258	13.39
		...	30	...	.277	8.071	7.26	51.16	.3553	63.35	24.70	22.17	2.258	14.69
		STD	40	40S	.322	7.981	8.40	50.03	.3474	72.49	28.55	21.70	2.258	16.81
		...	60	...	.406	7.813	10.48	47.94	.3329	88.73	35.64	20.77	2.258	20.58
		XS	80	80S	.500	7.625	12.76	45.66	.3171	105.7	43.39	19.78	2.258	24.51
		...	100	...	.594	7.437	14.96	43.46	.3018	121.3	50.95	18.83	2.258	28.14
		...	120	...	.719	7.187	17.84	40.59	.2819	140.5	60.71	17.59	2.258	32.58
		...	140	...	.812	7.001	19.93	38.50	.2673	153.7	67.76	16.68	2.258	35.65
		XXS	...	...	.875	6.875	21.30	37.12	.2578	162.0	72.42	16.10	2.258	37.56
		...	160	...	.906	6.813	21.97	36.46	.2532	165.9	74.69	15.80	2.258	38.48
		...	...	...	...	...	...	...	...	...	...	...	...	...
		...	...	...	...	...	...	...	...	...	...	...	...	...
10	10.750	...	...	5S	.134	10.482	4.36	86.29	.5992	63.0	15.19	37.39	2.814	11.71
		...	...	10S	.165	10.420	5.49	85.28	.5922	76.9	18.65	36.95	2.814	14.30
		...	20	...	.250	10.250	8.24	82.52	.5731	113.7	28.04	35.76	2.814	21.15
		...	30	...	.307	10.136	10.07	80.69	.5603	137.4	34.24	34.96	2.814	25.57
		STD	40	40S	.365	10.020	11.90	78.86	.5475	160.7	40.48	34.20	2.814	29.90
		XS	60	80S	.500	9.750	16.10	74.66	.5185	212.0	54.74	32.35	2.814	39.43
		...	80	...	.594	9.562	18.92	71.84	.4989	244.8	64.43	31.13	2.814	45.54
		...	100	...	.719	9.312	22.63	68.13	.4732	286.1	77.03	29.53	2.814	53.22
		...	120	...	.844	9.062	26.24	64.53	.4481	324.2	89.29	27.96	2.814	60.32
		XXS	140	...	1.000	8.750	30.63	60.13	.4176	367.8	104.13	26.06	2.814	68.43
		...	160	...	1.125	8.500	34.02	56.75	.3941	399.3	115.64	24.59	2.814	74.29
		...	...	...	...	...	...	...	...	...	...	...	...	...
		...	...	...	...	...	...	...	...	...	...	...	...	...
		...	...	...	...	...	...	...	...	...	...	...	...	...
12	12.75	...	...	5S	.156	12.438	6.17	121.50	.8438	122.4	20.98	52.65	3.338	19.2
		...	...	10S	.180	12.390	7.11	120.57	.8373	140.4	24.17	52.25	3.338	22.0
		...	20	...	.250	12.250	9.82	117.86	.8185	191.8	33.38	51.07	3.338	30.2
		...	30	...	.330	12.090	12.87	114.80	.7972	248.4	43.77	49.74	3.338	39.0
		STD	...	40S	.375	12.000	14.58	113.10	.7854	279.3	49.56	49.00	3.338	43.8
		...	40	...	.406	11.938	15.77	111.93	.7773	300.3	53.52	48.50	3.338	47.1
		XS	...	80S	.500	11.750	19.24	108.43	.7528	361.5	65.42	46.92	3.338	56.7
		...	60	...	.562	11.626	21.52	106.16	.7372	400.4	73.15	46.00	3.338	62.8
		...	80	...	.688	11.374	26.03	101.64	.7058	475.1	88.63	44.04	3.338	74.6
		...	100	...	.844	11.062	31.53	96.14	.6677	561.6	107.32	41.66	3.338	88.1
		XXS	120	...	1.000	10.750	36.91	90.76	.6303	641.6	125.49	39.33	3.338	100.7
		...	140	...	1.125	10.500	41.08	86.59	.6013	700.5	139.67	37.52	3.338	109.9
		...	160	...	1.312	10.126	47.14	80.53	.5592	781.1	160.27	34.89	3.338	122.6
		...	...	...	...	...	...	...	...	...	...	...	...	...
		...	...	...	...	...	...	...	...	...	...	...	...	...

Identification, wall thickness and weights are extracted from ANSI B36.10 and B36.19. The notations STD, XS, and XXS indicate Standard, Extra Strong, and Double Extra Strong pipe respectively.

Transverse internal area values listed in "square feet" also represent volume in cubic feet per foot of pipe length.

PIPE DATA — cont.

Nom- inal Pipe Size Inches	Outside Diam. Inches	Identification			Wall Thick- ness (t) Inches	Inside Diam- eter (d) Inches	Area of Metal Square Inches	Transverse		Moment of Inertia (I) Inches ⁴	Weight Pipe Pounds per foot	Weight Water per foot of pipe	External Surface Sq. Ft. per foot of pipe	Section Modulus $\left(2\frac{I}{O.D.}\right)$
		Steel		Stain- less Steel Sched. No.				Internal Area						
		Iron Pipe Size	Sched. No.					(a) Square Inches	(A) Square Feet					
14	14.00	...	...	5S	.156	13.688	6.78	147.15	1.0219	162.6	23.07	63.77	3.665	23.2
		...	...	10S	.188	13.624	8.16	145.78	1.0124	194.6	27.73	63.17	3.665	27.8
		...	10	...	.250	13.500	10.80	143.14	.9940	255.3	36.71	62.03	3.665	36.6
		...	20	...	.312	13.376	13.42	140.52	.9758	314.4	45.61	60.89	3.665	45.0
		STD	30	...	.375	13.250	16.05	137.88	.9575	372.8	54.57	59.75	3.665	53.2
		...	40	...	.438	13.124	18.66	135.28	.9394	429.1	63.44	58.64	3.665	61.3
		XS	...	...	.500	13.000	21.21	132.73	.9217	483.8	72.09	57.46	3.665	69.1
		...	60	...	.594	12.812	24.98	128.96	.8956	562.3	85.05	55.86	3.665	80.3
		...	80	...	.750	12.500	31.22	122.72	.8522	678.3	106.13	53.18	3.665	98.2
		...	100	...	.938	12.124	38.45	115.49	.8020	824.4	130.85	50.04	3.665	117.8
		...	120	...	1.094	11.812	44.32	109.62	.7612	929.6	150.79	47.45	3.665	132.8
		...	140	...	1.250	11.500	50.07	103.87	.7213	1027.0	170.28	45.01	3.665	146.8
		...	160	...	1.406	11.188	55.63	98.31	.6827	1117.0	189.11	42.60	3.665	159.6
16	16.00	...	...	5S	.165	15.670	8.21	192.85	1.3393	257.3	27.90	83.57	4.189	32.2
		...	...	10S	.188	15.624	9.34	191.72	1.3314	291.9	31.75	83.08	4.189	36.5
		...	10	...	.250	15.500	12.37	188.69	1.3103	383.7	42.05	81.74	4.189	48.0
		...	20	...	.312	15.376	15.38	185.69	1.2895	473.2	52.27	80.50	4.189	59.2
		STD	30	...	.375	15.250	18.41	182.65	1.2684	562.1	62.58	79.12	4.189	70.3
		...	40	...	.500	15.000	24.35	176.72	1.2272	731.9	82.77	76.58	4.189	91.5
		XS	...	...	.656	14.688	31.62	169.44	1.1766	932.4	107.50	73.42	4.189	116.6
		...	60	...	.844	14.312	40.14	160.92	1.1175	1155.8	136.61	69.73	4.189	144.5
		...	80	...	1.031	13.938	48.48	152.58	1.0596	1364.5	164.82	66.12	4.189	170.5
		...	100	...	1.219	13.562	56.56	144.50	1.0035	1555.8	192.43	62.62	4.189	194.5
		...	120	...	1.438	13.124	65.78	135.28	.9394	1760.3	223.64	58.64	4.189	220.0
		...	140	...	1.594	12.812	72.10	128.96	.8956	1893.5	245.25	55.83	4.189	236.7
		18	18.00	...	...	5S	.165	17.670	9.25	245.22	1.7029	367.6	31.43	106.26
...	...			10S	.188	17.624	10.52	243.95	1.6941	417.3	35.76	105.71	4.712	46.4
...	10			...	.250	17.500	13.94	240.53	1.6703	549.1	47.39	104.21	4.712	61.1
...	20			...	.312	17.376	17.34	237.13	1.6467	678.2	58.94	102.77	4.712	75.5
STD	...			...	.375	17.250	20.76	233.71	1.6230	806.7	70.59	101.18	4.712	89.6
...	30			...	.438	17.124	24.17	230.30	1.5990	930.3	82.15	99.84	4.712	103.4
XS	...			...	.500	17.000	27.49	226.98	1.5763	1053.2	93.45	98.27	4.712	117.0
...	40			...	.562	16.876	30.79	223.68	1.5533	1171.5	104.67	96.93	4.712	130.1
...	60			...	.750	16.500	40.64	213.83	1.4849	1514.7	138.17	92.57	4.712	168.3
...	80			...	.938	16.124	50.23	204.24	1.4183	1833.0	170.92	88.50	4.712	203.8
...	100			...	1.156	15.688	61.17	193.30	1.3423	2180.0	207.96	83.76	4.712	242.3
...	120			...	1.375	15.250	71.81	182.66	1.2684	2498.1	244.14	79.07	4.712	277.6
...	140			...	1.562	14.876	80.66	173.80	1.2070	2749.0	274.22	75.32	4.712	305.5
...	160	...	1.781	14.438	90.75	163.72	1.1369	3020.0	308.50	70.88	4.712	335.6		
20	20.00	...	...	5S	.188	19.624	11.70	302.46	2.1004	574.2	39.78	131.06	5.236	57.4
		...	...	10S	.218	19.564	13.55	300.61	2.0876	662.8	46.06	130.27	5.236	66.3
		...	10	...	.250	19.500	15.51	298.65	2.0740	765.4	52.73	129.42	5.236	75.6
		STD	20	...	.375	19.250	23.12	290.04	2.0142	1113.0	78.60	125.67	5.236	111.3
		...	30	...	.500	19.000	30.63	283.53	1.9690	1457.0	104.13	122.87	5.236	145.7
		XS	...	...	.594	18.812	36.15	278.00	1.9305	1703.0	123.11	120.46	5.236	170.4
		...	40	...	.812	18.376	48.95	265.21	1.8417	2257.0	166.40	114.92	5.236	225.7
		...	60	...	1.031	17.938	61.44	252.72	1.7550	2772.0	208.87	109.51	5.236	277.1
		...	80	...	1.281	17.438	75.33	238.83	1.6585	3315.2	256.10	103.39	5.236	331.5
		...	100	...	1.500	17.000	87.18	226.98	1.5762	3754.0	296.37	98.35	5.236	375.5
		...	120	...	1.750	16.500	100.33	213.82	1.4849	4216.0	341.09	92.66	5.236	421.7
		...	140	...	1.969	16.062	111.49	202.67	1.4074	4585.5	379.17	87.74	5.236	458.5
		22	22.00	...	...	5S	.188	21.624	12.88	367.25	2.5503	766.2	43.80	159.14
...	...			10S	.218	21.564	14.92	365.21	2.5362	884.8	50.71	158.26	5.760	80.4
...	10			...	.250	21.500	17.08	363.05	2.5212	1010.3	58.07	157.32	5.760	91.8
STD	20			...	.375	21.250	25.48	354.66	2.4629	1489.7	86.61	153.68	5.760	135.4
...	30			...	.500	21.000	33.77	346.36	2.4053	1952.5	114.81	150.09	5.760	117.5
XS	...			...	.875	20.250	58.07	322.06	2.2365	3244.9	197.41	139.56	5.760	295.0
...	60			...	1.125	19.75	73.78	306.35	2.1275	4030.4	250.81	132.76	5.760	366.4
...	80			...	1.375	19.25	89.09	291.04	2.0211	4758.5	302.88	126.12	5.760	432.6
...	100			...	1.625	18.75	104.02	276.12	1.9175	5432.0	353.61	119.65	5.760	493.8
...	120			...	1.875	18.25	118.55	261.59	1.8166	6053.7	403.00	113.36	5.760	550.3
...	140			...	2.125	17.75	132.68	247.45	1.7184	6626.4	451.06	107.23	5.760	602.4

Identification, wall thickness and weights are extracted from ANSI B36.10 and B36.19. The notations STD, XS, and XXS indicate Standard, Extra Strong, and Double Extra Strong pipe respectively.

Transverse internal area values listed in "square feet" also represent volume in cubic feet per foot of pipe length.

PIPE DATA — cont.

Nom- inal Pipe Size Inches	Outside Diam. Inches	Identification			Wall Thick- ness (t) Inches	Inside Diam- eter (d) Inches	Area of Metal Square Inches	Transverse		Moment of Inertia (I) Inches ⁴	Weight Pipe Pounds per foot	Weight Water Pounds per foot of pipe	External Surface Sq. Ft. per foot of pipe	Section Modulus $\left(2\frac{I}{O.D.}\right)$
		Steel		Stain- less Steel Sched. No.				Internal Area						
		Iron Pipe Size	Sched. No.					(a) Square Inches	(A) Square Feet					
24	24.00	...	...	5S	.218	23.564	16.29	436.10	3.0285	1151.6	55.37	188.98	6.283	96.0
		...	10	10S	.250	23.500	18.65	433.74	3.0121	1315.4	63.41	187.95	6.283	109.6
		STD	20	...	.375	23.250	27.83	424.56	2.9483	1942.0	94.62	183.95	6.283	161.9
		XS	...	...	.500	23.000	36.91	415.48	2.8853	2549.5	125.49	179.87	6.283	212.5
		...	30	...	.562	22.876	41.39	411.00	2.8542	2843.0	140.68	178.09	6.283	237.0
		...	40	...	.688	22.624	50.31	402.07	2.7921	3421.3	171.29	174.23	6.283	285.1
		...	60	...	.969	22.062	70.04	382.35	2.6552	4652.8	238.35	165.52	6.283	387.7
		...	80	...	1.219	21.562	87.17	365.22	2.5362	5672.0	296.58	158.26	6.283	472.8
		...	100	...	1.531	20.938	108.07	344.32	2.3911	6849.9	367.39	149.06	6.283	570.8
		...	120	...	1.812	20.376	126.31	326.08	2.2645	7825.0	429.39	141.17	6.283	652.1
		...	140	...	2.062	19.876	142.11	310.28	2.1547	8625.0	483.12	134.45	6.283	718.9
		...	160	...	2.344	19.312	159.41	292.98	2.0346	9455.9	542.13	126.84	6.283	787.9
26	26.00	...	10	...	.312	25.376	25.18	505.75	3.5122	2077.2	85.60	219.16	6.806	159.8
		STD	...	...	.375	25.250	30.19	500.74	3.4774	2478.4	102.63	216.99	6.806	190.6
		XS	20	...	.500	25.000	40.06	490.87	3.4088	3257.0	136.17	212.71	6.806	250.5
28	28.00	...	10	...	.312	27.376	27.14	588.61	4.0876	2601.0	92.26	255.07	7.330	185.8
		STD	...	...	.375	27.250	32.54	583.21	4.0501	3105.1	110.64	252.73	7.330	221.8
		XS	20	...	.500	27.000	43.20	572.56	3.9761	4084.8	146.85	248.11	7.330	291.8
		...	30	...	.625	26.750	53.75	562.00	3.9028	5037.7	182.73	243.53	7.330	359.8
30	30.00	...	...	5S	.250	29.500	23.37	683.49	4.7465	2585.2	79.43	296.18	7.854	172.3
		...	10	10S	.312	29.376	29.10	677.76	4.7067	3206.3	98.93	293.70	7.854	213.8
		STD	...	...	.375	29.250	34.90	671.96	4.6664	3829.4	118.65	291.18	7.854	255.3
		XS	20	...	.500	29.000	46.34	660.52	4.5869	5042.2	157.53	286.22	7.854	336.1
		...	30	...	.625	28.750	57.68	649.18	4.5082	6224.0	196.08	281.31	7.854	414.9
32	32.00	...	10	...	.312	31.376	31.06	773.19	5.3694	3898.9	105.59	335.05	8.378	243.7
		STD	...	...	.375	31.250	37.26	766.99	5.3263	4658.5	126.66	332.36	8.378	291.2
		XS	20	...	.500	31.000	49.48	754.77	5.2414	6138.6	168.21	327.06	8.378	383.7
		...	30	...	.625	30.750	61.60	742.64	5.1572	7583.4	209.43	321.81	8.378	474.0
		...	40	...	.688	30.624	67.68	736.57	5.1151	8298.3	230.08	319.18	8.378	518.6
34	34.00	...	10	...	.344	33.312	36.37	871.55	6.0524	5150.5	123.65	377.67	8.901	303.0
		STD	...	...	.375	33.250	39.61	868.31	6.0299	5599.3	134.67	376.27	8.901	329.4
		XS	20	...	.500	33.000	52.62	855.30	5.9396	7383.5	178.89	370.63	8.901	434.3
		...	30	...	.625	32.750	65.53	842.39	5.8499	9127.6	222.78	365.03	8.901	536.9
		...	40	...	.688	32.624	72.00	835.92	5.8050	9991.6	244.77	362.23	8.901	587.7
36	36.00	...	10	...	.312	35.376	34.98	982.90	6.8257	5569.5	118.92	425.92	9.425	309.4
		STD	...	...	.375	35.250	41.97	975.91	6.7771	6658.9	142.68	422.89	9.425	369.9
		XS	20	...	.500	35.000	55.76	962.11	6.6813	8786.2	189.57	416.91	9.425	488.1
		...	30	...	.625	34.750	69.46	948.42	6.5862	10868.4	236.13	417.22	9.425	603.8
		...	40	...	.750	34.500	83.06	934.82	6.4918	12906.1	282.35	405.09	9.425	717.0

Identification, wall thickness and weights are extracted from ANSI B36.10 and B36.19. The notations STD, XS, and XXS indicate Standard, Extra Strong, and Double Extra Strong pipe respectively.

Transverse internal area values listed in "square feet" also represent volume in cubic feet per foot of pipe length.

ENGINEERING DEPARTMENT

CUSTOMER _____
 SUBJECT MIXED PHASE LINE SIZING

PAGE NO. _____
 DATE _____
 PROJECT _____
 BY _____

$$\begin{aligned} \text{LIQUID VOLUME FRACTION} &= \frac{V_L}{V_L + V_G} = \frac{\frac{W_L}{S.G. \times 62.4}}{\frac{W_L}{S.G. \times 62.4} + \frac{W_G}{\text{\#}/\text{FT}^3}} \\ &= \frac{\text{_____} \times 62.4}{\text{_____} + \text{_____}} \\ &= \frac{\text{_____}}{\text{_____}} = \text{_____} = \text{_____} \end{aligned}$$

$$\begin{aligned} \text{TOTAL FLOW GAS} &= W_L + W_G = \text{_____} + \text{_____} = \text{_____} \quad \text{\#}/\text{HR} \\ \text{TOTAL FLOW LIQUID} &= \frac{W_L + W_G}{S.G. \times 500} + \frac{\text{_____}}{\text{_____} \times 500} = \text{_____} \quad \text{GPM} \end{aligned}$$

TRY _____ " LINE

$$\frac{\text{TOTAL FLOW } \Delta P_G}{\text{TOTAL FLOW } \Delta P_L} = \frac{\Delta P_{Go} \times \frac{1}{\text{\#}/\text{FT}^3}}{\Delta P_{Lo} \times S.G.} = \frac{\text{_____} \times \frac{1}{\text{_____}}}{\text{_____} \times \text{_____}} = \text{_____} = \text{_____}$$

$$\Delta P_{Go} = f \times \frac{336}{d^5} \times \left(\frac{W}{1000} \right)^2 = \frac{\text{_____} \times 336 \times \text{_____}^2}{\text{_____} \times 10^6} = \text{_____}$$

$$\Delta P_{Tp} = \text{TOTAL FLOW } \Delta P_L \times \text{FACTOR} = \text{_____} \times \text{_____} = \text{_____}$$

TRY _____ " LINE

$$\frac{\text{TOTAL FLOW } \Delta P_G}{\text{TOTAL FLOW } \Delta P_L} = \frac{\Delta P_{Go} \times \frac{1}{\text{\#}/\text{FT}^3}}{\Delta P_{Lo} \times S.G.} = \frac{\text{_____} \times \frac{1}{\text{_____}}}{\text{_____} \times \text{_____}} = \text{_____} = \text{_____}$$

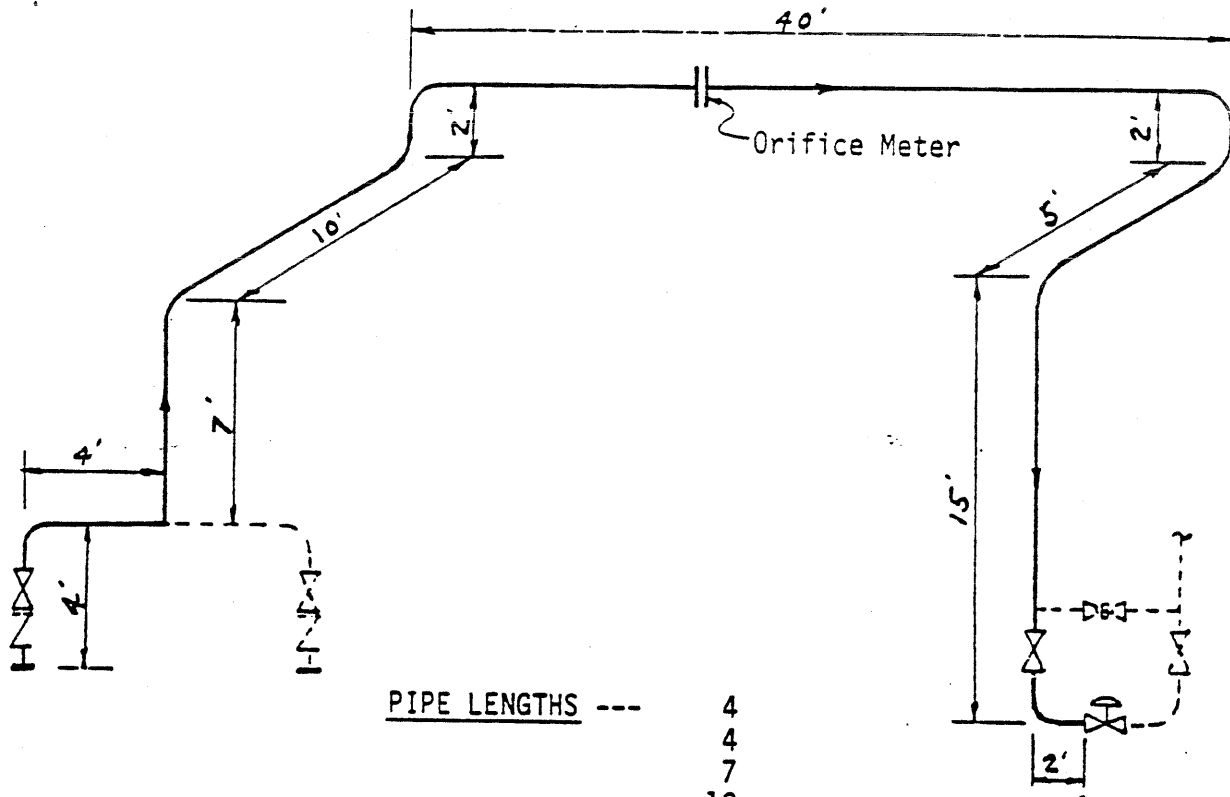
$$\Delta P_{Go} = f \times \frac{336}{d^5} \times \left(\frac{W}{1000} \right)^2 = \frac{\text{_____} \times 336 \times \text{_____}^2}{\text{_____} \times 10^6} = \text{_____}$$

$$\Delta P_{Tp} = \text{TOTAL FLOW } \Delta P_L \times \text{FACTOR} = \text{_____} \times \text{_____} = \text{_____}$$

USE _____ " LINE

CUSTOMER _____
 SUBJECT TYPICAL CALCULATION OF
PIPING EQUIVALENT LENGTH
8" PUMP DISCHARGE LINE

PAGE NO. _____
 DATE _____
 PROJECT _____
 BY HCB



PIPE LENGTHS ---	
4	
4	
7	
10	
2	
40	
2	
5	
15	
2	
	91

VALVES & FITTINGS

PIPE DIAMETERS

1 Swing Check Valve		135
2 Gate Valves	2 x 13 =	26
8 90° Elbows	8 x 20 =	160
1 Tee (Branch Flow)		60
1 Tee (Through Flow)		20
	$401 \times \frac{8''}{12} =$	267

Total Equivalent Feet = 358 (Say 350 Ft.)

Total line friction drop is determined by multiplying the total equivalent feet by the corrected friction pressure drop per 100 feet as determined from line sizing. Pressure at the control valve inlet equals the pump discharge pressure minus the total line friction drop and orifice meter pressure drop, plus or minus the differential static head.

Two Phase Flow Problem Solution:

Liquid: 500 gpm
0.75 sp.gr.

Vapor: 40,000 lb/h
0.9 ft³/lb s.v.

I. Calculate Liquid Volume Fraction:

$$\frac{V_L}{V_L + V_G}$$

$$V_L = 500 \frac{\text{gal}}{\text{min}} \times \frac{1 \text{ ft}^3}{7.48 \text{ gal}} \times 60 \text{ min} = 4,010 \frac{\text{ft}^3}{\text{h}}$$

$$V_G = 40,000 \frac{\text{lb}}{\text{h}} \times 0.9 \frac{\text{ft}^3}{\text{lb}} = 36,000 \frac{\text{ft}^3}{\text{h}}$$

$$\frac{V_L}{V_L + V_G} = \frac{4,010}{4,010 + 36,000} = \frac{4,010}{40,010} = 0.1$$

II. Calculate Total Weight Flow

$$W_{\text{LQ}} = 500 \frac{\text{gal}}{\text{min}} \times 60 \frac{\text{min}}{\text{hr}} \times (8.34 \frac{\text{lb}}{\text{gal}} \times 0.75) = 187,650 \frac{\text{lb}}{\text{h}}$$

$$W_{\text{VAP}} = 40,000 \frac{\text{lb}}{\text{h}}$$

$$W_{\text{TOTAL}} = 187,650 + 40,000 = 227,650 \frac{\text{lb}}{\text{h}}$$

Two Phase Flow Problem Solution: (Continued)**Try 10" Schedule 80 Pipe**

$$\begin{aligned}\text{III. } \Delta P_g^* &= \Delta P_{g0}^* \times \text{S.V.} \\ &= 3 \times 0.9 = 2.7\end{aligned}$$

$$\begin{aligned}\text{IV. } \Delta P_L^* \\ Q \text{ gpm} &= 500 \frac{\text{gal}}{\text{min}} \times \frac{227,650}{187,650} = 606.6 \text{ gpm} \\ \Delta P_L^* &= 0.1 \times 0.75 = 0.075\end{aligned}$$

$$\text{V. } \frac{\Delta P_g^*}{\Delta P_L^*} = \frac{2.7}{0.075} = 36$$

$$\begin{aligned}\text{VI. } F &= 7 \\ \therefore \Delta P_{TP} &= 7 \times 0.075 = 0.525\end{aligned}$$

$\therefore$ 10" is acceptable

HYDRAULIC TABULATION (A)

[illegible]



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SHEET _____

PROJECT _____

CUST. NO. _____

HYDRAULIC TABULATION

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LINE										
API OR LB/GAL AT 60° F										
AVERAGE MOL WT										
TEMPERATURE, ° F										
FLOWING SP GR										
SP VOL, CU FT/LB										
FLOW VIS, CENTISTOKES										
VIS CORR FACTOR										
	NOR	MAX	NOR	MAX	NOR	MAX	NOR	MAX	NOR	MAX
FLOWING USGPM										
FLOW, LB/HR × 10 ³										
DESTINATION, PSIG										
STATIC, PSI										
EXCHANGE, PSI										
PIPING, PSI										
VALVE, PSI										
PUMP DISCHARGE, PSIG										
PUMP SUCTION, PSIG										
DIFFERENTIAL, PSI										
DIFFERENTIAL HEAD, FT										
PRESSURE LEVEL, PSIG (BV)										
NORMAL FLOW	SUCT	DISCH	SUCT	DISCH	SUCT	DISCH	SUCT	DISCH	SUCT	DISCH
PIPE SIZE, IPS										
PIPE CLASS										
VELOCITY, FPM										
FRICTION, PSI/100 FT (UNCORR)										
FRICTION, PSI/100 FT (CORR)										
PUMP DESCRIPTION										
	OPER	SPARE	OPER	SPARE	OPER	SPARE	OPER	SPARE	OPER	SPARE
TYPE										
ITEM NO										
DRIVER										
POWER CONDITION										
NPSH AVAILABLE										
NOTES										



ENGINEERING DESIGN SEMINAR

FALL 1994

HYDRAULICS

Presented By

BRYON BRANDT

NPSH (R)

REQUIRED

THIS IS A CHARACTERISTIC OF THE PUMP. THE VALUE IS EXPERIMENTALLY DETERMINED, BY THE PUMP MANUFACTURER.

NPSH (A)

AVAILABLE

THIS IS THE NPSH DESIGNED INTO THE SYSTEM FOR THE PUMP MENTIONED ABOVE. THIS VALUE MUST BE GREATER THAN THE NPSH(R) FOR PROPER OPERATION OF THE PUMP.

SINGLE STAGE PUMPS (NPSH 0.1 FT. H₂O. 60 FEET - 1400 FEET
 50 FEET - 1000 FEET)

MINIMUM REQUIRED NPSH

34

32

30

28

26

24

22

20

18

16

14

12

10

8

6

4

2

NPSH REQUIRED - FEET OF LIQUID

3550 RPM (60 FEET)

3550 RPM (60 FEET)

3550 RPM (60 FEET)

3550 RPM (60 FEET)

3550 RPM (60 FEET)

3550 RPM (60 FEET)

3550 RPM (60 FEET)

3

2

1

PD 877-A

5000

4500

4000

3500

3000

2500

2000

1500

1000

500

PUMP CAPACITY IN GPM

1
 2
 3
 BOTTOM OF CASE
 TO 1/2 OF PUMP (FEET)

OUTLINE
HYDRAULICS

- A. GENERAL COMMENTS**
- B. TYPICAL PRESSURE DROPS FOR EQUIPMENT**
- C. EXAMPLES**
 - 1. NPSH FOR PUMP**
 - 2. PUMPED CIRCUIT**

1. OBJECTIVES

- A. DETERMINE LINE SIZES AND PRESSURE DROP (PSI/100 ft)**
- B. DETERMINE EQUIPMENT PRESSURE DROP**
- C. DETERMINE VARIABLE PRESSURE DROP / INCREASE**
 - I. PRESSURE DROP FOR CONTROL VALVES**
 - II. DIFFERENTIAL HEAD FOR PUMPS AND COMPRESSORS**

HEATER PRESSURE DROPS

- C. Although the final heater pressure drops must be determined by the heater designer or heater vendor, the hydraulic engineer needs to have some approximation of heater pressure drops in order to proceed with their preliminary hydraulic survey.

The following typical heater pressure drops may be used on a preliminary basis, to be confirmed or corrected as heater design information becomes available:

Crude Heaters	125 psi
Vacuum Heaters	75 psi
Unibon Heaters	20-60 psi
Platforming (per Heater)	3-20 psi
Thermal Crackers	200 psi
Coker Heaters	300 psi
Visbreakers	250 psi
Hot Oil Heaters	20-40 psi
Fired Reboilers	50 psi
Fractionator Charge	40 psi

D. **Heat Exchanger Pressure Drops**

Heat exchanger pressure drops vary from mm. of mercury to as much as 25 psi. Because the pressure drops vary so widely, there is no substitute for the good judgement of the engineer. For normal, fluid exchangers, allow at least 5 psi per shell on each side, as a minimum. Some additional guidelines are as follows:

Cooling water side	10 psi
Combined Feed Exchangers	2-5 psi per side (Shell)
Condensers	1-5 psi
Reboilers-Kettle & Thermosyphon	0.2 - 0.5 psi
Reboilers-forced circulation	5 - 10 psi
Vacuum condensers	10 - 25 mm mercury

Vacuum condenser

10-25 mm mercury

allow at least 5 psi per shell on each side

E. Control Valve Pressure Drops

Control valve pressure drops must be considered during the hydraulic analysis of a system. However, the amount of pressure drop to be considered requires experience and judgement.

In order to provide some guidance in this area, for control valves in pump discharge circuits are allotted the maximum of the following pressure drops:

- 10 • 25 psi minimum
- 25% • 50% of system friction pressure drop Normal Flow
- 10% of pump differential

Most other control valves are allowed pressure drop in accordance with the available pressure. Provision of control valve pressure drop needs to be sufficient to compensate for changes in operating conditions, fluid properties and system aging.

HYDRAULICS

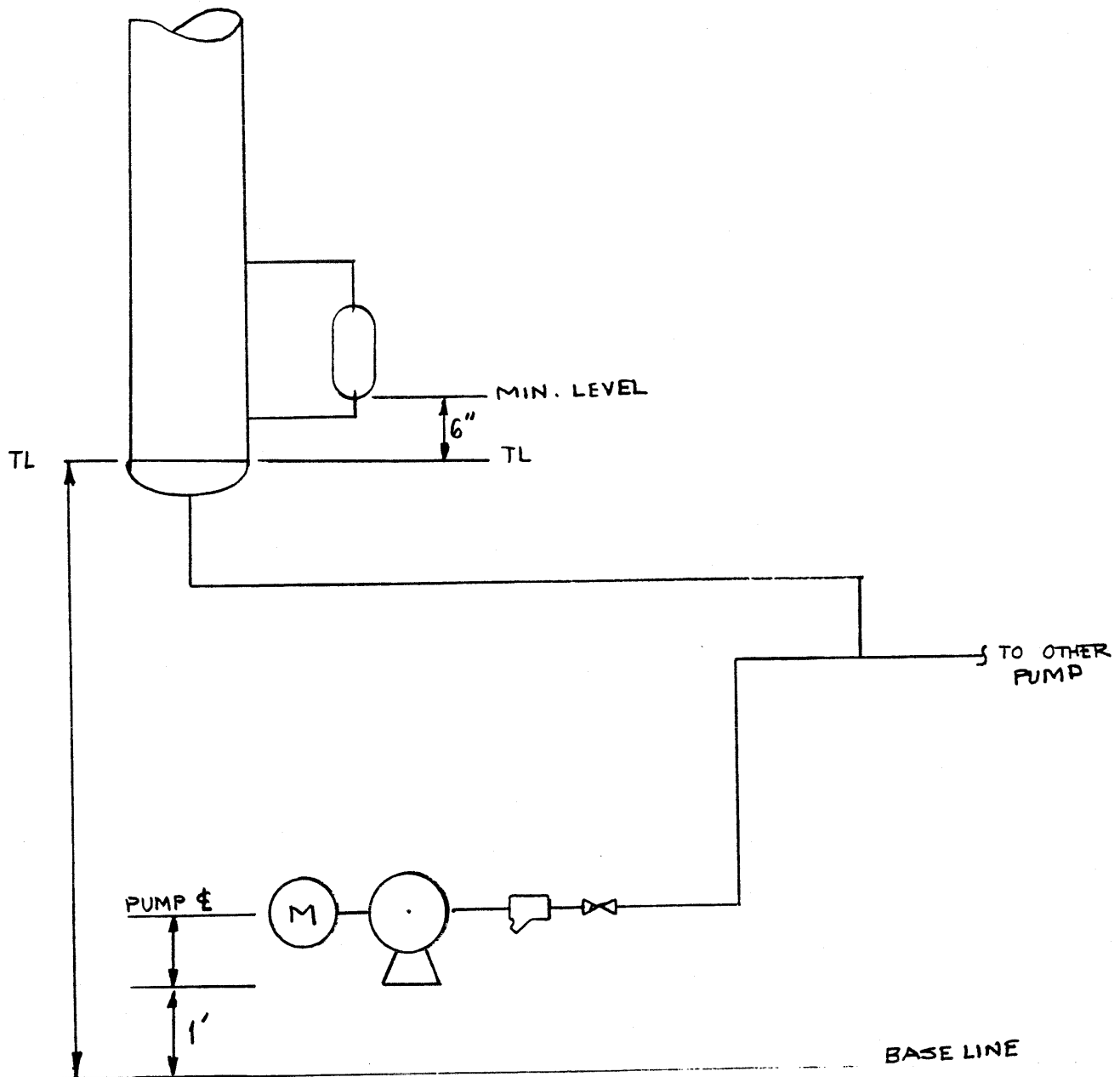
A. Net
Positive
Suction
Head

There is a minimum positive suction head (pressure) above the fluid vapour pressure required for centrifugal pumps.

NPSH (R)

NPSH

- 1. NET POSITIVE SUCTION HEAD (NPSH) IS THE PRESSURE OVER AND ABOVE THE VAPOUR PRESSURE OF THE LIQUID BEING PUMPED.**
- 2. THIS ADDITIONAL PRESSURE PREVENTS VAPORIZATION OF LIQUID AT THE PUMP INLET THUS INSURING PROPER OPERATION OF THAT PUMP.**
- 3. NPSH IS EXPRESSED IN FEET OF LIQUID BEING PUMPED.**



PUMP REQUIREMENTS

CAPACITY : 500 gpm
Sp. Gravity : 0.65
LINE FREQ : 50 Hz
PUMP SPEED: 1450 rpm

EXAMPLE: DESIGN A SYSTEM THAT PROVIDES SUFFICIENT NPSH FOR THE FOLLOWING PUMP:

SINGLE STAGE PUMP

Capacity 500 gpm

Specific Gravity 0.65

Line Frequency 50 Hz

Pump RPM 1450 (Half Speed)

Assume Vapour Pressure = System Pressure

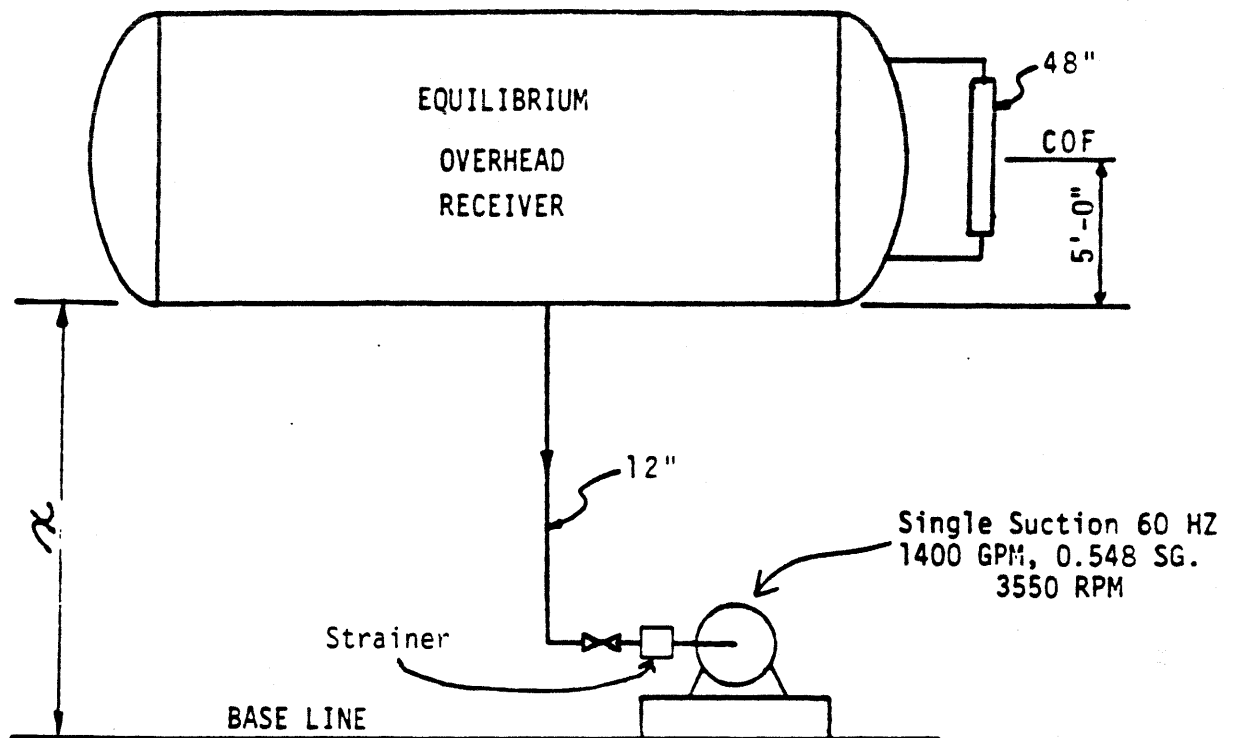
NPSH EXAMPLE CALCULATION

1.	NPSH(R) From Chart or Manufacturer	7.0 ft
2.	Pump Centerline Above Base Line	2.5 ft
3.	Friction Loss	
	For 8" Line $\Delta P_{100} = 0.11$ psi	
	500 equivalent Feet	2.0 ft
	Suction Valve (Assume Gate)	
	Equivalent Length = 13 D	
	$\Delta P = (0.11)(8/6)^5(13)(6/12)(1/100)(2.31/0.65)$	0.1 ft
	Suction Strainer	
	Equivalent Length = 300 ft	
	(0.46 psi) (300/100) (2.31/0.65)	4.9 ft
4.	System Pressure - Vapour Pressure = 0	0.0 ft
5.	Minimum Level in Vessel	(0.5) ft
6.	Contingency	2.0 ft
	15 % of NPSH(R)	
	2.0 ft Minimum	

Summary

1.	NPSH(R)	7.0	ft
2.	Pump Centerline Elevation	2.5	ft
3.	Friction Loss = (2.0 + 0.1 + 4.9)	7.0	ft
4.	System Pressure	0.0	ft
5.	Minimum Level	(0.5)	ft
6.	Contingency	<u>2.0</u>	<u>ft</u>
TOTAL		18	ft

(From Baseline to Bottom of Vessel)



$$\chi = h_{NPSH} + h_{CL} + h_{PFL} - h_p - h_{MLL} + h_{CONT}$$

UOP Inc.

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SHEET _____

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CUST. NO. _____

HYDRAULIC TABULATION

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LINE	PUMP SUCTION										
API OR LB/GAL AT 60° F											
AVERAGE MOL WT											
TEMPERATURE, ° F											
FLOWING SP GR	0.548										
SP VOL, CU FT/LB											
FLOW VIS, CENTISTOKES											
VIS CORR FACTOR											
	NOR	MAX	NOR	MAX	NOR	MAX	NOR	MAX	NOR	MAX	
FLOWING USGPM	1400										
FLOW, LB/HR x 10 ³											
DESTINATION, PSIG											
STATIC, PSI											
EXCHANGE, PSI											
PIPING, PSI											
VALVE, PSI											
PUMP DISCHARGE, PSIG											
PUMP SUCTION, PSIG											
DIFFERENTIAL, PSI											
DIFFERENTIAL HEAD, FT											
PRESSURE LEVEL, PSIG (BV)											
NORMAL FLOW	SUCT	DISCH	SUCT	DISCH	SUCT	DISCH	SUCT	DISCH	SUCT	DISCH	
PIPE SIZE, IPS	12										
PIPE CLASS SCH	3/8"										
VELOCITY, FPM											
FRICTION, PSI/100 FT (UNCORR)	0.16										
FRICTION, PSI/100 FT (CORR)	0.09										
PUMP DESCRIPTION	TYPE 2A										
	OPER	SPARE	OPER	SPARE	OPER	SPARE	OPER	SPARE	OPER	SPARE	
TYPE											
ITEM NO											
DRIVER											
POWER CONDITION											
NPSH AVAILABLE											
NOTES											

1. Estimate NPSH required.
Pump rate 1400 gpm, 0.548 S.G., head less than 1400 feet.
From curve (single suction 3550 RPM), minimum required NPSH = (+) 23 Ft.
2. Estimate pump centerline elevation.
From curve, pump centerline is 2 feet above base plate.
Assume foundation projection 1 foot above base line.
Centerline elevation above base line (+) 3 Ft.

3. Estimate piping friction loss
 $\Delta P/100'$ for 12" pipe = 0.09 psi
Assume 500 equivalent feet of suction piping
$$\Delta P \text{ (piping)} = \frac{500}{100} \times 0.09 \times \frac{2.31 \text{ ft. water/psi}}{0.548 \text{ S.G.}} = 1.9 \text{ feet}$$

Check for smaller suction valve
 $\Delta P/100'$ for 10" pipe = 0.22 psi
 Fully open gate valve is equivalent of 13 pipe diameters of piping

$$\Delta P \text{ (valve)} = \frac{13}{100} \times \frac{10}{12} \times 0.22 \times \frac{2.31}{0.548} = 0.1 \text{ foot}$$

Estimate pump suction strainer pressure drop (10" strainer)

$$\Delta P \text{ (strainer)} = \frac{300}{100} \times 0.22 \times \frac{2.31}{0.548} = 2.8 \text{ Feet}$$

- Total suction piping system friction loss = say (+) 5 feet
4. Check system absolute pressure
Liquid is from an equilibrium overhead receiver
System absolute pressure equals liquid vapor pressure
Additional equivalent liquid head available = (-) 0 feet
 5. Consider minimum controlled liquid level
Center of float is 5'-0" above bottom of vessel
Float length is 48"
Minimum controlled level is 3'-0" above bottom of vessel
Pump is not expected to operate at full rate beyond control range
Liquid available for NPSH (-) 3 feet
 6. Provide for contingency
Standard contingency = 0.15 x 23 feet = 3.5 feet
System is clean

Total contingency to be provided (+) 3.5 feet

Minimum elevation of vessel above base line (x) = 31.5 feet

II. Procedure

- A. Choose a "System" based on fixed terminal pressures. Determine line size and pressure drop (psi/100 ft) for the line or lines within the system.**
- B. Estimate equivalent length of pipe for each segment.**
- C. Calculate fixed pressure drops for the system (Static heads that do not change)**
- D. Calculate control valve pressure drop**
- E. Calculate the pump differential**
- F. Re-calculate control valve pressure drop, system pressure drop and pump differential for alternate cases.**



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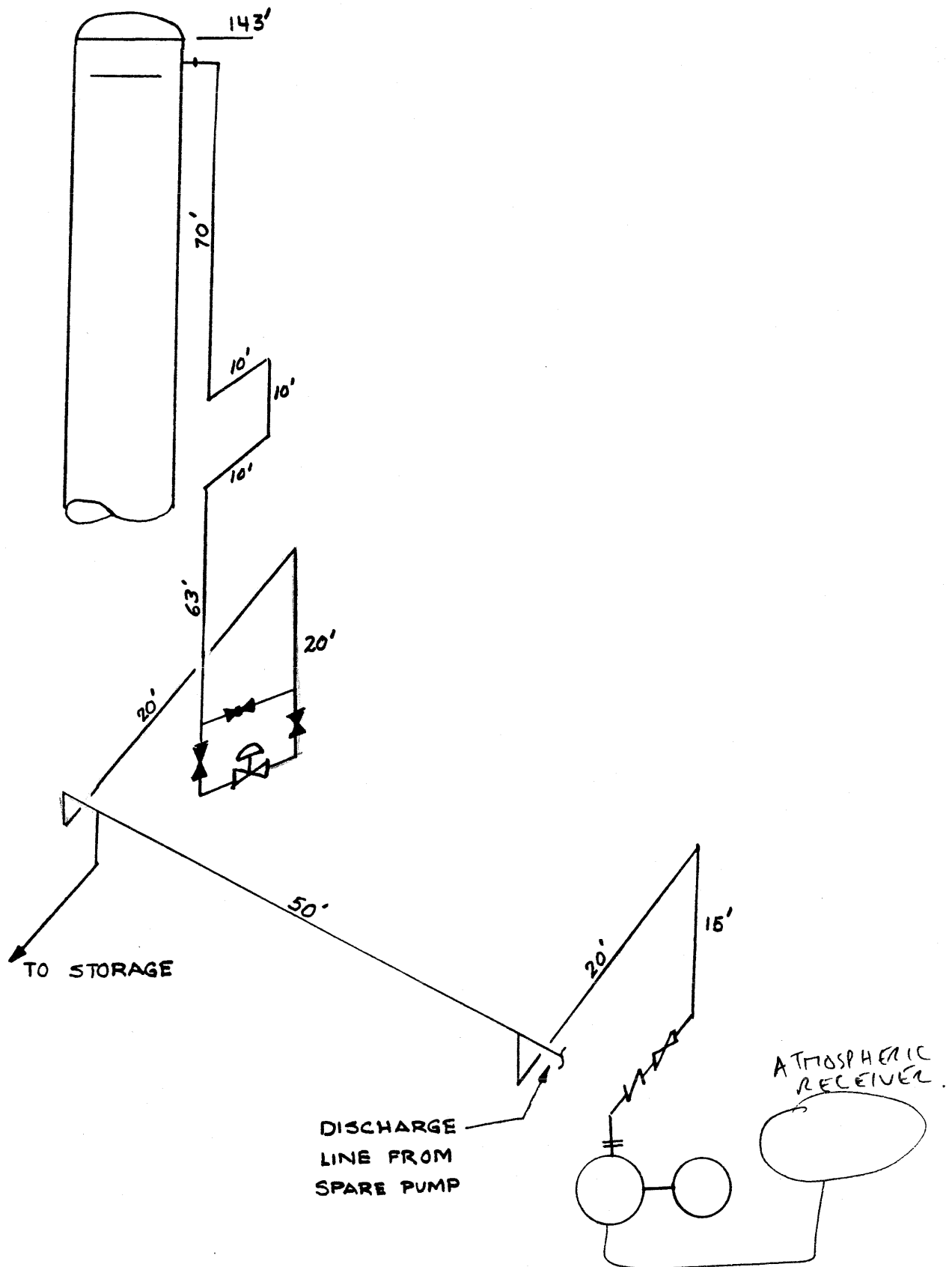
PROJECT _____

CUST. NO. _____

HYDRAULIC TABULATION

LINE	OVHD PUMP SUCTION		OVHD PUMP DISCHARGE		REFLUX					
API OR LB/GAL AT 60° F										
AVERAGE MOL WT										
TEMPERATURE, ° F										
FLOWING SP GR	0.86		→		→					
SP VOL, CU FT/LB										
FLOW VIS, CENTISTOKES										
VIS CORR FACTOR										
	NOR	MAX	NOR	MAX	NOR	MAX	NOR	MAX	NOR	MAX
FLOWING USGPM	160	176	160		130					
FLOW, LB/HR x 10 ³										
DESTINATION, PSIG										
STATIC, PSI										
EXCHANGE, PSI										
PIPING, PSI										
VALVE, PSI										
PUMP DISCHARGE, PSIG										
PUMP SUCTION, PSIG										
DIFFERENTIAL, PSI										
DIFFERENTIAL HEAD, FT										
PRESSURE LEVEL, PSIG (BV)										
NORMAL FLOW	SUCT	DISCH	SUCT	DISCH	SUCT	DISCH	SUCT	DISCH	SUCT	DISCH
PIPE SIZE, IPS	6			3		3				
PIPE CLASS	40			40		40				
VELOCITY, FPM				410		330				
FRICTION, PSI/100 FT (UNCORR)	0.08			2.5		1.70				
FRICTION, PSI/100 FT (CORR)	0.07			2.15		1.46				
PUMP DESCRIPTION	TYPE 2A.		TYPE 3A		TYPE 3C					
	OPER	SPARE	OPER	SPARE	OPER	SPARE	OPER	SPARE	OPER	SPARE
TYPE										
ITEM NO										
DRIVER										
POWER CONDITION										
NPSH AVAILABLE										
NOTES										

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HYDRAULIC TABULATION
(A)

PROJECT SPECIFICATION

SHEET

REV	DATE	BY	APP'D	REV	DATE	BY	APP'D

Line No (CV No)	Size, in	Schedule	$\Delta P/100$ ft psi	Est EQ ft + 100	Description	ΔP psi	Inlet Press psig	ΔP psi	Inlet Press psig	ΔP psi	Inlet Press psig	Design Press psig
1					REFLUX TO COLUMN		5					
2					STATIC HD. 143' (.86/2.31)	53.24						
3	3	40	1.46	2.5	LINE TO TRAY 1							
4					6 90° ELL 120 D							
5					1 TEE ST. 20 D							
6					1 GATE VALVE 13 D							
7					SUBTOTAL 153 D							
8					EQ LENGTH = 38'							
9					STRAIGHT PIPE = 163							
10					TOTAL EQ LENGTH - 201'							
12					SAY 250'							
14					CONTROL VALVE							
16	3	40	1.46	1.0	LINE TO CV.							
17					4 90° ELLS 80 D							
18					1 TEE ST 20 D							
19					1 GATE 13 D							
20					113 D							
21					EQ. LENGTH 28'							
22					ST PIPE 40							
23					68'							
					SAY 100'							

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Line No (CV No)	Size, in	Schedule	ΔP/100 ft psi	Est EQ ft + 100	Description	ΔP	Inlet	ΔP	Inlet	ΔP	Inlet	Design Press psig
						psi	Press psig	psi	Press psig	psi	Press psig	
1	3	40	2.15	2.0	PUMP DISCHARGE LINE							
2					4 90° ELLS 80 D							
3					1 TEE (BRANCH) 60 D							
4					1 TEE (STR.) 20 D							
5					1 CHECK 135 D							
6					1 GATE 13 D							
7					1 328 D							
8					EQUIV. LENGTH 82'							
9					STRAIGHT PIPE 85'							
10					167							
12					USE 200'							
13												
14					PUMP							
15					STATIC (16') (0.86/2.31)							
16												
17	6	40	0.07	3.0								
18					SEE 'HYD. GEN COMMENTS'							
19					ITEM 'A-3' NPSH CALC.							
20												
21												
22												
23												

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PROJECT SPECIFICATION
SHEET

REV	DATE	BY	APP'D	REV	DATE	BY	APP'D

Process Division
Universal Oil Products Company
20 HOP Plaza - Algonquin & Mt. Prospect Roads
Des Plaines, Illinois 60016

AROMATICS FRACTIONATION
EXAMPLE FOR LINE SIZING ONLY

PAGE NO. 2
DATE _____
PROJECT _____
BY _____

ENGINEERING DEPARTMENT

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Process Division
Universal Oil Products Company
20 IOP Plaza - Algonquin & Mt. Prospect Roads
Des Plaines, Illinois 60016

AROMATICS FRACTIONATION

EXAMPLE FOR LINE SIZING ONLY

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DATE _____
PROJECT _____
BY _____

ENGINEERING DEPARTMENT

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HYDRAULIC TABULATION

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PROJECT SPECIFICATION

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Process Division

Universal Products Company

20 UOP Plaza - Algonquin & Mt. Prospect Roads
Des Plaines, Illinois 60016 312-763-6000

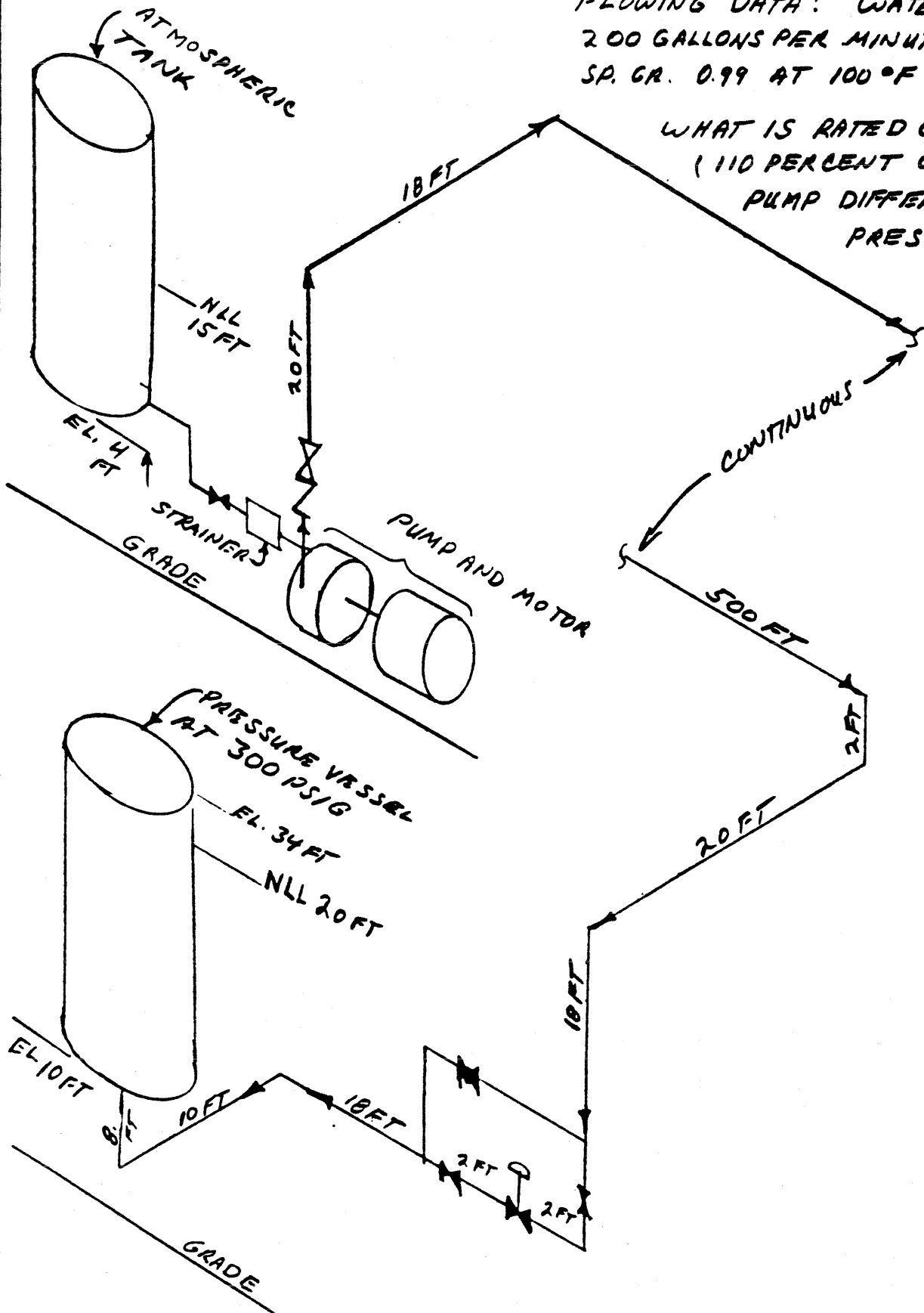
PIPING SKETCH NO. _____

DR. _____ CK. _____

DATE _____ PROJECT _____

FLOWING DATA: WATER
200 GALLONS PER MINUTE
SP. GR. 0.99 AT 100°F

WHAT IS RATED CASE
(110 PERCENT OF NORMAL,
PUMP DIFFERENTIAL
PRESSURE?)





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LINE										
API OR LB/GAL AT 60° F										
AVERAGE MOL WT										
TEMPERATURE, ° F										
FLOWING SP GR										
SP VOL, CU FT/LB										
FLOW VIS, CENTISTOKES										
VIS CORR FACTOR										
	NOR	MAX	NOR	MAX	NOR	MAX	NOR	MAX	NOR	MAX
FLOWING USGPM										
FLOW, LB/HR x 10 ³										
DESTINATION, PSIG										
STATIC, PSI										
EXCHANGE, PSI										
PIPING, PSI										
VALVE, PSI										
PUMP DISCHARGE, PSIG										
PUMP SUCTION, PSIG										
DIFFERENTIAL, PSI										
DIFFERENTIAL HEAD, FT										
PRESSURE LEVEL, PSIG (BV)										
NORMAL FLOW	SUCT	DISCH	SUCT	DISCH	SUCT	DISCH	SUCT	DISCH	SUCT	DISCH
PIPE SIZE, IPS										
PIPE CLASS										
VELOCITY, FPM										
FRICTION, PSI/100 FT (UNCORR)										
FRICTION, PSI/100 FT (CORR)										
PUMP DESCRIPTION										
	OPER	SPARE	OPER	SPARE	OPER	SPARE	OPER	SPARE	OPER	SPARE
TYPE										
ITEM NO										
DRIVER										
POWER CONDITION										
NPSH AVAILABLE										
NOTES										

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ENGINEERING DESIGN SEMINAR

SEPTEMBER 6, 1994 – NOVEMBER 11, 1994

LINE SIZING

LINE SIZING CRITERIA

INDEX OF TYPE NUMBERS

<u>Type</u>	<u>Description</u>
1.	Gravity flow
2.	Pump suction
3.	Pump discharge
4.	Liquid to non-pumped reboiler
5.	Reboiler return to column
6.	Column overhead vapor
7.	Column hot vapor by-pass
8.	Column overhead condenser rundown
9.	Compressor suction
10.	Compressor discharge
11.	High available pressure drop (25 psi or more available for piping friction)
12.	Feed to a column
13.	Vacuum unit heater transfer
14.	Steam
15.	Condensing steam turbine exhaust
16.	Liquid at its bubble point to a control valve or steam trap
17.	Steam condensate after a control valve or steam trap
18.	Make-up gas to a hydrogen consuming process
19.	Fuel gas to heaters
20.	Fuel oil to heaters
21.	Atomizing steam to heaters

INDEX OF TYPE NUMBERS

(Continued)

<u>Type</u>	<u>Description</u>
22.	Instrument air piping
23.	Cooling water
24.	Static electricity consideration

Type 1. Gravity flow

Criteria: $\Delta P/100'$ (PSI) = 0.20 max.

Remarks: Can be tighter if line is mostly vertical.

Type 2. Pump Suction

- a. Liquid at bubble point or less than 50°F below it.

Criteria: If not FCC main column bottoms or similar solids - carrying stream, $\Delta P/100'$ (PSI) = 0.20 max.

If FCC MC bottom or similar stream, velocity should be 180 FPM to avoid settling of solids. If ΔP of 0.20 PSI/100' has been exceeded, use the largest size that will still give 180 FPM.

Remarks: For lines 3" and smaller, 180 FPM will result in $\Delta P/100'$ in excess of 0.20 PSI which should be allowed for in determining NPSH availability.

- b. Liquid 50°F or more below bubble point.

Criteria: $\Delta P/100'$ (PSI) = 0.35 max.

Remarks: Watch viscosity for heavy cool liquids. Consider viscosity when it is 2.0 centistokes or more, at which point the actual pressure drop could be as much as 27% higher than that calculated using viscosity of 0.6 centistokes.

Type 3. Pump Discharge

- a. Single line pump discharge

Criteria: $\Delta P/100'$ (PSI) = 5.0 max.
Velocity (FPM) = 700 max.

Remarks: Carbon steel pump discharge piping is sized within the limits of the above criteria and with an economic consideration of piping material costs compared to pumping costs depending on whether the pump discharge line is considered to be "low pressure level" or "high pressure level". The dividing line is as follows:

"Low pressure level" includes pump discharge lines with design pressure of 1400 psig and design temperature of 150°F (or other combinations of pressure and temperature to give equal or lesser required pipe thickness and flange ratings). For pump discharge lines in this pressure-temperature range, optimum sizing is as indicated by curves added to the liquid line sizing chart PD 435-C for sp.gr. 0.6 to 1.0.

"High pressure level" includes design pressure and design temperature combinations resulting in pipe thicknesses and flange ratings greater than above. Due to the high cost of heavy wall pipe and heavy flanges, pump discharge lines in the "high pressure level" category are more likely to be sized close to the limit of the above criteria.

Alloy pump discharge piping is more likely to be sized at or above the limits of the above criteria due to the very high cost of alloy materials. However, at velocities in excess of 700 FPM, the increased erosion rate may require heavier pipe wall thickness at an increased material cost.

As long as the flow remains turbulent, the optimum size for a given flow rate is practically independent of viscosity. For laminar flow, the above curves on PD 435-C do not exactly represent optimum diameters, but it is suggested that they be used for sizing anyway, observing especially the limitation of 5.0 psi/100' maximum ΔP corrected for viscosity. The flow can be assumed to be laminar at Reynolds Numbers below 2000 and turbulent at 2000 and higher. The Reynolds Number can be calculated as follows:

$$\text{Reynolds Number} = \frac{(3160)(Q)}{(d)(\text{cstks})}$$

Where Q = flowing GPM

d = i.d. (inches)

cstks = flowing viscosity in centistokes

- b. Downstream of a pump discharge with different conditions than at the pump.

Criteria:

- 1) $\Delta P/100'$ (PSI) = 5.0 max.
- 2) If 100% liquid, velocity (FPM) = 700 max.
- 3) If 100% vapor, velocity (FPM) = $6000/\sqrt{\rho_v}$ max.

where ρ_v = flowing density, lb/ft³

- 4) If the line is the transfer line of a fired reboiler heater or other pumped reboiler, and it is desired to minimize heater outlet temperature:

$\Delta P/100'$ (PSI) max. = 2.5% of column bottom absolute pressure.

- 5) If the material in the line is in vertical upward two-phase flow, such as feed to a column or inlet to a crude heater, check to avoid slug flow. If it is impossible to satisfy this criterion (which sets a maximum permissible diameter) and also limitations 1 and 4 above, the solution will be to take (and allow for) more pressure drop, or to revise relative amounts of vapor and liquid to specify more vapor.

Remarks: Economic considerations involved in sizing carbon steel pump discharge system piping at "low pressure level" and "high pressure level" and alloy pump discharge system piping should be similar to Type 3a above.

c. Branches from a pump discharge.

Criteria: Treat as Type 3a.

Remarks: Be aware that the common pump must satisfy the pressure drop in all branches. It is possible that a low capacity branch might be sized for a high pressure drop while the high capacity branches require a low pressure drop. The common pump would be required to provide sufficient discharge pressure to satisfy the pressure drop of the low capacity branch, while control valves in the high capacity lines would handle greater than desired pressure drops.

d. Branches downstream of a pump discharge with different conditions than at the pump.

Criteria: Treat as Type 3b.

Remarks: Consider pressure drop balance as discussed for Type 3c.

Type 4. Liquid to non-pumped reboiler.

Criteria: $\Delta P/100'$ (PSI) = 0.15 to 0.20

Remarks: This type is to be sized in conjunction with the return line from the same reboiler.

Type 5. Reboiler return to column

Criteria:

1. Kettle type: $\Delta P/100'$ (PSI) = 0.20 max.
2. Thermosyphon or once-through type, non-kettle, non-pumped. For pumped types see Type 3b.

Remarks: Maximum permissible size = 30" nominal. If calculated diameter is above this number, divide flow in half and size for this reduced flow.

For non-kettle types (two-phase flow), the line should be checked for slug flow. If slug flow is indicated, the solution will be to take (and allow for) more pressure drop, or to revise the relative amounts of vapor and liquid to specify more vapor.

Type 6. Column overhead vapor

- a. All except FCC main column and crude vacuum column overhead vapor lines.

Criteria:

Limiting equations

$$\Delta P/100' \text{ (PSI)} = 0.20 \sqrt{p} \left(\frac{100}{160 + 8.34d} \right) \text{ max.}$$

$$\text{Velocity (FPM)} = 6000 \sqrt{\rho_v} \text{ max.}$$

Use half of the above limiting pressure drop for columns where minimum pressure is critical.

p = receiver pressure, psia

d = i.d., inches

ρ_v = overhead vapor flowing density, lb/ft³

Remarks: Sizing of the above column overhead vapor lines is based upon an approach to economic optimization within fixed limitations of pressure drop and velocity. The equations have been developed for carbon steel material. Alloy overhead vapor lines should be sized slightly tighter due to the higher material cost, but still within the criteria of the limiting equations.

b. FCC main column overhead vapor

Criteria: $\Delta P/100'$ (PSI) = 0.10 max.

c. Crude vacuum column overhead

The method of sizing is as follows: Determine equivalent length of the line. Size line so that ΔP over its entire length is not more than 7% of flash zone absolute pressure, limited to flash zone pressures of 35 mm and greater.

Type 7. Column hot vapor by-passCriteria: $\Delta P/100'$ (PSI) = 0.5 max.

Remarks: For amount of vapors thru hot vapor by-pass, use the following formula:

$$W = \left[(\text{Mol/hr})_1 + 0.06 (\text{Mol/Hr})_2 \right] \left[M_2 \right]$$

W = by-pass vapor, lb/hr.
 $(\text{Mol/hr})_1$ = normal mols/hr of net gas
 $(\text{Mol/hr})_2$ = normal mols/hr of gross column overhead vapors
 M_2 = mol weight of gross overhead vapors

Type 8. Column overhead condenser rundown.

a. Totally condensing, single phase:

Criteria:

Limiting equations

$$\Delta P/100' \text{ (PSI)} = 0.10 \sqrt{p} \left(\frac{100}{53.3 + 2.78d} \right) \text{ max.}$$

Velocity (FPM) = 200 max.

Use half of the above limiting pressure drop for columns where minimum pressure is critical.

p = receiver pressure, psia
d = i.d., inches

Remarks:

Special attention should be given to the rundown line if it is part of a pressure relief route. This situation exists when pressure relief is via a vent or relief on the receiver rather than via a relief valve on the OH vapor line or column proper. The rundown line should be at least as large as such a vent, and at least one size larger than the inlet of any RV on the receiver whose function is to protect the column. If several RV's are on the receiver serving this function the rundown line should be at least one size larger than a size whose inside cross sectional area equals the sum of the areas of the relief valve inlets.

- b. Totally condensing, with traces of a second liquid present and a piping arrangement that would permit pockets of the second liquid phase to accumulate.

Criteria and remarks: Column overhead condensers are often placed below the receiver in order to provide ΔP to operate a hot vapor by-pass. In cases like this, a moderately high velocity should exist in the run-down piping (350 FPM). This becomes important in column overhead systems where traces of a heavier liquid, such as water or HF can collect in the low points of a rundown line. The higher velocities tend to keep the line clear of a pocket of heavier liquid.

However, see the remarks under Type 8a above for a discussion of rundown lines when they are part of a pressure relief route. A conflict between the need for adequate liquid velocity during normal operation and the need of low ΔP during pressure relief may influence the design of the pressure relief system.

- c. Partially condensing, vapor and liquid present.

$$\text{Criteria: } \Delta P/100' \text{ (PSI)} = 0.10 \sqrt{P \left(\frac{100}{53.3 + 2.78d} \right)} \text{ max.}$$

Use half of the above limiting pressure drop for columns where minimum pressure is critical.

p = receiver pressure, psia
d = i.d., inches

Remarks: Because this two-phase flow line could be vertical upflow, the line should be checked for slug flow. If slug flow is indicated, a smaller diameter should be selected, until slug flow does not exist. However, if it is impossible to satisfy both the slug flow criteria and the max $\Delta P/100'$ limitation given above, solution will be to analyze piping layout with an eye toward relaxation of the max. $\Delta P/100'$ rule.

Special attention should be given to the rundown line if it is part of a pressure relief route, as described for Type 8a. If there is a conflict between diameter required for pressure relief and diameter required for avoidance of slug flow, consideration should be given to using several smaller lines in parallel or to revising the pressure relief arrangements.

Type 9. Compressor suction

a. Reciprocating compressor

$$\text{Criteria: } \Delta P/100' \text{ (PSI)} = 0.043 \sqrt{p} \text{ max.}$$

$$\Delta P/100' \text{ (PSI)} = 1.0 \text{ max.}$$

$$\text{Velocity (FPM)} = 2000 \sqrt{\frac{28.8}{MW}} \text{ max.}$$

p = line pressure, psia
 MW = gas molecular weight

Remarks: Line is defined as being between a suction drum (or vessel serving as a suction drum) and the compressor. Lead-in lines to individual cylinders should also be sized according to the above criteria.

b. Centrifugal compressor

$$\text{Criteria: } \Delta P/100' \text{ (PSI)} = 0.043 \sqrt{p} \text{ max.}$$

$$\Delta P/100' \text{ (PSI)} = 1.0 \text{ max.}$$

$$\text{Velocity (FPM)} = 3540/\rho_v^{0.25} \text{ max.}$$

p = line pressure, psia
 ρ_v = gas flowing density, lb/ft³

Remarks: Line is defined as being between a suction drum (or vessel serving as a suction drum) and the compressor.

Type 10. Compressor discharge

a. Reciprocating compressor

$$\text{Criteria: } \Delta P/100' \text{ (PSI)} = 0.043 \sqrt{p} \text{ max.}$$

$$\Delta P/100' \text{ (PSI)} = 1.0 \text{ max.}$$

$$\text{Velocity (FPM)} = 3000 \sqrt{\frac{28.8}{MW}} \text{ max.}$$

p = line pressure, psia
 MW = gas molecular weight

Remarks: Line is defined as being between the compressor and a junction with a line carrying other fluids, or to a cooler or vessel. Lead-out lines from individual cylinders should also be sized according to the above criteria.

b. Centrifugal compressor

Criteria: $\Delta P/100'$ (PSI) = $0.043 \sqrt{p}$ max.

$\Delta P/100'$ (PSI) = 1.0 max.

Velocity (FPM) = $6000/\sqrt{\rho_v}$ max.

p = line pressure, psia
 ρ_v = gas flowing density, lb/ft³

Remarks: Line is defined as being between the compressor and a junction with a line carrying other fluids, or to a cooler or vessel.

Type 11. High available pressure drop (25 psi or more available for piping friction, within the battery limits).

Criteria: Use up, but do not exceed, the available pressure drop. Also, observe the following limitations, except for pressure relief:

1. 100% liquid
 $\Delta P/100'$ (PSI) = 7.0 max.
 Velocity (FPM) = 700 max.
2. 100% vapor
 $\Delta P/100'$ (PSI) = 7.0 max.
 Velocity (FPM) = $6000/\sqrt{\rho_v}$ max.
3. Vapor plus liquid
 $\Delta P/100'$ (PSI) = 5.0 max.

Remarks: Allow high piping ΔP , but consider erosion, noise, and vaporization. For vaporizing materials, use downstream conditions for calculation of ΔP .

Type 12. Feed to a column

Criteria and remarks:

1. If line is a pump discharge or is downstream of a pump discharge, treat as Type 3, except limit the 100% liquid case to a velocity of 500 FPM.

2. If line has high available pressure drop (25 psi or more available for piping friction), treat as Type 11, except limit the 100% liquid case to a maximum velocity of 500 FPM.
3. If line is other as indicated in 1 or 2, above:

$$\Delta P/100' \text{ (PSI)} = 3.0 \left(\frac{100}{114 + 10d} \right) \text{ max.}$$

- A) If flow is 100% liquid:

$$\text{Velocity (FPM)} = 500 \text{ max.}$$

- B) If flow is 100% vapor:

$$\text{Velocity (FPM)} = 6000/\sqrt{P_v} \text{ max.}$$

- C) If flow is two-phase: Apply the criteria for slug flow. If it is impossible to satisfy both this criterion and the pressure drop of this item 3, the solution will be to take (and allow for) more pressure drop, or to revise relative amounts of vapor and liquid to specify more vapor.

Type 13. Vacuum unit heater transfer

The method of sizing is as follows: Determine equivalent length of the line. Determine heater outlet pressure, which is often 3.0 psia. Base line sizing calculations on only the vapor portion of the flow, but in calculations of pressure drop and velocity, use diameter of only 98% of the actual diameter, to account for presence of liquid.

Observing sonic velocity limitation and allowing for changing pressure along the length of the line, size line to use up the available pressure drop between heater and flash zone. If pressure in downstream end of the line is raised because of sonic velocity limitation, the nozzle at the inlet to the column should be enlarged until sonic velocity or less can be attained in the nozzle at flash zone pressure.

Type 14. Steam

Criteria and remarks:

1. Saturated, 15 psig and less:

$$\text{Velocity (FPM)} = 6000 \text{ max.}$$

$$\Delta P/100' \text{ (PSI)} = 1.1 \text{ max.}$$

Higher rates than these are permissible where high pressure drop is available, but velocity should be less than 10,000 FPM.

2. Saturated, over 15 psig:

$$\text{Velocity (FPM)} = 10,000 \text{ max.}$$

$$\Delta P/100' \text{ (PSI)} = 0.02 \text{ p max.}$$

p = pressure, psia.

3. Superheated, over 200 psig

$$\text{Velocity (FPM)} = 15,000 \text{ max.}$$

$$\Delta P/100' \text{ (PSI)} = 0.012 \text{ p max.}$$

p = pressure, psia.

Type 15. Condensing steam turbine exhaust

The method of sizing is as follows:

Determine equivalent length of the line.

For convenience, calculations should be based on full weight flow from turbine as if it had a steam quality of 100%.

Operating pressure of turbine exhaust and condenser inlet must be known. Size line to use up the difference in pressure between turbine and condenser, except observe maximum velocity as follows:

$$\text{Velocity (FPM)} = 1200/\sqrt{\rho_v} \text{ max.}$$

ρ_v = flowing density of steam at inlet to condenser, lb/ft³

Type 16. Liquid at its bubble point to a control valve or steam trap

$$\text{Criteria: } \Delta P/100' \text{ (PSI)} = 0.5 \text{ to } 1.5 \text{ max.}$$

$$\text{Velocity (FPM)} = 700 \text{ max.}$$

Remarks: Consider elevations of liquid surface and control valve. Consider length of line. The pressure drop due to friction should be well below the static head increase in pressure due to lower elevation of the control valve, in order to avoid vaporization before valve.

Type 17. Steam condensate after a control valve or steam trap

Criteria and remarks: There are many situations possible in the operation of condensate removal piping. Consideration should be given to the points discussed below.

1. With control valve located in steam line.

The control valve may be placed in the steam line, if the condensate will still have sufficient pressure to flow to its destination. This would be the case when the condensate is at a temperature whose saturation pressure is sufficiently above the condensate destination pressure to permit flow. Low condensate temperatures can be tolerated when flow is to a condensate pot operating under a vacuum.

To size the condensate line one must first obtain the destination pressure. Then an initial condensate temperature (and pressure) must be determined. This will depend on the process-side temperatures of the exchanger, on whether the flow is countercurrent or co-current, and on the condensate temperature approach to process-side temperature. Lower condensate temperatures will be governing for condensate line sizing.

If the length of the condensate line is known, this length (equivalent feet) should be used in the pressure drop calculation. If the length is not known, as is generally the case, 300 equivalent feet may be used as being the distance to a condensate header or pot. Pipe friction pressure drop should be not more than 1/2 of the total pressure drop. It may be necessary to consider the line in sections for calculation purposes in order to account for the increased flashing as pressure falls. PD 395A may be used to find the piping two-phase pressure drop as a function of a fictitious all-liquid ΔP .

2. With control valve in condensate line.

The control valve is often placed in the condensate line when process-side temperatures are low, resulting in low condensate temperatures. The pressure before the control valve in this case will be full steam pressure, less a small amount for exchanger pressure drop. The temperature of the condensate before the control valve can be anything from saturation temperature down to the process side temperature at the condensate outlet. For condensate line sizing, higher temperature will be governing, since more flashing will result. Condensate temperature equal to steam temperature should therefore be assumed unless there is reason to believe it to be lower.

3. General Remarks, applicable to all cases.

Use a unit pressure drop 1-1/2 times the value for clean commercial steel pipe, to allow for roughening of the pipe walls due to the corrosive effects of condensate.

Pressure drop per length of pipe will be greatest at the downstream end of the pipe where the pressure level is the lowest. More liquid will have flashed to vapor, and the vapor density is the lowest. There should be a limitation on instantaneous pressure drop as follows:

$$\Delta P/100' \text{ (PSI)} = 7.5 \text{ max.}$$

This should be calculated using 1-1/2 times the values for clean commercial steel pipe as mentioned above. Often this limitation will be governing, with the result that the steam trap or control valve will be able to operate with much more than 1/2 of the total pressure drop.

Type 18. Make-up gas to a hydrogen consuming process

Criteria: $\Delta P/100'$ (PSI) = 1.0 max.

Velocity (FPM) = $6000/\sqrt{P_v}$ max.

Remarks: Consider length of line. Take smaller $\Delta P/100'$ for long lines.

Type 19. Fuel gas to heaters

Criteria:

1. Before control valve:

$\Delta P/100'$ (PSI) = 0.05 p max.

p = gauge pressure before valve

2. After control valve:

$\Delta P/100'$ (PSI) = 0.1 p max.

p = gauge pressure after valve.

If pressure is not known, the following standard values may be used:
For gas with gross heating value of 500 BTU/SCF or more:
10 psig

For gas with gross heating value less than 500 BTU/SCF:
20 psig

3. Header:

$\Delta P/100'$ (PSI) = 0.05 p max.

Comments of Item 2 apply, except that p refers to gauge pressure in header.

Remarks: Quantity of gas can be calculated from process specification heater duty, using an appropriate heater efficiency and fuel gas heating value.

If more than one process stream is to be heated in the same heater box, careful determination should be made for the amount of heat to be released from each set of burners.

Type 20: Fuel oil to heaters

Criteria:

GPM	Size
0 - 5.9	1" - Sch. 80
6 - 19.9	1-1/2" - Sch. 80
20 - 34.9	2" - Sch. 80
35 - 100	3" - Sch. 40
101 - 300	4" - Sch. 40

Remarks: Use 3 volumes recirculated for 1 volume burned. Use flowing temperature such as to give a viscosity of 50 centistokes. Specific gravity is about 0.9. Size lines as above.

Note that this is laminar flow.

Use same criteria for return lines to surge, storage, or refinery fuel oil system.

Type 21. Atomizing steam to heaters

Criteria: Usual steam criteria

Remarks: Use 3-4 lbs. of steam per gallon of fuel oil burned. Use pressure of 75 psig maximum after valve if there is a valve.

Type 22. Instrument air piping

Criteria: Main air supply header shall be 1-1/2" or larger.

Branch Header line size:

Number of taps	1 - 5	6 - 10	11 - 15	16 - 20
Branch header size	1/2"	3/4"	1"	1-1/2"

Type 23. Cooling water

Criteria:

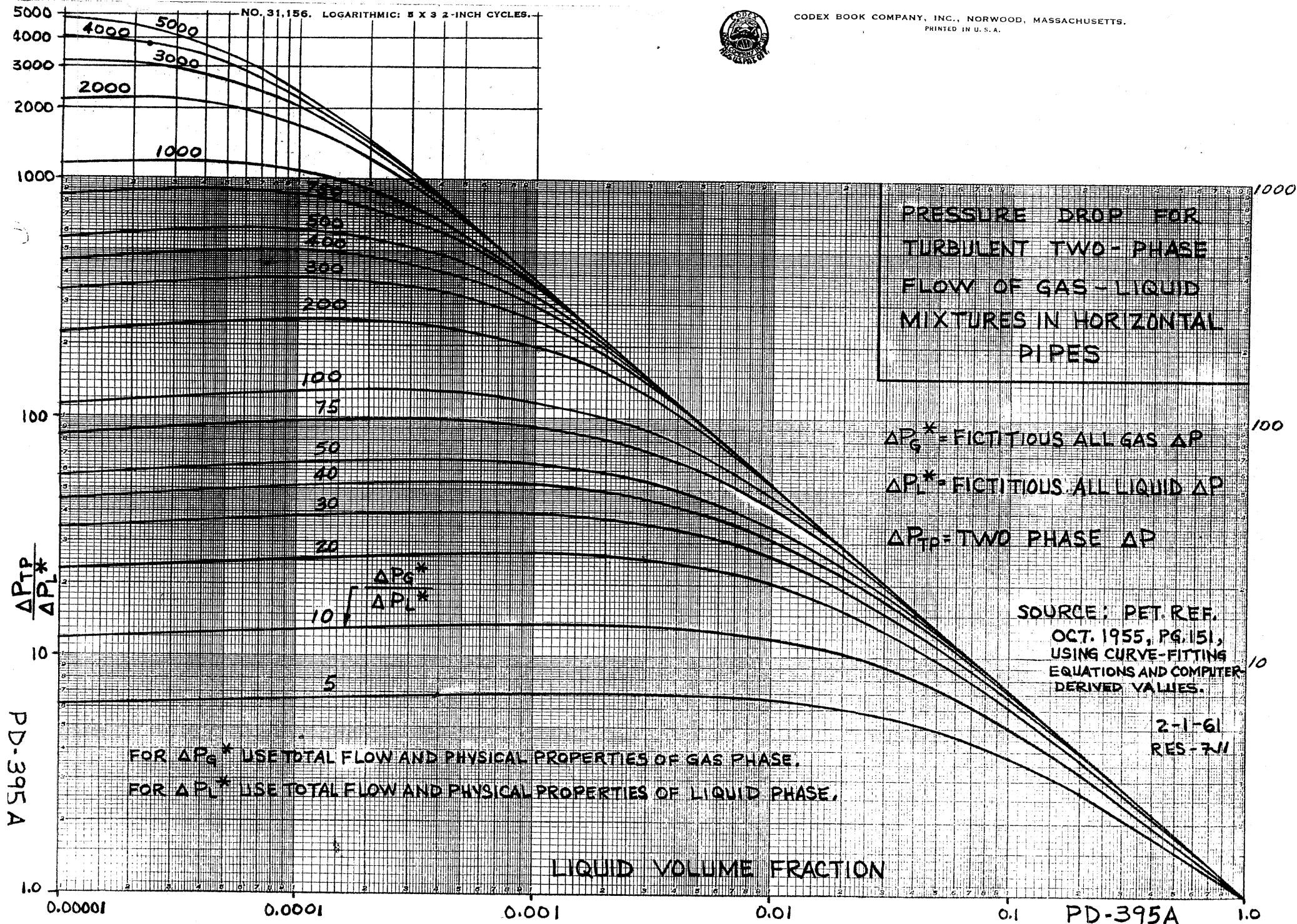
0-650 GPM:	Max. $\Delta P/100'$ = 1.3 PSI
651-2800 GPM:	Max. Velocity = 500 FPM
2801-7000 GPM:	Max. Velocity = 600 FPM
Over 7001 GPM:	Max. Velocity = 700 FPM

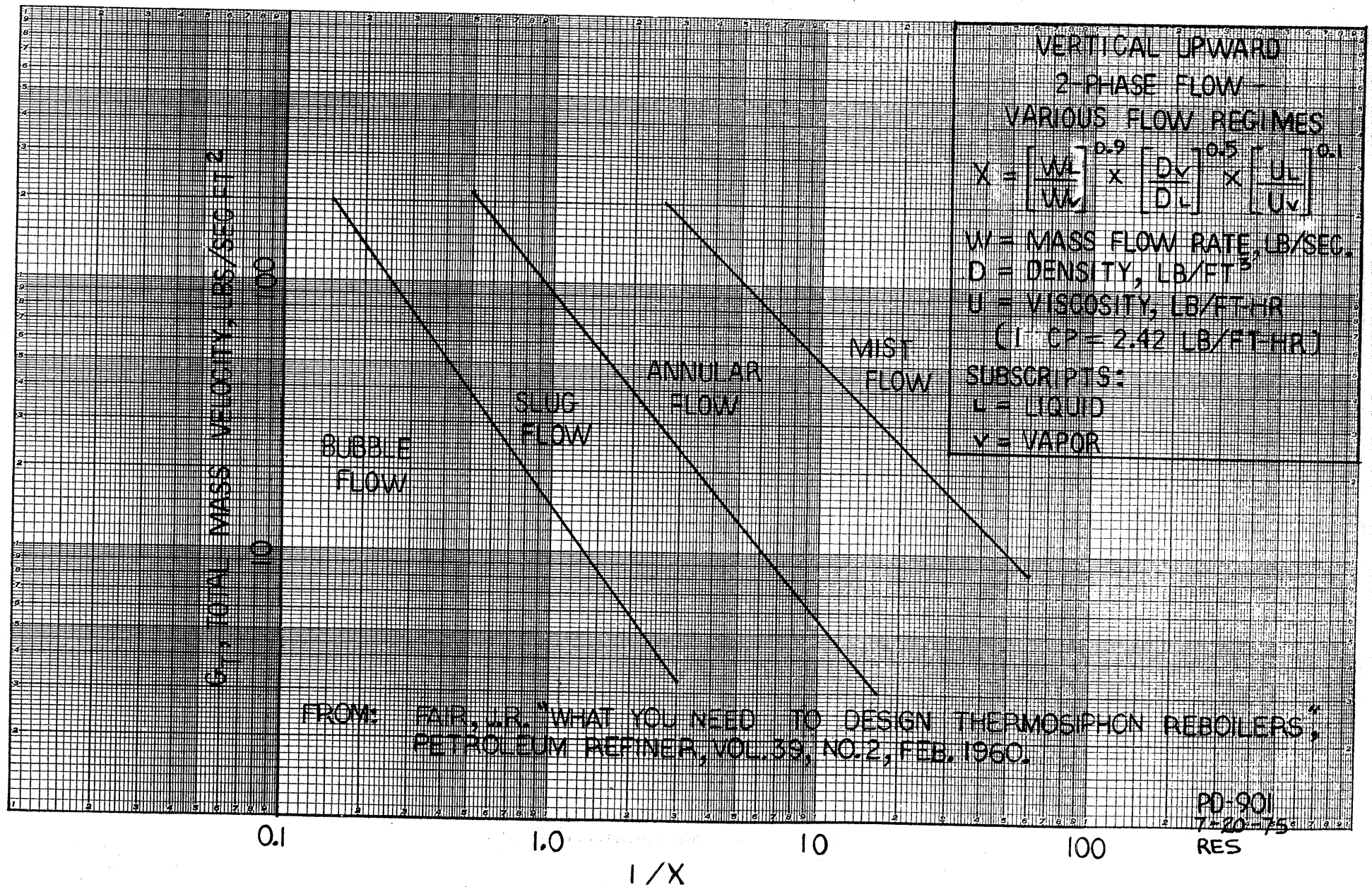
Remarks: The 1.3 PSI/100' criterion is based on $\Delta P/100'$ obtained by using PD 435-C. Pressure drop after a long period of usage may be twice as high as this. If film type corrosion protection is used, maximum velocity should be reduced to 350-500 FPM.

Type 24. Static electricity consideration

Criteria: Velocity (FPM) = 400 max.

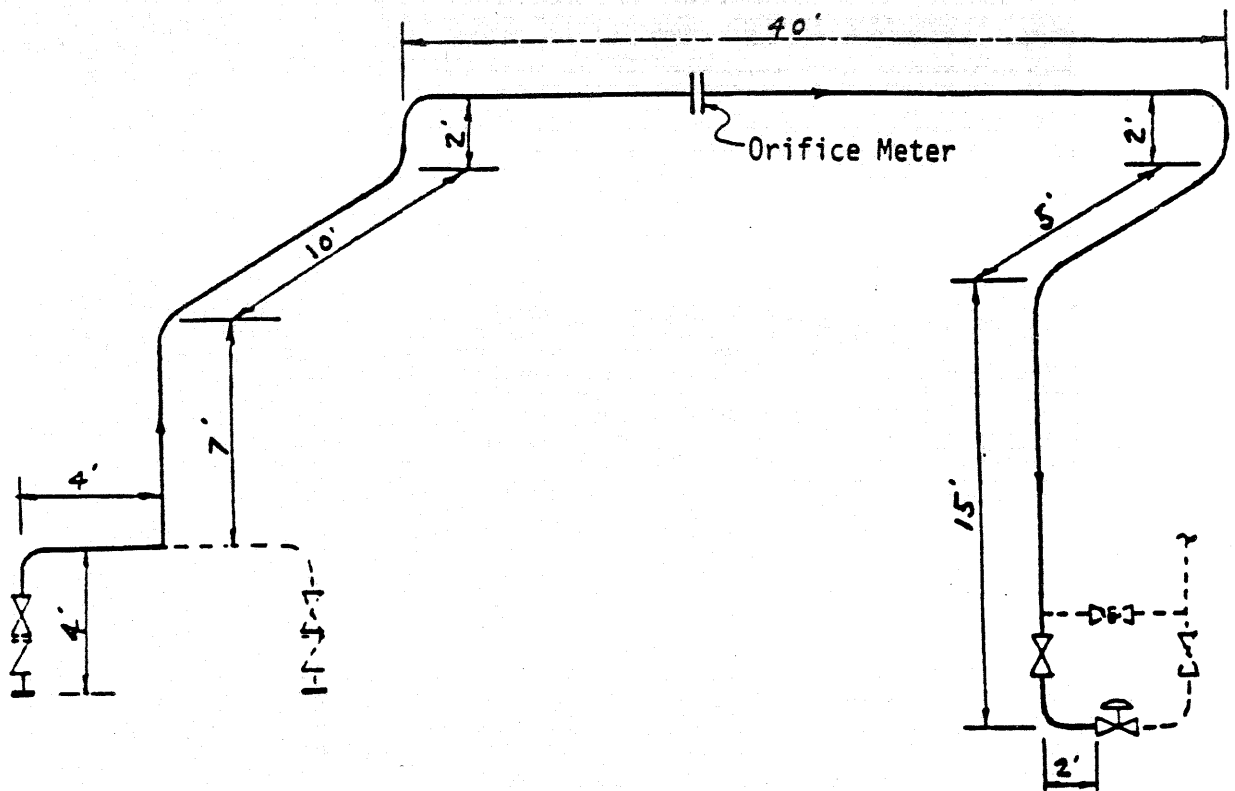
Remarks: When the flowing hydrocarbon is a material whose vapor pressure is such as to form an explosive mixture with air, the flowing velocity must be limited in order to minimize the buildup of static electricity. This consideration is particularly important when handling materials such as kerosene and jet fuel to storage tanks.





CUSTOMER _____
SUBJECT _____
_____ TYPICAL CALCULATION OF _____
_____ PIPING EQUIVALENT LENGTH _____
_____ 8" PUMP DISCHARGE LINE _____

PAGE NO. _____
DATE _____
PROJECT _____
BY _____ HCB



8 - 90° LONG RADIUS EL	8 x 20 = 160 D
2 - GATES	2 x 13 = 26 D
1 - CHECK VALVE	1 x 135 = 135 D
1 - BRANCH TEE	1 x 60 = 60 D
1 - FLOW THRU	1 x 20 = 20 D
<u>TOTAL FOR FITTING</u>	401 D
ST. RUN OF PIPE	41 ft

$$\begin{aligned} \text{Total Ed. Length}_{12''} &= 91 + 401 \left(\frac{D}{12} \right) \\ &= 91 + 401 = 500 \text{ ft} \end{aligned}$$

Principle Criteria

1. **Pressure Drop in psi/100 ft of pipe**
2. **Velocity in feet per minute (fpm)**

Required Physical Properties

1. **Flowing Specific Gravity (Sp.Gr.)**

Ratio of the liquid density at its flowing temperature to the density of water at 60°F

2. **Vapor Density (lb/ft³)**
3. **Vapor Specific Volume (ft³/lb)**

SONIC VELOCITY - of a vapor

- 1. Maximum velocity that the fluid cannot exceed**
- 2. Usually occurs at end of a pipe or system**
(at a discontinuity in cross-sectional area)
- 3. Examples of common occurrence:**
 - a. Vacuum Heater Transfer Line**
 - b. Pressure Relief Piping**
 - c. High Pressure Drop systems**

PRESSURE DROP FOR LIQUID FLOWS

The general equation for pressure drop of a liquid in a pipe can be expressed as the Darcy Equation in the form:

$$\Delta P = \frac{f \times \rho \times L \times V^2}{144 \times D^5 \times g}$$

where:

ΔP	=	Pressure Drop	(psi)
ρ	=	Density	(lb/ft ³)
f	=	Darcy Friction Factor	
	=	four times the Fanning Friction Factor	
L	=	Length of pipe	(ft)
V	=	Velocity	(ft/sec)
D	=	Internal Diameter	(ft)
d	=	Internal diameter	(in)
g	=	Gravitational constant	(32.2 ft/sec ²)
Q	=	Flow	(gpm)

By rearrangement of the equation we can obtain:

$$\Delta P = \frac{0.000216 \times f \times L \times \rho \times Q^2}{d^5}$$

Pressure Drop for Liquid Flows (Continued)

Assume $L = 100 \text{ ft}$

Define $\Delta P_{(100)} = 100 \Delta P$

and since $\rho = 62.4 \times \text{SG}$

where $\text{SG} = \text{Specific Gravity of fluid}$

Substitution and re-arrangement yields:

$$\frac{\Delta P_{100}}{\text{SG}} = \frac{1.348 f \times Q^2}{d^5}$$

Define:

$$\Delta P_{0(100)} = \frac{\Delta P_{100}}{\text{SG}}$$

By Substitution:

$$\Delta P_{0(100)} = \frac{1.348 f \times Q^2}{d^5}$$

For small changes in flow, Q , assume Fanning Friction Factor remains constant.

Thus we can define a constant K as follows:

$$\frac{1.348 f}{d^5} = \text{Constant}, K$$

The equation then becomes:

$$\Delta P_{0(100)} = K Q^2$$

Which plots as a straight line on a Log-Log Graph.

Liquid Flow Line Sizing / ΔP Calculation

1. **Flow Rate** 500 gpm
 Flowing Sp.Gr. 0.75
 Viscosity 0.6 centistoke
 - a. **Find $\Delta P/100'$ in 6" Sch 80 Pipe**
 - b. **Find $\Delta P/100'$ in 8" Sch 40 Pipe**
 - c. **Find Velocity in 8" Sch 40 Pipe**
 - d. **Find Corrected $\Delta P/100'$ in 6" Sch 80 Pipe if $\nu = 50$ centistoke**
 - e. **What size pipe would result in a $\Delta P/100' = 0.28$ psi if flow is 4000 gpm, Sp. Gr. = 0.8 and $\nu = 0.6$ centistoke?**

PRESSURE DROP FOR VAPOR FLOWS

The general equation for pressure drop of a vapor in a pipe can be expressed as the Darcy Equation in the form:

$$\Delta P = \frac{3.36 \times 10^{-6} \times f \times L \times W^2 \times \bar{V}}{d^5}$$

Where:

ΔP	=	Pressure drop	(psi)
ρ	=	Density	(lb/ft ³)
f	=	Darcy Friction Factor	
	=	four times the Fanning Friction Factor	
L	=	Length of pipe	(ft)
$\bar{V}$	=	Specific Volume	(ft ³ /lb)
d	=	Internal diameter	(in)
W	=	Mass Flow Rate	(lb/h)

Pressure Drop for Vapor Flows (Continued)

Assume $L = 100$ ft

Define $\Delta P_{(100)} = 100 \frac{\Delta P}{V}$

By substitution and re-arrangement we obtain:

$$\Delta P_{100} = \frac{336 f}{d^5} \left(\frac{W}{1000} \right)^2$$

For small changes in flow, W , assume the fanning friction factor, f , remains constant. Thus:

$$\frac{336 f}{d^5} = \text{Constant}, K$$

$$\Delta P_{(100)} = K \left(\frac{W}{1000} \right)^2$$

This plots as a straight line on a Log - Log graph.

Vapor Flow Line Sizing / ΔP Calculation

1. **Flowing Quantity** = 40,000 lb/h
 Specific Volume = 0.9 ft³/lb

- a. **Find $\Delta P/100'$ in 6" Sch 80 pipe**

Given: $Q = 40,000$ lb/h $\rho = 1.6$ lb/ft³ $\Delta P = 1.5$ psi

- b. **Find $\Delta P/100'$ in 8" Sch 40 pipe**

Given: $Q = 40,000$ lb/h $\rho = 1.6$ lb/ft³ $\Delta P = 0.25$ psi

- c. **Find Velocity in 8" Sch 40 pipe**

Given: $Q = 40,000$ lb/h $\rho = 1.6$ lb/ft³ $V = 2.4$ ft/s

- d. **What size pipe is required to obtain a $\Delta P/100'$ equal to or less than 0.4 psi, if the flow is 100,000 lb/h and density is 2 lb/ft³?**

What is the velocity in the line?

Given: $Q = 100,000$ lb/h $\rho = 2$ lb/ft³ $V = 4.4$ ft/s

Vapor Flow Line Sizing / ΔP Calculation

1. **Flowing Quantity** = 40,000 lb/h
 Specific Volume = 0.9 ft³/lb

- a. Find $\Delta P/100'$ in 6" Sch 80 pipe

- b. Find $\Delta P/100'$ in 8" Sch 40 pipe

- c. Find Velocity in 8" Sch 40 pipe

- d. What size pipe is required to obtain a $\Delta P/100'$ equal to or less than 0.4 psi, if the flow is 100,000 lb/h and density is 2 lb/ft³?

What is the velocity in the line?

Two-Phase Flow Pressure Drop

1. Calculate fictitious all vapor pressure drop, ΔP^*_G using total mass flow and flowing vapor properties

Note: If the line size is to be determined, calculate ΔP^*_G based upon an assumed line size. Then, if necessary after Step 6, re-estimate the line size and repeat the calculation until ΔP_{TP} is sufficiently close to the desired value.

2. Calculate fictitious all liquid pressure drop, ΔP^*_L by converting total mass flow to liquid, gpm, and use the flowing properties of the liquid phase.

Note: If the line size is to be determined, calculate ΔP^*_L based upon an assumed line size. Then, if necessary after Step 6, re-estimate the line size and repeat the calculation until ΔP_{TP} is sufficiently close to the desired value.

3. Calculate the ratio $\Delta P^*_G / \Delta P^*_L$
4. Calculate the actual liquid volume fraction

$$\frac{V_L}{V_L + V_G} = \text{LiquidVolumeFraction}$$

5. Using these last two values and chart determine factor, f

Where:

$$f = \Delta P_{TP} / \Delta P^*_L$$

6. Calculate two-phase pressure drop, ΔP_{TP}

$$\Delta P_{TP} = f \times \Delta P^*_L$$

TWO-PHASE FLOW PRESSURE DROP CALCULATION

Example:

Vapor Flow	47,000 lb/h
Specific Volume	0.303 lb/ft ³
Liquid Flow	443 gpm
Specific Gravity	0.494
Line Size	12 inch Sch 40

Step 1:

Calculate the liquid volume fraction:

$$\frac{V_L}{V_L + V_g}$$

Calculate the Liquid Volume:

$$V_L = \frac{443 \text{ gpm} \times 8.34 \text{ lb/gal} \times 0.494 \times 60 \text{ min/h}}{0.494 \times 62.4 \text{ lb/ft}^3}$$

$$\therefore V_L = 3552.5 \text{ ft}^3/\text{h}$$

Calculate the Vapor Volume:

$$V_g = \frac{47000 \text{ lb/h}}{1/0.303 \text{ lb/ft}^3}$$

$$\therefore V_g = 14241 \text{ ft}^3/\text{h}$$

$$\text{Liquid Volume Fraction} = 3552.5 / (3552.5 + 14241) = 0.199 \quad \text{say } 0.2$$

**TWO-PHASE FLOW
PRESSURE DROP CALCULATION
(continued)**

Step 2:

Calculate the total weight flow:

$$W_{\text{total}} = W_{\text{liquid}} + W_{\text{vapor}}$$

$$W_{\text{liquid}} = 443 \text{ gal/min} \times 8.34 \text{ lb/gal} \times 0.494 \times 60 \text{ min/h} = 109,508.5 \text{ lb/h}$$

$$W_{\text{vapor}} = 47000 \text{ lb/h}$$

$$W_{\text{total}} = 109508.5 + 47000 = 156,508.5$$

Step 3:

Calculate ΔP_g^* assuming all of the material is vapor and use the vapor fraction properties.

Use ΔP chart to get $\Delta P_{0/100}$

$$\Delta P_{0/100} = 0.47 \text{ (for 12" Sch 40)}$$

$$\Delta P_{100} = 0.47 \times 0.303 = 0.142 \text{ psi/100'}$$

**TWO-PHASE FLOW
PRESSURE DROP CALCULATION
(continued)**

Step 4:

Calculate ΔP_L^*

Calculate the liquid volumetric flow assuming all of the material is liquid and has the properties of the liquid fraction.

$$Q \text{ gpm} = 443 \text{ gpm} \times \frac{156508.5 \text{ lb/h}}{109508.5 \text{ lb/r}} = 633 \text{ gpm}$$

Use the ΔP chart for liquids to get $\Delta P_{0/100}$

$$\Delta P_{0/100} = 0.034 \text{ psi for 12 inch Sch 40 pipe}$$

$$\Delta P_{100} = 0.034 \times .494 = 0.017 \text{ psi/100'}$$

Step 5:

Calculate the ratio of the fictitious gas to liquid pressure drop

$$\Delta P_g^* / \Delta P_L^* = 0.142 / 0.017 = 8.4$$

Step 6:

From Two-Phase Flow Chart

$$f = 3.0$$

$$f = \Delta P_{TP} / \Delta P_L^*$$

$$\Delta P_{TP} = 3.0 \times 0.017 = 0.05 \text{ psi/100'}$$

**TWO-PHASE FLOW
PRESSURE DROP CALCULATION****Example:**

Vapor Flow	47,000 lb/h
Specific Volume	0.303 ft³/lb
Liquid Flow	443 gpm
Specific Gravity	0.494
Line Size	12 inch Sch 40

Step 1:

Calculate the liquid volume fraction:

$$\frac{V_L}{V_L + V_g}$$

Calculate the Liquid Volume:

$$V_L = \frac{443 \text{ gpm} \times 8.34 \text{ lb/gal} \times 0.494 \times 60 \text{ min/h}}{0.494 \times 62.4 \text{ lb/ft}^3}$$

$$\therefore V_L = 3552.5 \text{ ft}^3/\text{h}$$

Calculate the Vapor Volume:

$$V_g = 47000 \text{ lb/h} \times 0.303 \text{ ft}^3/\text{lb}$$

$$\therefore V_g = 14241 \text{ ft}^3/\text{h}$$

$$\text{Liquid Volume Fraction} = \frac{3552.5}{3552.5 + 14241} = 0.199 \quad \text{say } 0.2$$

**TWO-PHASE FLOW
PRESSURE DROP CALCULATION
(continued)**

Step 2:

Calculate the total weight flow:

$$W_{\text{total}} = W_{\text{liquid}} + W_{\text{vapor}}$$

$$W_{\text{liquid}} = 443 \text{ gal/min} \times 8.34 \text{ lb/gal} \times 0.494 \times 60 \text{ min/h} = 109,508.5 \text{ lb/h}$$

$$W_{\text{vapor}} = 47000 \text{ lb/h}$$

$$W_{\text{total}} = 109508.5 + 47000 = 156,508.5$$

Step 3:

Calculate ΔP_g^* assuming all of the material is vapor and use the vapor fraction properties.

Use ΔP chart to get $\Delta P_{0/100}$

$$\Delta P_{0/100} = 0.47 \text{ (for 12" Sch 40)}$$

$$\Delta P_{100} = 0.47 \times 0.303 = 0.142 \text{ psi/100'}$$