



Training Services

Line Sizing and Hydraulics

IPD-2004/LS-1

General Line Sizing Comments

- Guides and Approximations
- Reduce Time for Line Sizing
- Computer Not Required
- Good Judgment and Experience

IPD-2004/LS-2

Guidelines

- Use “normal” flow rates and “normal” pressures from process design
- Consider effect of:
 - Design flow rates
 - Maximum flow rates
 - Startup
 - Shutdown
 - Upset

IPD-2004/LS-3

Guidelines (continued)

- Use flow sketch to summarize hydraulics and line sizing data
- Flow sketch will help to visualize effect of static head

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Principle Criteria

- **Pressure Drop in psi/100 Feet**
- **Velocity in Feet per Minute**

IPD-2004/LS-5

Required Physical Properties

- **Flowing Specific Gravity - ratio of the density of the liquid at its flowing temperature to the density of water at a base temperature, usually 60°F (15.6°C) or 39.2°F (4°C), its point of maximum density (1000 g/cm³)**
- **Vapor Density - pounds per cubic foot**
- **Vapor Specific Volume - cubic feet per pound**

IPD-2004/LS-6

Sonic Velocity of a Vapor

- A compressible fluid cannot move faster than the speed of sound in that fluid
- Typical problem in vacuum heater transfer lines, pressure relief piping, and high pressure drop systems
- Usually occurs at end of a pipe or system (at a change in cross-sectional area)
- If sonic velocity is disregarded, the flow rate may be over-calculated

IPD-2004/LS-7

Sonic Velocity of a Vapor (continued)

- For a typical C_p/C_v of 1.1, the speed of sound is equal to:

$$V_s = 14,000 \sqrt{\frac{\text{Temperature } ^\circ\text{R}}{\text{Molecular Weight}}}$$

- Sonic velocity is expressed in units of feet per minute
- Sonic velocity is proportional to:

$$\sqrt{C_p/C_v}$$

IPD-2004/LS-8

Specific Volume Change

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

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Mechanical Considerations

- Minimum size rack piping 1"
- Minimize purchasing, detailing and inventory by avoiding 1¼", 2½", 3½", and 5" pipe
- For 2" and smaller pipe size, Schedule 80 minimum is recommended

IPD-2004/LS-10

Pipe Wall Thickness

- Pipe O.D. is constant
- I.D. changes as wall thickness changes
- Be careful of I.D. in high pressure or high corrosion allowance systems
- Wall thickness tolerance is $\pm 12\%$ for seamless pipe up to 24" O.D.
- Wall thickness tolerance is $\pm 0.01"$ if pipe is fabricated from rolled plate

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Revamp Considerations

- Economics and decision factors are different
- Line size can often be smaller than for new plants

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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:

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

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Pressure Drop for Liquid Flows (continued)

where:

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

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Pressure Drop for Liquid Flows ***(continued)***

- By rearrangement of the equation, we can obtain:

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

IPD-2004/LS-15

Pressure Drop for Liquid Flows ***(continued)***

- Simplifications
 - Assume $L = 100$ ft of equivalent length
 - Define $\Delta P_{(100)} = 100 \Delta P$
 - Substituting $\rho = 62.4 \text{ lb/ft}^3 \times SG$
where $SG = \text{Specific Gravity of fluid}$
 - By substitution and rearrangement yields:

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

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Pressure Drop for Liquid Flows ***(continued)***

- 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:

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

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Pressure Drop for Liquid Flows ***(continued)***

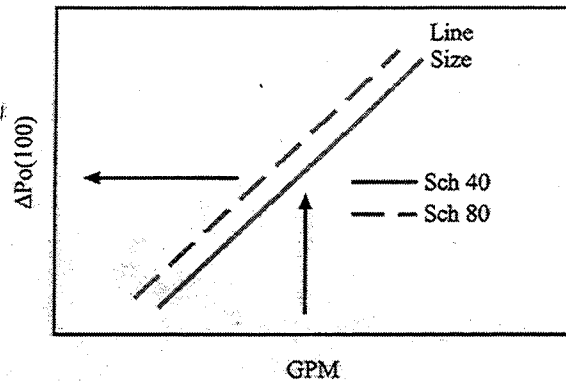
- The equation then becomes:

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

which plots as a straight line on a Log-Log graph

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UOP Pressure Drop Chart for Liquid Flow



$\Delta P_o(100)$ based on liquid viscosity of 0.6 centistoke and turbulent flow

LS-R00-17
IPD-2004/LS-19

Viscosity Correction

- Chart ΔP is based on a liquid with a kinematic viscosity of 0.6 centistoke
- For materials with different viscosities, multiply chart ΔP correction factor $(\nu/0.6)^{0.2}$

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

- ν Kinematic viscosity in centistoke
- μ Absolute viscosity in centipose
- ρ Density, grams/cc @ 4°C
- $\nu = \frac{\mu}{\rho}$

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Viscosity Correction (continued)

■ **Example:**

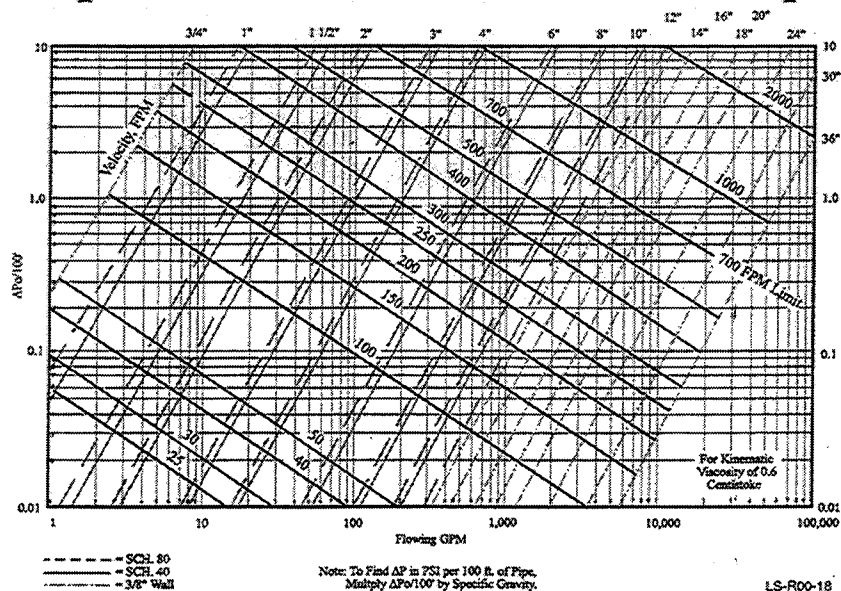
– For $\nu = 20$ Centistokes

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

(Correction is for turbulent flow, Reynolds Number > 2000)

IPD-2004/LS-21

Liquid Flow thru Commercial Steel Pipe



Liquid Flow Line Sizing/ ΔP Calculation

- 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 = 0.135
- 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?

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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:

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

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Pressure Drop for Vapor Flows (continued)

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)

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Pressure Drop for Vapor Flows (continued)

■ Simplifications

- Assume $L = 100$ ft
- Define $\Delta P_{0(100)} = 100 \frac{\Delta P}{V}$
- By substitution and re-arrangement we obtain:

$$\Delta P_{0(100)} = \frac{336 f}{d^5} \left(\frac{W}{1000} \right)^2$$

IPD-2004/LS-26

Pressure Drop for Vapor Flows (continued)

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

Thus:

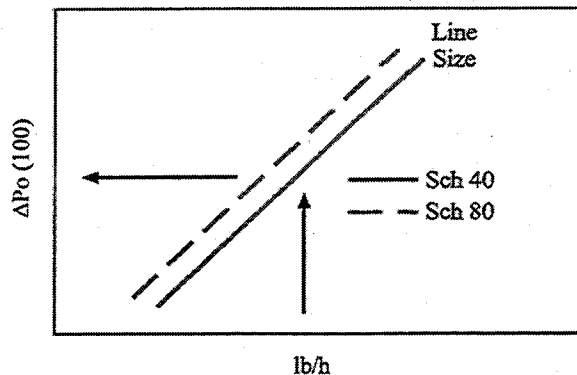
$$\frac{336 f}{d^5} = \text{Constant, } K$$

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

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

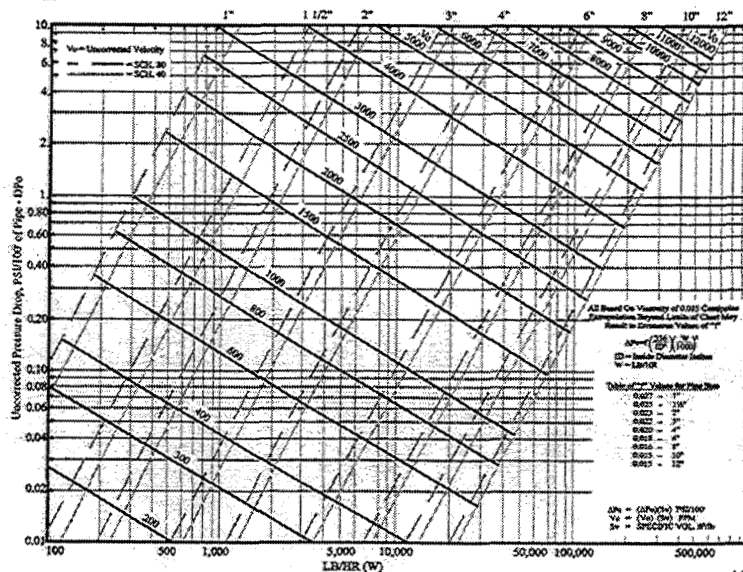
IPD-2004/LS-27

UOP Pressure Drop Chart for Vapor Flow



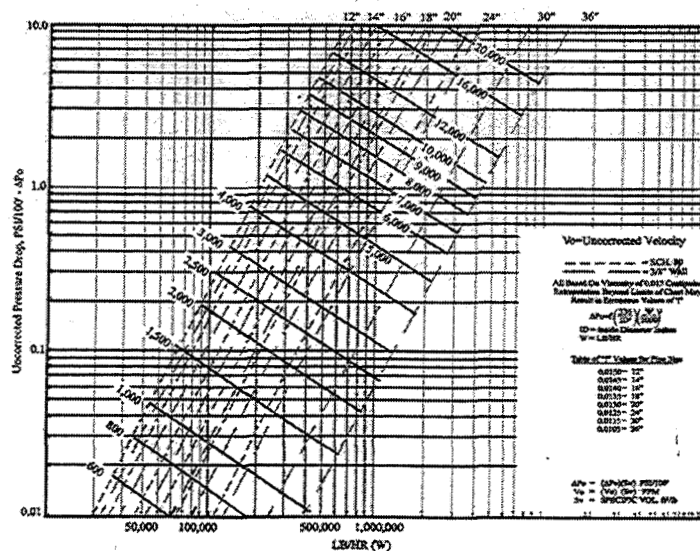
LS-P00-19
IPD-2004/LS-28

Vapor Flow thru Commercial Steel Pipe



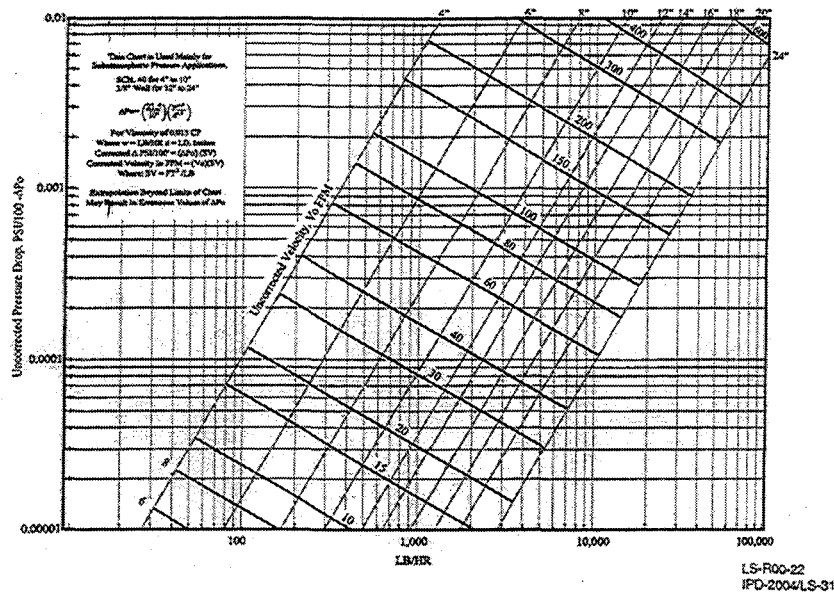
LS-R00-20
IPD-2004/LS-29

Vapor Flow thru Commercial Steel Pipe (See Other Chart for Smaller Sizes)



LS-R00-21
IPD-2004/LS-30

Vapor Flow thru Commercial Steel Pipe



Vapor Flow Line Sizing/ ΔP Calculation

- 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 would result in 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?
 - e. What is the velocity in the line?

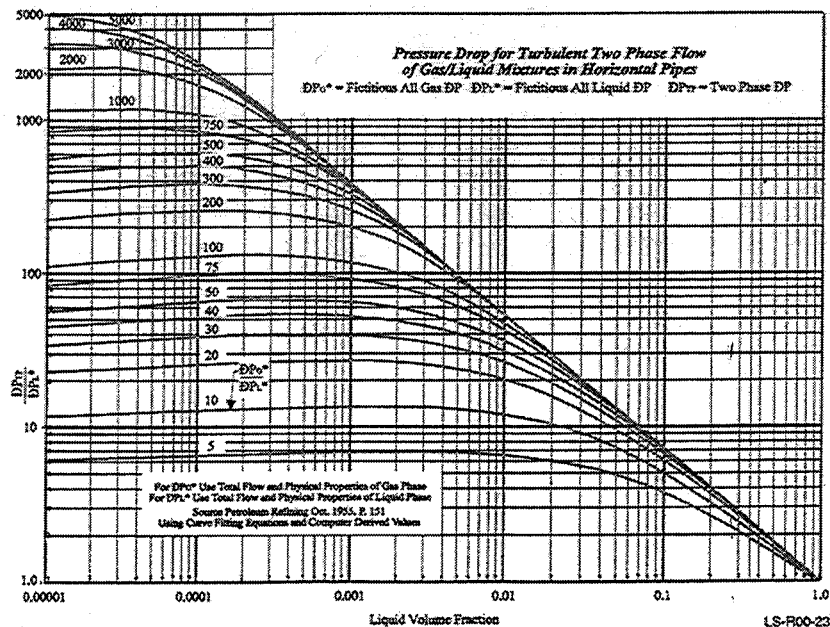
Two-Phase Flow Pressure Drop

■ Correlating Factors

- Liquid volume fraction
- Ratio of pseudo 100% gas ΔP and pseudo 100% liquid ΔP
- Ratio of ΔP two phase and pseudo 100% liquid ΔP

— find liq. volume fraction first to get the idea of correction factor.

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Two-Phase Flow Pressure Drop ***(continued)***

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

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Two-Phase Flow Pressure Drop ***(continued)***

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

$$\text{Liquid Volume Fraction} = \frac{V_L}{V_L + V_G}$$

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Two-Phase Flow Pressure Drop ***(continued)***

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}

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

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Two-Phase Flow Pressure Drop ***(continued)***

Note

If the line size is to be determined, calculate ΔP^*_G and ΔP 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 rate.

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Two-Phase Flow Pressure Drop Calculation (continued)

■ Step 1

- Calculate the mass flow rates

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

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

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

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

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Two-Phase Flow Pressure Drop Calculation (continued)

■ Step 2

- Calculate ΔP^*_G assuming all of the material is vapor and use the vapor fraction properties
- Use ΔP chart to get $\Delta P_{0/100}$
- $\Delta P_{0/100} = 0.47$ (for 12" Sch 40)
- $\Delta P_{/100} = 0.47 \times 0.303 = 0.142 \text{ psi/100'}$

IPD-2004/LS-42

Two-Phase Flow Pressure Drop Calculation (continued)

■ Step 3

- ▮ Calculate ΔP^*_L
- Calculate the liquid volumetric flow assuming all of the material is liquid and has the properties of the liquid fraction

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

- Use the DP chart for liquids to get $\Delta P_{0/100}$
 $\Delta P_{0/100} = 0.034 \text{ psi for 12 inch Sch 40 pipe}$
 $\Delta P_{/100} = 0.034 \times 0.494 = 0.017 \text{ psi/100'}$

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Two-Phase Flow Pressure Drop Calculation (continued)

■ Step 4

- Calculate the ratio of the fictitious gas to liquid pressure drop

$$\Delta P^*_G / \Delta P^*_L = 0.142 / 0.017 = 8.4$$

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Two-Phase Flow Pressure Drop Calculation (continued)

■ Step 5

- Calculate the liquid volume fraction

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

- Calculate the liquid volume

$$V_L = \frac{443 \text{ gpm} \times 60 \text{ min/h}}{7.48 \text{ g/ft}^3}$$

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

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Two-Phase Flow Pressure Drop Calculation (continued)

■ Step 5 (continued)

- Calculate the vapor volume

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

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

- Liquid volume fraction = $\frac{3552.5}{3552.5 + 14241}$

Say 0.2

IPD-2004/LS-45

Two-Phase Flow Pressure Drop Calculation (continued)

- **Step 6**
 - From two-phase flow chart
 - $f = 3.0$
 - $f = \Delta P_{TP}^* / \Delta P_L^*$
 - $\Delta P_{TP}^* = 3.0 \times 0.017 = 0.05 \text{ psi/100'}$

IPD-2004/LS-47

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 ft ³ /lb

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Flow Patterns Check for Slug Flow in 12" Schedule 40 Pipe

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

$$v_c = \frac{60}{\sqrt{\rho_{mp}}} \text{ in ft/s}$$

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Flow Patterns

$$\rho_{mp} = \frac{156,508}{17,794} = 8.80 \text{ lbs/cu.ft.}$$

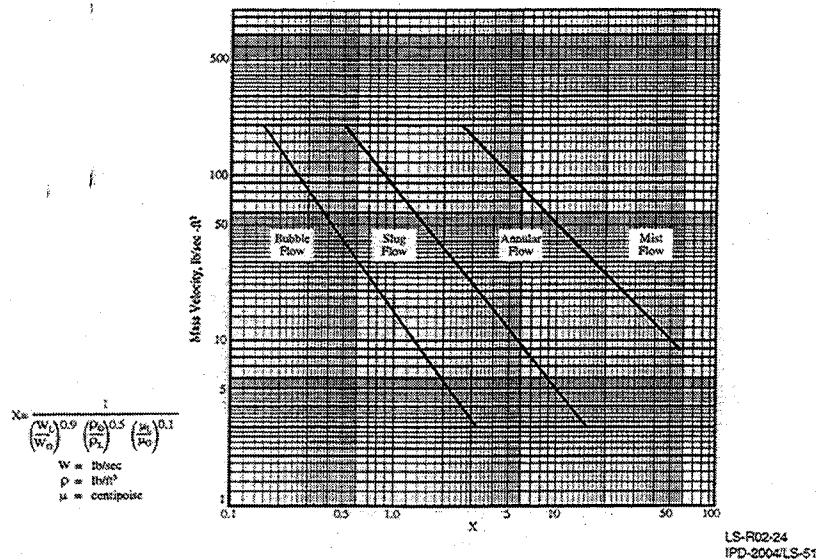
$$v_c = \frac{60}{\sqrt{8.80}} = 20.2 \text{ ft/s}$$

$$v_{12"} = \frac{17,794}{3600 \times 0.7773} = 6.36 < 20.2 \text{ ft/s}$$

Check further by use of chart

IPD-2004/LS-50

Approximate Two-Phase Flow Patterns (Vertical Upflow)



Flow Patterns

■ Calculate Chart Coordinates

$$\text{Mass velocity} = \frac{156,508}{3600 \times 0.7773} = 55.9 \text{ lb/s-ft}^2$$

$$\frac{1}{\left(\frac{W_L}{W_G}\right)^{0.9} \left(\frac{\rho_G}{\rho_L}\right)^{0.5} \left(\frac{\mu_L}{\mu_G}\right)^{0.1}} = \frac{1}{2.14 \times 0.33 \times 1.35} = 1.04$$

Flow Patterns (continued)

$$(W_L/W_G)^{0.9} = (109,509/47,000)^{0.9} = 2.14$$

$$(\rho_G/\rho_L)^{0.5} = (3.30/30.8)^{0.5} = 0.33$$

$$(\mu_L/\mu_G)^{0.1} = (0.6 \times 0.494/0.015)^{0.1} = 1.35$$

Slug flow is indicated

IPD-2004/LS-53

Line Sizing Criteria

- Tables give pressure drop and velocity for various flows and pipe sizes - BUT -
- The engineer needs to be familiar with the reasonable and desirable piping design pressure drop and velocity for a given service - HENCE -
- Line sizing criteria which are based upon years of experience and studies, but should always to treated as a guide

IPD-2004/LS-54

Line Sizing Criteria ***(continued)***

- **Assumptions for Economic Pipe Sizing**
 - Flow in pipe is turbulent
 - Motive power is supplied by pump or compressor
 - Pump NPSH requirement must be met
 - Slurry lines to have velocity high enough to avoid settling, but low enough to avoid excessive erosion

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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

IPD-2004/LS-56

***Line Sizing Criteria
Index of Type Numbers
(continued)***

<u>Type</u>	<u>Description</u>
7.	Column Hot Vapor Bypass
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

IPD-2004/LS-57

***Line Sizing Criteria
Index of Type Numbers
(continued)***

<u>Type</u>	<u>Description</u>
13.	Vacuum Unit Heater Transfer
16.	Liquid at its Bubble Point to a Control Valve or Steam Trap
17.	Steam Condensate After a Control Valve or Steam Trap
18.	Makeup Gas to a Hydrogen Consuming Process
23.	Cooling Water
24.	Static Electricity Consideration

IPD-2004/LS-58

Type 1 Gravity Flow

- **Criteria:** $\Delta P/100$ (psi) = 0.15 max.
- **Remarks:** Can be higher if line is mostly vertical

IPD-2004/LS-59

Type 2 Pump Suction

- **Liquid at bubble point or less than 50°F below it**
 - **Criteria:** $\Delta P/100$ (psi) = 0.15 max.
 - **If FCC main column bottom or similar solids-carrying stream, velocity should be 180 feet per minute minimum (fpm) to avoid settling of solids**
 - **For lines 3" and smaller, 180 fpm will result in $\Delta P/100$ in excess of 0.20 psi which should be accommodated in determining NPSH availability**

IPD-2004/LS-60

Type 2 Pump Suction (continued)

- **Liquid 50°F or more below bubble point or having vapor pressure 25 psi below system pressure**
 - **Criteria: $\Delta P/100$ (psi) = 0.35 max.**

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Type 3 Pump Discharge

- **Single Line Pump Discharge**
 - **Criteria: $\Delta P/100$ (psi) = 1.5 max.
Velocity (fpm) = 700 max.**
- **Applies To Carbon Steel Piping**
 - **“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.**

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Type 3 Pump Discharge (continued)

- Applies to Carbon Steel Piping (cont.)
 - "High pressure level" results in increased pipe thicknesses and flange ratings. Pump discharge lines are usually sized close to the upper limit.
 - 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.

IPD-2004/LS-63

Type 3 Pump Discharge (continued)

- For laminar flow, LS-R00-18 is not optimum.
Laminar flow exists for Reynolds Numbers below 2000

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

Where Q = flowing gpm
d = i.d. (inches)
cstks = flowing viscosity in centistokes

IPD-2004/LS-64

Type 3 Pump Discharge (continued)

■ Downstream of a pump discharge with different conditions than at the pump

- Criteria: $\Delta P/100$ (psi) = 1.5 max.
- If 100% liquid, velocity (fpm) = 700 max.
- If 100% vapor, velocity (fpm) = $6000/\sqrt{\rho_v}$
where ρ_v = flowing density, lb/ft³

IPD-2004/LS-65

Type 3 Pump Discharge (continued)

- 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

IPD-2004/LS-66

Type 3
Pump Discharge
(continued)

- Avoid slug flow in vertical upward two-phase flow. If it is impossible to satisfy this criterion (which sets a maximum permissible diameter) and those given previously, then
- Take (and allow for) more pressure drop
 - Specify more vapor

IPD-2004/LS-67

Type 4
Liquid to Non-Pumped Reboiler

- Criteria: $\Delta P/100 \text{ (psi)} = 0.15 \text{ to } 0.20$

IPD-2004/LS-68

Type 5 *Reboiler Return to Column*

■ Criteria:

- Kettle type: $\Delta P/100 \text{ (psi)} = 0.15 \text{ max.}$
- Thermosyphon or once-through type, non-kettle, non-pumped. For pumped types, see Type 3
 - $\Delta P/100 \text{ (psi)} = 0.10 - 0.20 \text{ max.}$
 - Velocity $\leq 5.0 \sqrt{\frac{\rho_L - \rho_V}{\rho_V}}$

Remarks: Maximum permissible size = 30" nominal

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Type 5 *Reboiler Return to Column*

- ### ■ For two-phase flow, the line should be checked for slug flow

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Type 6 Column Overhead Vapor

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

<i>Operating Pressure, psia</i>	<i>$\Delta P/100$</i>
≥ 300	1.25
150 to 300	0.75
14.7 to 150	0.3
3.75 to 14.7	0.15
≤ 3.75	4% of absolute pressure

IPD-2004/LS-71

Type 6 Column Overhead Vapor (continued)

- Criteria: limiting equations

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

$$- \text{Velocity (fpm)} = 6000 / \sqrt{\rho_v} \text{ Max.}$$

p = receiver pressure, psia

d = i.d., inches

ρ_v = overhead vapor flowing density, lb/ft³

IPD-2004/LS-72

Type 6

Column Overhead Vapor

(continued)

- FCC main column overhead vapor
 - Criteria: $\Delta P/100$ (psi) = 0.10 max.
- Crude vacuum column overhead
 - ΔP over its entire length is not more than 7% of flash zone absolute pressure, limited to flash zone pressures of 35mm and greater

IPD-2004/LS-73

Type 7

Column Hot Vapor Bypass

- Criteria: $\Delta P/100$ (psi) = 0.5 max.
 - Remarks: For amount of vapors through hot vapor bypass, use the following formula:

$$W = [(Mol/h)_1 + 0.06 (Mol/h)_2][M_2]$$

- W = bypass vapor, lb/h
(Mol/h)₁ = normal mols/h of net gas
(Mol/h)₂ = normal mols/h of gross column overhead vapors
M₂ = mol weight of gross overhead vapors

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Type 8 *Column Overhead Condenser Rundown*

■ **Totally condensing, single phase:**

– **Criteria: Limiting equations**

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

$$\text{Velocity (fpm)} = 200 \text{ max.}$$

p = receiver pressure, psia

d = i.d., inches

IPD-2004/LS-75

Type 8 *Column Overhead Condenser Rundown* *(continued)*

- **Reduce to 50% where minimum pressure at column is critical**

IPD-2004/LS-75

Type 8
Column Overhead Condenser Rundown
(continued)

- Totally condensing, with traces of a second liquid present and a piping arrangement that would permit pockets of the second liquid phase to accumulate
- Velocity ≥ 350 fpm

IPD-2004/LS-77

Type 8
Column Overhead Condenser Rundown
(continued)

- Partially condensing, vapor and liquid present

– 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 at column is critical

p = receiver pressure, psia

d = i.d., inches

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Type 8

Column Overhead Condenser Rundown

(continued)

- Check for slug flow on vertical upflow lines
- Special attention should be given to the rundown line if it is part of a pressure relief route

IPD-2004/LS-79

Type 9

Compressor Suction

- Reciprocating Compressor
 - 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

IPD-2004/LS-80

Type 9 *Compressor Suction* (continued)

■ Centrifugal Compressor

- 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

IPD-2004/LS-81

Type 10 *Compressor Discharge*

■ Reciprocating Compressor

- 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

IPD-2004/LS-82

Type 10 Compressor Discharge (continued)

■ 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

IPD-2004/LS-63

Type 11 High Available Pressure Drop ≥ 25 psi

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

■ 100% liquid

$\Delta P/100$ (psi) = 2.0 max.

Velocity (fpm) = 700 max.

IPD-2004/LS-34

Type 11
High Available Pressure Drop ≥ 25 psi
(continued)

- 100% vapor
 $\Delta P/100$ (psi) = 1.0 max.
Velocity (fpm) = $6000/\sqrt{\rho_v}$ max.
- Vapor plus liquid
 $\Delta P/100$ (psi) = 2.0 max.

IPD-2004/LS-85

Type 11
High Available Pressure Drop ≥ 25 psi
(continued)

Remarks

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

IPD-2004/LS-86

Type 12 Feed to a Column

- If line is a pump discharge, treat as Type 3, except limit the 100% liquid case to a velocity of 700 fpm
- If line has high available pressure drop, treat as Type 11, except limit the 100% liquid case to a maximum velocity of 700 fpm

IPD-2004/LS-87

Type 12 Feed to a Column (continued)

- If line is other as indicated above

$$- \Delta P/100 \text{ (psi)} = 3.0 \left[\frac{100}{114 + 10d} \right] \text{max.}$$

- If flow is 100% liquid
 - Velocity (fpm) = 700 max.

IPD-2004/LS-88

Type 12 Feed to a Column (continued)

- If flow is 100% vapor:
 - Velocity (fpm) = $6000/\sqrt{\rho_v}$ max.
- If flow is two-phase: Apply the criteria for slug flow

IPD-2004/LS-89

Type 13 Vacuum Unit Heater Transfer

- 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, use 98% of the actual inside diameter to account for presence of liquid
- Observe the sonic velocity limitation; use 70% V_s for design

IPD-2004/LS-90

Type 16
Liquid at its Bubble Point
to a Control Valve or Steam Trap

- Criteria: $\Delta P/100$ (psi) = 0.5 to 1.5 max.
Velocity (fpm) = 700 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.

IPD-2004/LS-61

Type 17
Steam Condensate
After a Control Valve or Steam Trap

- With control valve located in steam line
 - $\Delta P = 1/2 (P_{\text{sat.stm at exchanger temp}} - (P_{\text{cond. at battery limit}}))$
- With control valve in condensate line
 - $\Delta P/100$ (psi) = 7.5 max.
- Limit $\Delta P/100$ to 67% of above to allow for roughing of pipe wall

IPD-2004/LS-92

Type 18 Make-up Gas to a Hydrogen Consuming Process

■ Criteria

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

$$\text{Velocity (fpm)} = 6000/\sqrt{\rho v} \text{ max.}$$

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

IPD-2004/LS-93

Type 23 Cooling Water

■ Criteria

0-700 gpm:	Max. $\Delta P/100$	= 1.3 psi
701-2800 gpm:	Max. Velocity	= 500 fpm
2801-7000 gpm:	Max. Velocity	= 600 fpm
Over 7001 gpm:	Max. Velocity	= 700 fpm

- If film type corrosion protection is used, maximum velocity should be reduced to 350-500 fpm.

IPD-2004/LS-94

Type 24

Static Electricity Consideration

- **Criteria:** Velocity (fpm) = 400 max.
- **Remarks:** For hydrocarbons whose vapor pressure is such as to form an explosive mixture with air, such as kerosene and jet fuel to storage tanks.

IPD-2004/LS-95

Hydraulics

- **Objectives**
- **Procedure**
- **Equipment Elevations**
- **Typical Equipment Pressure Drops**
- **Operating at Non-Design Conditions**
- **Examples**
 - NPSH for a pump
 - Pumped circuit

IPD-2004/LS-96

Objectives

- Establish Logical Piping/Equipment Systems
- Determine Performance Requirements of Pumps, Compressors, Control Valves
- Set Location for Relief Valves
- Establish Design Pressure for Equipment

IPD-2004/LS-97

Procedure

- Establish Process Conditions
- Lay Out Hydraulic System
- Size Lines and Determine Pressure Drop
- Set Equipment Elevations
- Select Fixed Pressure Point

IPD-2004/LS-98

Procedure ***(continued)***

- **Select Equipment Pressure Drops**
- **Determine Variable Pressure Drop/Increase**
 - Pressure drop for control valves
 - Differential head for pumps and compressors
- **Tabulate Pressure Values in Circuit**
- **Determine Equipment Maximum Operating Pressure**
- **Select Relief Valve Location and Set Pressure**
- **Establish Equipment Design Pressure**

IPD-2004/LS-99

Elements of a Hydraulic System

- **Fixed Pressure Point**
- **Static Pressure Requirements**
- **Variable Pressure Requirements**
- **Pressure Source or Generator**
- **Pressure Controller**

IPD-2004/LS-100

Column Elevation Set By

- Bottoms Pump Suction Head Requirement
- Thermosyphon Reboiler Head Requirement
- Mechanical Requirement

IPD-2004/LS-101

Receiver Elevation Set By

- Overhead Pump Head Requirement
- Mechanical Requirements
 - Water boot

IPD-2004/LS-102

Net Positive Suction Head *NPSH*

- Pressure requirement in excess of the fluid vapor pressure at the suction flange of a pump
- NPSH(R) is a characteristic of the pump
- NPSH(A) is set by the design engineer
- Expressed in feet of fluid being pumped

IPD-2004/LS-103

NPSH

- Contractor's Calculation
- Engineer's Calculation

IPD-2004/LS-104

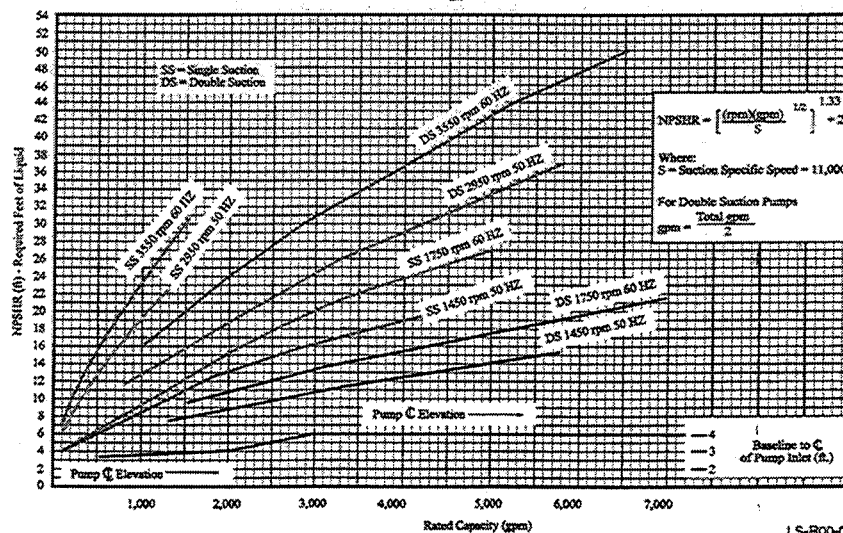
NPSH

■ Engineer's Calculation to Set a Vessel Evaluation

- Estimate minimum NPSH required
- Estimate pump centerline above base line
- Estimate suction piping friction loss
- Investigate system absolute pressure
- Determine minimum controlled liquid level in the vessel
- Evaluate need for contingency

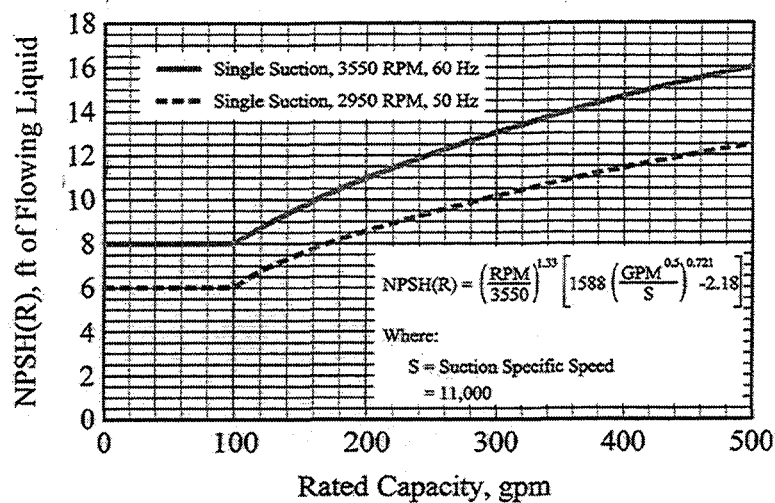
IPD-2004/LS-105

Single Stage Centrifugal Pumps Minimum Required NPSH



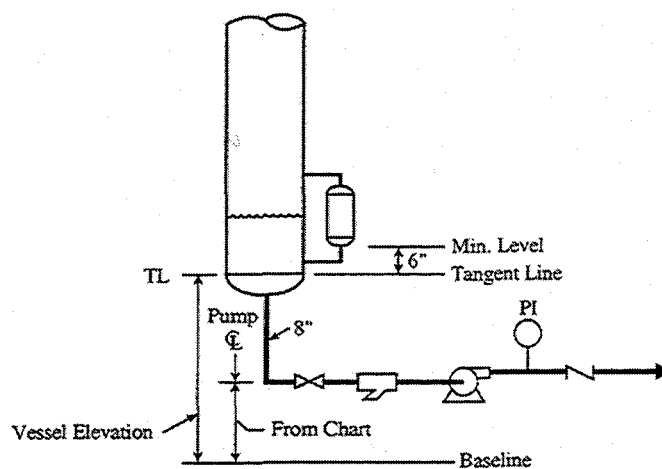
LS-R00-01
IPD-2004/LS-105

NPSH(R) for Single Centrifugal Pumps



LS-R00-02
IPD-2004/LS-107

Typical Column Bottoms Pump



LS-R00-03
IPD-2004/LS-108

NPSH

- Design a system that provides sufficient NPSH for the following column bottoms pump

Single Stage Pump

Capacity	500 gpm
Specific Gravity	0.65
Line Frequency	50 Hz
Pump RPM	1450 (Half Speed)
Assume Vapor Pressure = System Pressure	

IPD-2004/LS-109

NPSH Example Calculation

1. NPSH(R) from chart or manufacturer 6.2 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 valve - one line size smaller)
Equivalent length = 13 D
 $\Delta P = (0.11 \text{ psi})(8''/6'')^5(13)(6''/12'')(1/100)(2.31/0.65)$ 0.1 ft
Suction strainer
Equivalent length = 300 ft
 $(0.46 \text{ psi})(300/100)(2.31/0.65)$ 4.9 ft

IPD-2004/LS-110

NPSH Example Calculation (continued)

4. System Pressure - Vapor 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	

IPD-2004/LS-111

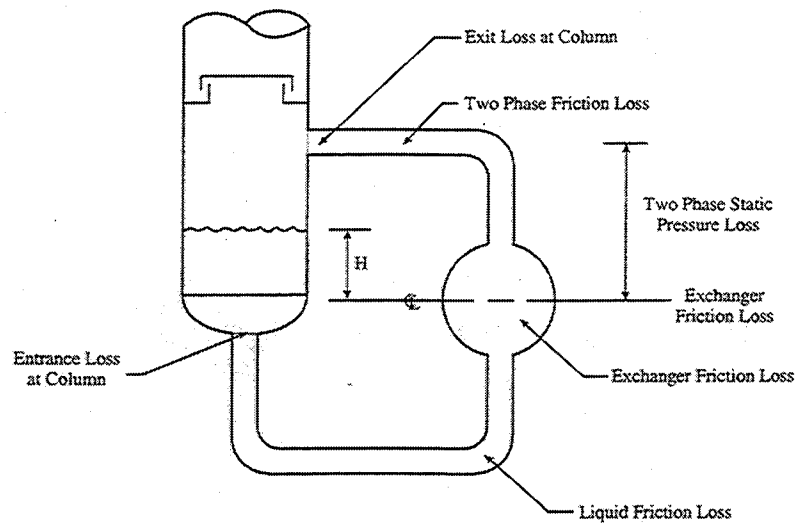
NPSH Example Problem Summary

1. NPSH(R)	6.2 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	2.0 ft
TOTAL	<u>17.2 ft</u>

(From Baseline to Bottom of Vessel)

IPD-2004/LS-112

Thermosyphon Reboiler Hydraulics



LS-R00-05
IPD-2004/LS-113

Thermosyphon Reboiler Systems *Trial Line Size for Maximum 30% Vaporization*

- Inlet Piping
 - $12 < d^2/Q < 15$
- Outlet Piping
 - $24 < d^2/Q < 30$

IPD-2004/LS-114

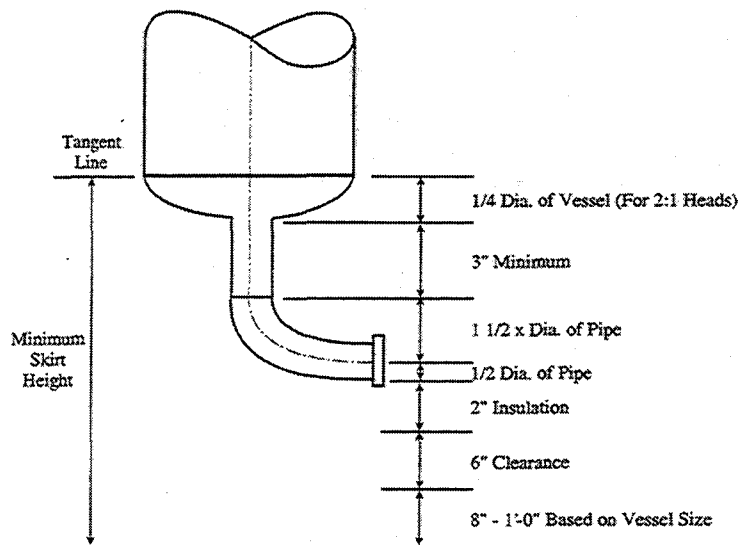
Thermosyphon Reboiler Systems

Determine Required Driving Head, H

- Entrance Loss = $\frac{0.5 V^2}{2 g} \times \frac{S.G.}{2.31}$
- Line Loss to Exchanger
- Line Loss to Column
- Exchanger Loss
- Exit Loss = $\frac{v^2}{2 g} \times \frac{S.G.}{2.31}$
- Static Loss to Column
- Contingency

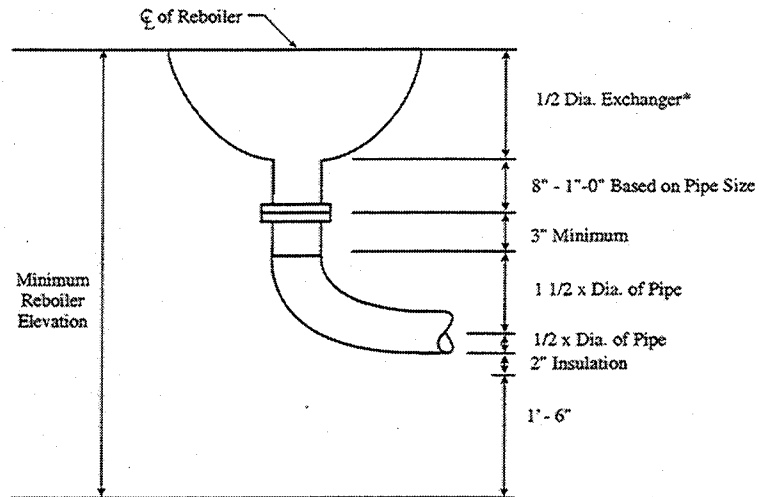
IPD-2004/LS-115

Minimum Column Elevation



LS-R00-09
IPD-2004/LS-116

Minimum Reboiler Elevation



* For Kettle Type This Dimension Should Be from Top of Wier to Bottom of Reboiler.

LS-R00-10
IPD-2004/LS-117

Piping Pressure Drop

- ΔP charts give pressure drop for 100 feet of piping
- But piping circuits consists of straight piping and fittings, like
 - Elbows
 - Tees
 - Valve
- Solution is to convert fitting ΔP to equivalent straight pipe length

IPD-2004/LS-118

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	Half open	450
	Y-Pattern ¹	(No obstruction in, bevel, or plug type seat)	Fully open	175
		With stem 45 degrees from run of pipe line	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
	Wedge, Disc, Double Disc, or Plug Disc		Fully open	15
			Three-quarters open	35
Gate Valves			One-half open	180
			One-quarter open	900
	Pip Stock		Fully open	17
			Three-quarters open	50
Concentric Pipe Line (Gate, Ball, and Plug Valves)				100
Check Valves	Conventional Swing Clearway (wing)		0.5" ... Fully open	175
	Globe Lift or Stop; Stem Perpendicular to Run or Y-Pattern		0.5" ... Fully open	50
	Angle Lift or Stop		2.0" ... Fully open	Same as Globe
	In-Line Ball	2.5 vertical and 0.25 horizontal ... Fully open	2.0" ... Fully open	150
Foot Valves with Strainer			0.3" ... Fully open	420
Remotely Valves (closed and larger)			0.4" ... Fully open	75
Cocks	Straight-Through	Rectangular plug port area to 100% of pipe area	Fully open	40
			Half open	18
	Three-Way	Rectangular plug port area equal to 50% of pipe area (fully open)	Flow straight through	44
			Flow through branch	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
	Same: Corner Elbow			57
	Standard Tee	With flow through run		20
		With flow through branch		60
Close Pattern Return Bend			30	
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-20

¹ Exact equivalent length is equal to the length between flange faces or welding ends.

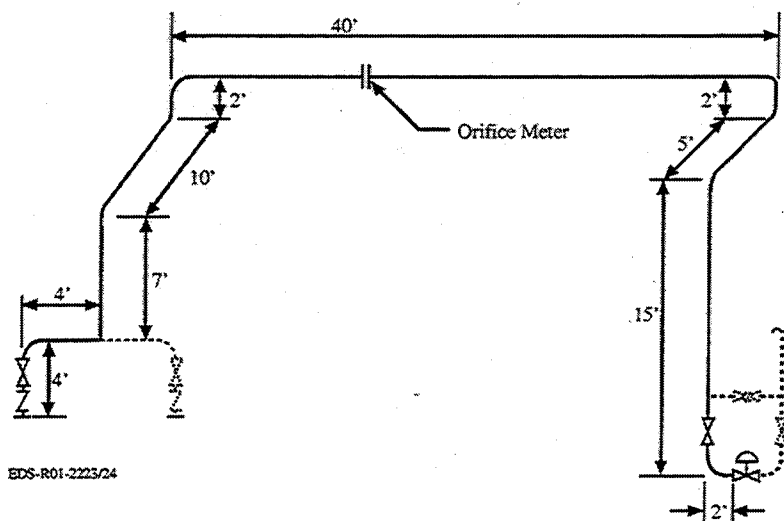
² Minimum calculated pressure drop (psi) across valve to provide sufficient flow to lift disc fully.

Cross Co. "Flow of Fluids through Valves, Fittings and Pipes,"
Technical Paper 410

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

LS-R00-26
IPD-2004/LS-119

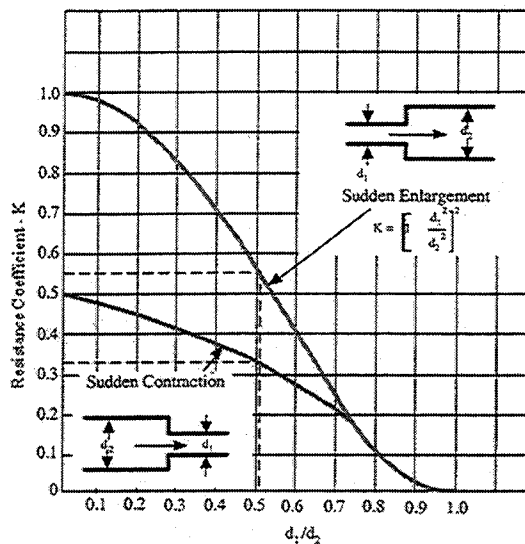
Typical Calculation of Piping Equivalent Length - 8" Pump Discharge Line



EDS-R01-2223/24

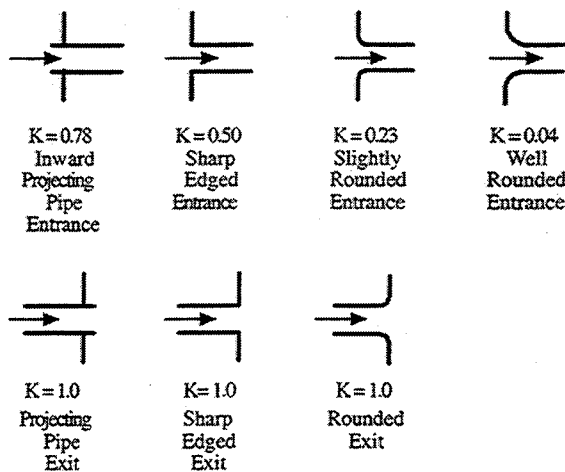
IPD-2004/LS-120

Resistance Due to Sudden Enlargements and Contractions



LS-R00-29
IPD-2004/LS-121

Resistance Due to Pipe Entrance and Exit



LS-R00-30
IPD-2004/LS-122

Typical Heater Pressure Drops

■ Crude Heaters	125 psi
■ Vacuum Heaters	75 psi
■ Hydrotreating Heaters	20-60 psi
■ Platforming (per heater)	3-20 psi
■ Thermal Crackers	200 psi

← depends on material
higher material cost,
smaller size → higher ΔP

IPO-2004/LS-123

Typical Heater Pressure Drops ***(continued)***

■ Coker Heaters	300 psi
■ Visbreakers	250 psi
■ Hot Oil Heaters	20-40 psi
■ Fired Reboilers	50 psi
■ Fractionator Charge	40 psi

**Preliminary pressure drops - Must be
confirmed or corrected based on final
heater design**

IPO-2004/LS-124

Typical Heat Exchanger Pressure Drops

- For normal, fluid exchangers, allow at least 5 psi pressure drop on each side of each shell

IPD-2004/LS-125

Typical Heat Exchanger Pressure Drops (continued)

■ Exceptions

- Cooling Water Side 10 psi
- Combined Feed Exchangers 2-5 psi/side
- Condensers 1-5 psi
- Reboilers - Kettle and
Thermosyphon 0.2-0.5 psi
- Reboilers - Forced
Circulation 5-10 psi
- Vacuum Condensers 10-25 mm mercury

IPD-2004/LS-125

Control Valve Pressure Drops

- **Control valves in pump discharge circuits - allow greatest of:**
 - 25 psi
 - 50% of system friction pressure drop
 - 7-10% of pump differential

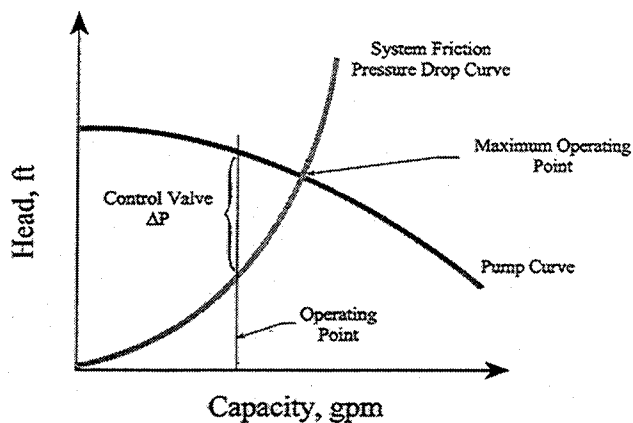
IPD-2004/LS-127

Control Valve Pressure Drops (continued)

- **For other control valves, allow pressure drop in accordance with available pressure**
- **Control valve rangeability consideration is from turndown to 110% capacity determines normal ΔP**
- **Control valve compensates for changes in operations and system aging**

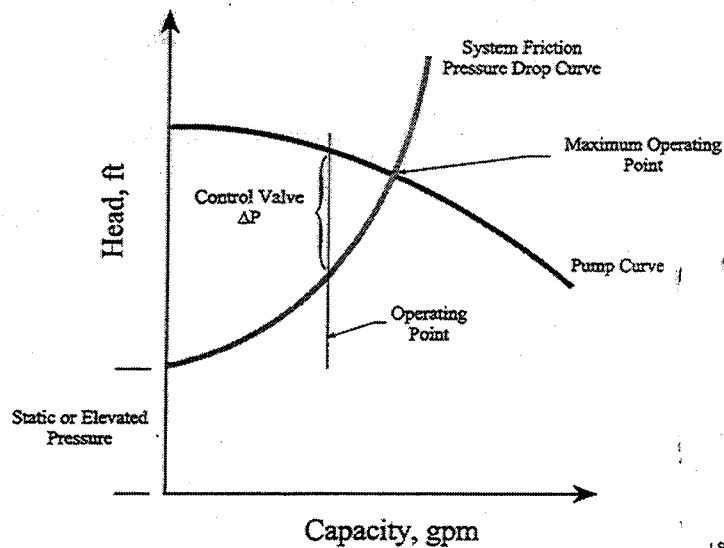
IPD-2004/LS-128

System Hydraulic Curves Atmospheric Fixed Point Pressure



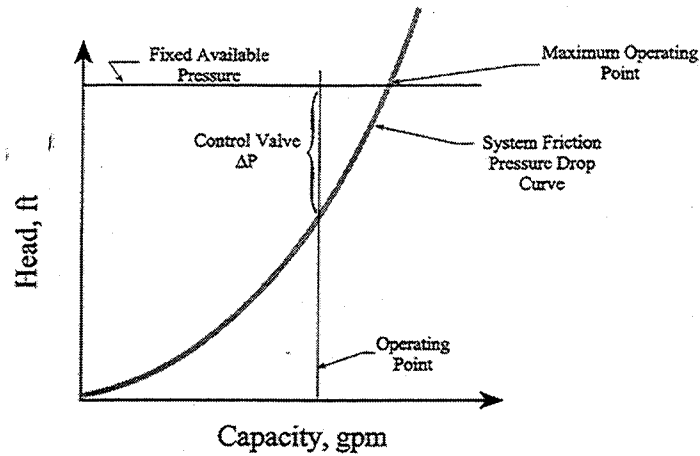
LS-R00-06
IPD-2004/LS-129

System Hydraulic Curves Elevated Fixed Point Pressure



LS-R00-07
IPD-2004/LS-130

System Hydraulic Curves Fixed Available Pressure Source



LS-R00-08
IPD-2004/LS-131

Control Valve ΔP Selection

Situations

Fixed	0	0	250	500
Frictional	25	100	100	100
Total	25	100	350	600

ΔP Options

25 Min.	25	25	25	25
50% Friction	12.5	50	50	50
7-10% Diff	2.5	10	35	60

Pump Discharge	50	150	400	660
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IPD-2004/LS-132

Hydraulics of a Fractionating Column

■ Goal

- Determine normal operating pressure profile
- Determine relief valve settings and location
- Determine equipment design pressure

IPD-2004/LS-133

Hydraulics of a Fractionating Column *(continued)*

■ Procedure

- Establish process flow diagram for fractionator
- Establish fixed pressure locations
- Establish line sizes and lengths
- Establish pressure drops for each piping segment
- Establish fixed pressure drops (static head)
- Establish equipment and control valve pressure drop
- Establish the pump differential

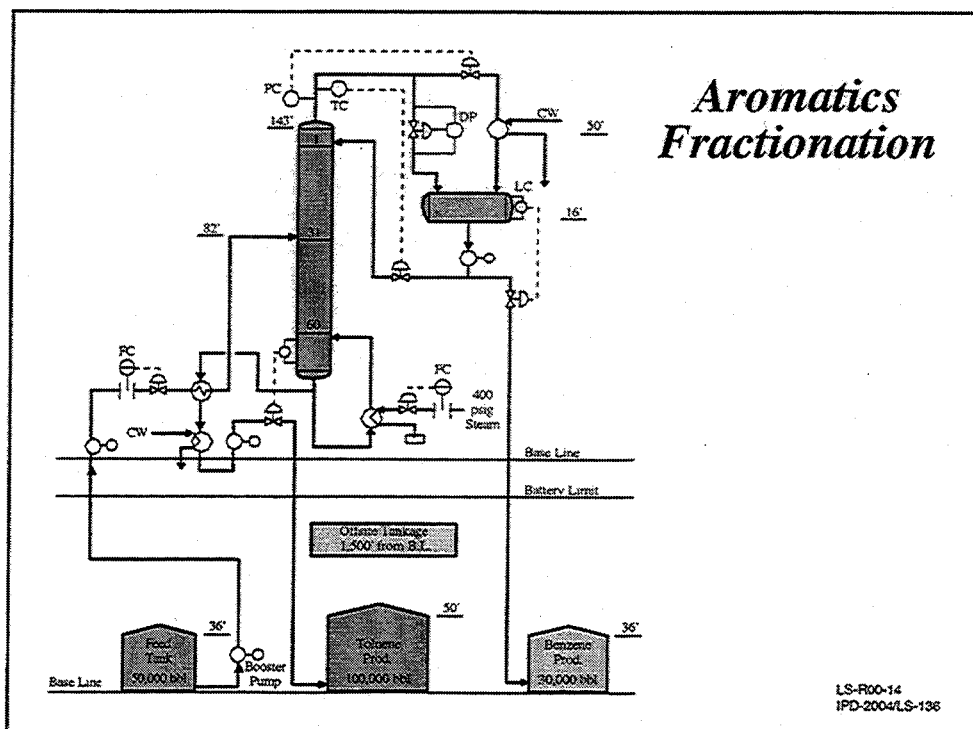
IPD-2004/LS-134

Hydraulics of a Fractionating Column (continued)

■ Procedure

- Recalculate control valve pressure drop, system pressure drop, and pump differential for alternate cases
- Establish relief valve setting and location
- Establish equipment pressure at relief valve setting
- Set Design pressure of equipment
- Check for over-capacity requirements
- Check for alternate operations

IPD-2004/LS-135



Heat and Weight Balances

25 East Algonquin Road Des Plaines, Illinois 60017 U.S.A.
Engineering Department

Aromatics Fractionation
Example for Line Sizing Only

Page No. _____
Date _____
Prepared _____
By _____

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Stream	Flow (kg/hr)	K	W ₁	Flowing Sp. Gr.	γ	Dist. /Dist. (kg Azeo)	Reflux Ratio (kg Azeo/kg Feed)	Flowing CPM (°C)	Heat per kg	ΔT ₁	Dist. /B	γ ₁ Azeo
Aromatics from Storage	(7.28)	10.0	89	0.86	100	-	5000	148	718	63700	18	1.14
Feed - Bottoms Exchanger Duty												1.72
Feed to Column	(7.28)	10.0	89	0.82	160	7	-	155	718	63700	45	2.86
Overhead Vapors to Condenser	-		78	(0.22)	195	5	-	(87)	883	68900	225	15.5
Condenser Duty												14.3
Material to Receiver	(7.37)	9.75	78	0.86	100	0	5340	160	883	68900	17	1.2
Reflux	(7.37)	9.75	78	0.86	100	0	4340	130	718	56000	17	1.0
Benzene Product	(7.37)	9.75	78	0.86	100	0	1000	30	165	12900	17	0.2
Liquid to Reboiler	(7.26)		92	0.76	265	10	26,600	890	3670	338000	97	32.80
Reboiler Duty												16.56
Material from Reboiler	(7.26)		92	-	265	10	-	-	3670	338000	146	49.36
Vapor			92	(0.30)	265	10	(11.15)	(105)	1223	119000	243	27.46
Liquid	(7.28)		92	0.76	265	10	17700	592	2447	225000	97	21.90
Bottoms to Exchanger	(7.28)	10.1	92	0.76	265	-	4000	134	553	50800	97	4.92
Exchanger Duty	(7.28)											1.72
Bottoms to Cooler	(7.28)	10.1	92	0.79	200	-	4000	129	553	50800	63	3.20
Cooler Duty	(7.28)	-										2.30
Bottoms to Storage	(7.28)	10.1	92	0.85	100	-	4000	119	553	50800	18	0.90

LS-R00-36
IPD-2004/LS-137

Heat and Weight Balances

25 East Algonquin Road, Des Plaines, Illinois 60017 U.S.A.
Engineering Department

Aromatics Fractionation
Example for Line Sizing Only

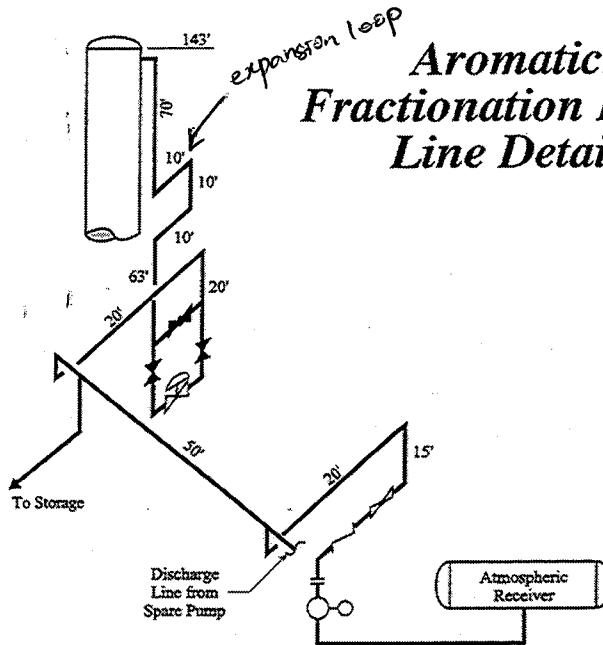
Page No. 2
Date _____
Project _____
By _____

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LS-R00-37
IPD-2004/LS-138

Aromatics Fractionation Reflux Line Details



LS-R00-15
IPD-2004/LS-139

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Line No. (CV No.)	Size, in	Schedule	API 100 ft psi	Ex EQ U + 100	Description	ΔP psi	Inlet Press psig	ΔP psi	Inlet Press psig	ΔP psi	Inlet Press psig	Design Press psig	REV	DATE	BY	APP'D	DATE	BY	APP'D
1																			
2																			
3																			
4																			
5																			
6																			
7																			
8																			
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LS-R00-34
IPD-2004/LS-140

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Line No. (CV No.)	Size, in	Schedule	ΔP/100 ft psi	Ex. 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 Head 143' ($\frac{2.5}{151}$)	53.24						
3	3	40	1.46	2.5	Line to Tray 1							
4					6 90° Ells 120 D							
5					1 Tee St 20 D							
6					1 Gate Valve 13 D							
7					Subtotal 153 D							
8					Equivalent Length 38'							
9					Straight Pipe 163'							
10					Total Eq. Length 201'							
11					Say 250'							
12												
13					Control Valve							
14												
15	3	40	1.46	1.0	Line to CV							
16					4 90° Ells 80 D							
17					1 Tee St 20 D							
18					1 Gate Valve 13 D							
19					Subtotal 113 D							
20					Equivalent Length 28'							
21					Straight Pipe 40'							
22					Total Eq. Length 68'							
23					Say 100'							
24												
25												

UOP
31 East Alameda Road, P.O. Box 6007, U.S.A.
HYDRAULIC TABULATION
(A)

REV	DATE	BY	DATE	REV	DATE	BY	DATE

LS-R00-38
IPD-2004/LS-141

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Line No. (CV No.)	Size, in	Schedule	ΔP/100 ft psi	Ex. EQ. ft + 100	Description	ΔP psi	Inlet Press psig	ΔP psi	Inlet Press psig	ΔP psi	Inlet Press psig	Design 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 (Straight) 20 D							
5					1 Check 135 D							
6					1 Gate 13 D							
7					Subtotal 328 D							
8					Equiv. Length 82'							
9					Straight Pipe 85'							
10					167'							
11					Use 200'							
12												
13					Pump							
14					Static (16') ($\frac{2.5}{151}$)							
15												
16	6	40	0.07	3.0								
17					See Hyd. Gen. Comments*							
18					Item "A-3" NPSH Calc.							
19												
20												
21												
22												
23												
24												
25												

UOP
31 East Alameda Road, P.O. Box 6007, U.S.A.
HYDRAULIC TABULATION
(A)

REV	DATE	BY	DATE	REV	DATE	BY	DATE

LS-R00-39
IPD-2004/LS-142

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UOP 33 East Algonquin Road, Des Plaines, Illinois 60017 U.S.A. HYDRAULIC TABULATION (A)										REV. DATE BY DATE BY DATE BY DATE BY DATE BY			
Line No. (CV No.)	Size, in.	Schedule	DP/100 ft	Flow ft ³ /min	Description	DP psi	Inlet Press. psig	DP psi	Inlet Press. psig	DP psi	Inlet Press. psig	Design Press. psig	
1					Reflux to Column		5						
2					Static Head 143' (2.51)	53.24	58.24						
3	3	40	1.46	2.5	Line to Tray 1	3.65	61.89						
4					Control Valve								
5	3	40	1.46	1.0	Line to Control Valve	1.5							
6	3	40	2.15	2.0	Pump Dischg. Line	4.3							
7					Pump		5.8						
8					Static 16' (2.51)	(6)	(0.2)						
9	3	40	0.07	30		0.2	0						
10													
11													
12													
13													
14													
15													
16													
17													
18													
19													
20													
21													
22													
23													
24													
25													

LS-R00-40
IPD-2004/LS-143

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33 East Algonquin Road, Des Plaines, Illinois 60017 U.S.A.

HYDRAULIC TABULATION

Sheet _____
Project _____

Line	Old Pump Section		Reflex		Net Product		Old Pump Discharge
Alt. or Elev. at 60°F							
Average mol wt							
Temperature, °F							
Flowing SPGR	0.86						
Sp. vol., Cu. ft./lb.			0.65				
Flow Via Compressor							
Via Cent. Feed							
Flowing USGPM	Net 160	Max 189			Net 130	Max 156	Net 30
Flow, lbs. x 10 ³							Max 31
Distillation, psig							Net 160
Static, psi							Max 189
Exhausts, psi							
Typing, psi							
Valve, psi							
Pump Discharge, psig							
Pump Section, psig							
Differential, psi							
Differential Head, ft							
Pressure Level, psia							
Normal Flow							
Pipe Size, IPS	6	6			3	3	1.5
Pipe Class	40	40			40	40	40
Velocity, FPS	100	118			330	396	275
Reboil, psia (100 ft. above)	0.08	0.11			1.7	2.45	2.5
Reboil, psia (at Econ)	0.07	0.10			1.66	2.10	2.15
Pump Description							
Type	Oper	Spun	Oper	Spun	Oper	Spun	Oper
Item No.							
Power Condition							
Notes Available							
Notes							

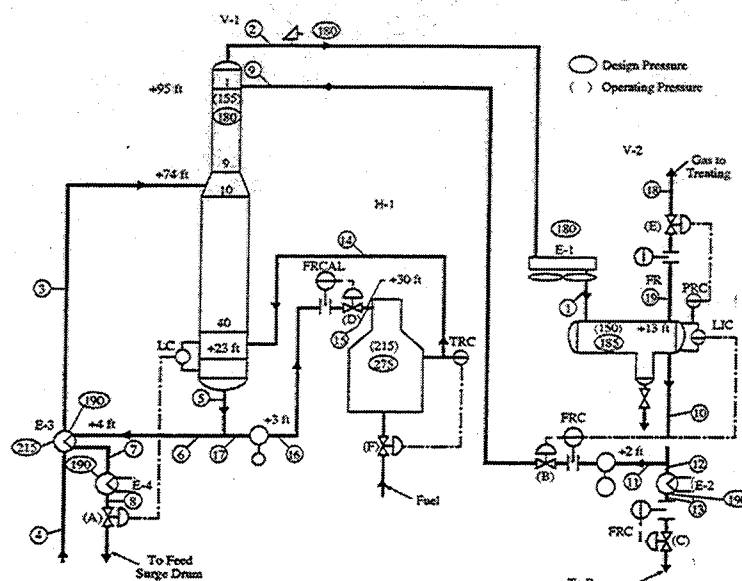
LS-R00-35
IPD-2004/LS-144

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 HYDRAULIC TABULATION										Sheet _____ Project _____					
Loc															
API or ISO at 60°F															
Average mol wt															
Temperature, °F															
Flowing SP GR															
Sp vol, Cu Bbl															
Flow Vel, Centistokes															
Vis Cent Poise															
Flowing USOPH															
Flow, bbl x 10 ³															
Distillation, psig															
Static, psi															
Exchangers, psi															
Piping, psi															
Valve, psi															
Pump Discharge, psig															
Pump Suction, psig															
Differential Head, ft															
Pressure Level, psig															
Normal Flow															
Pipe Size, IPS															
Pipe Class															
Velocity, FPM															
Friction, psi/100 ft (Baron)															
Friction, psi/100 ft (Coul)															
Pump Description															
Type															
Item No.															
Driver															
Power Condition															
NPSH Available															
Notes															

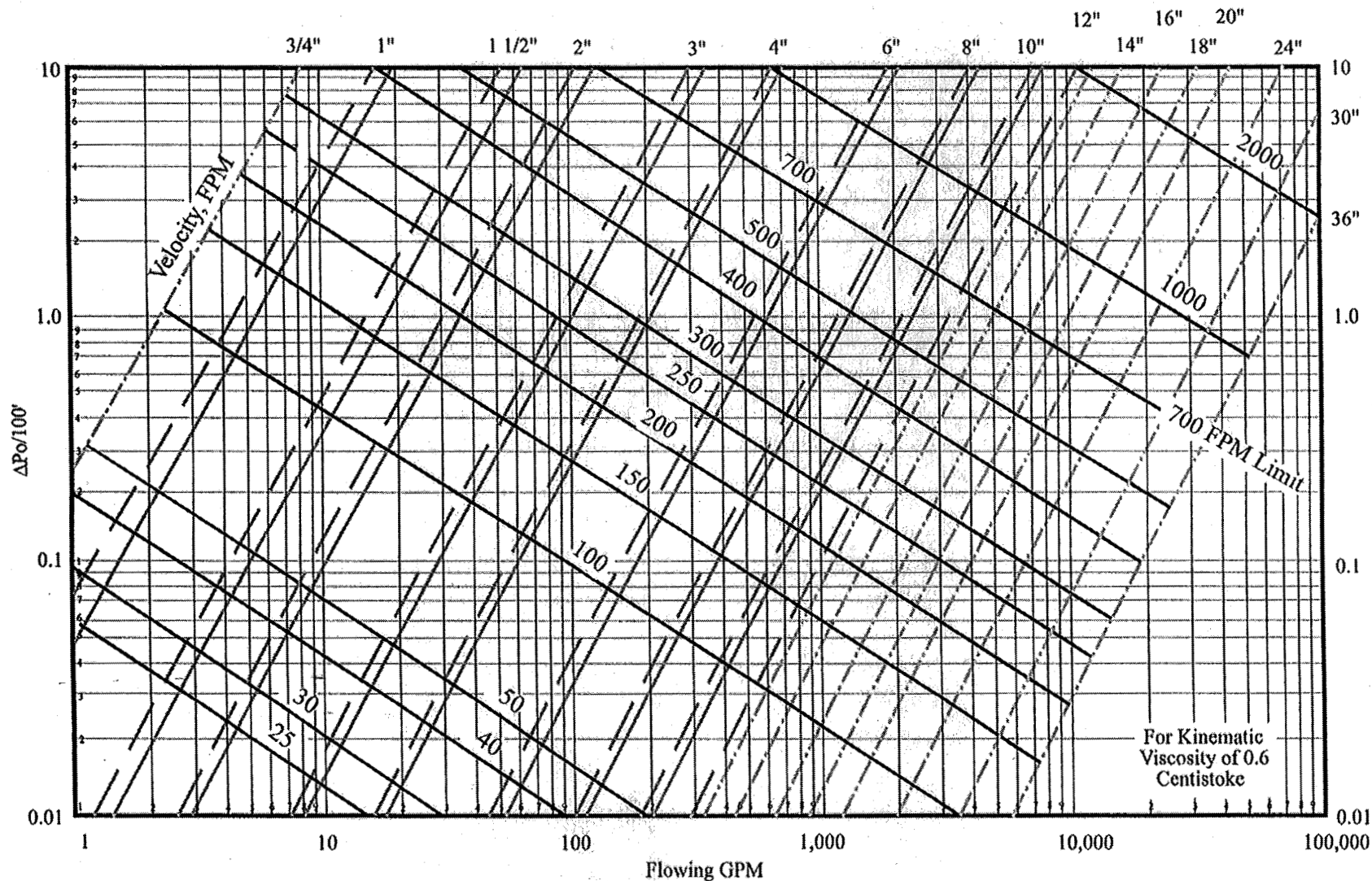
LS-R00-41
IPD-2004/LS-145

Fractionator Hydraulic Diagram



EDS-R00-2239
IPD-2004/LS-146

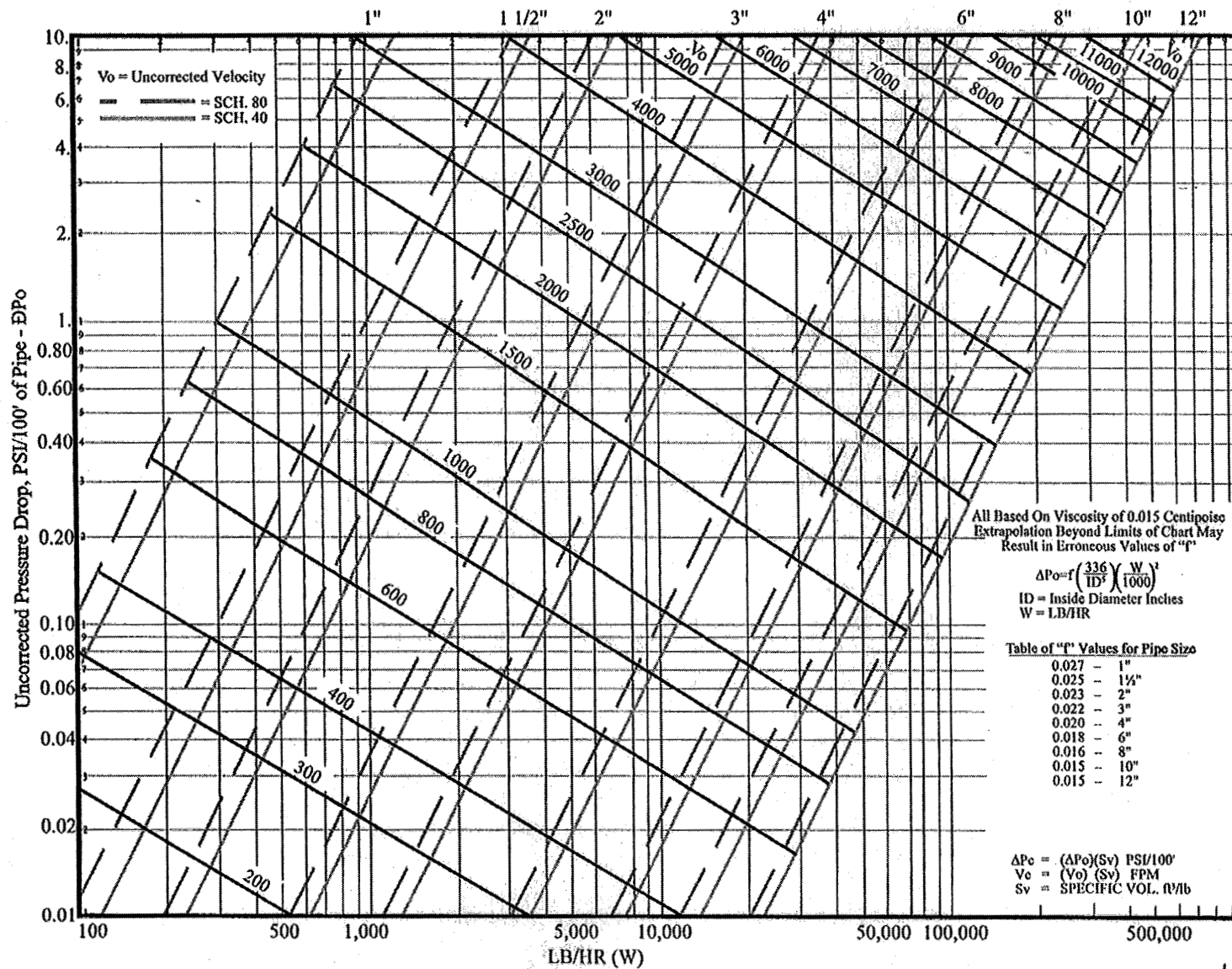
Liquid Flow thru Commercial Steel Pipe



Note: To Find ΔP in PSI per 100 ft. of Pipe,
 Multiply $\Delta P_o/100'$ by Specific Gravity.

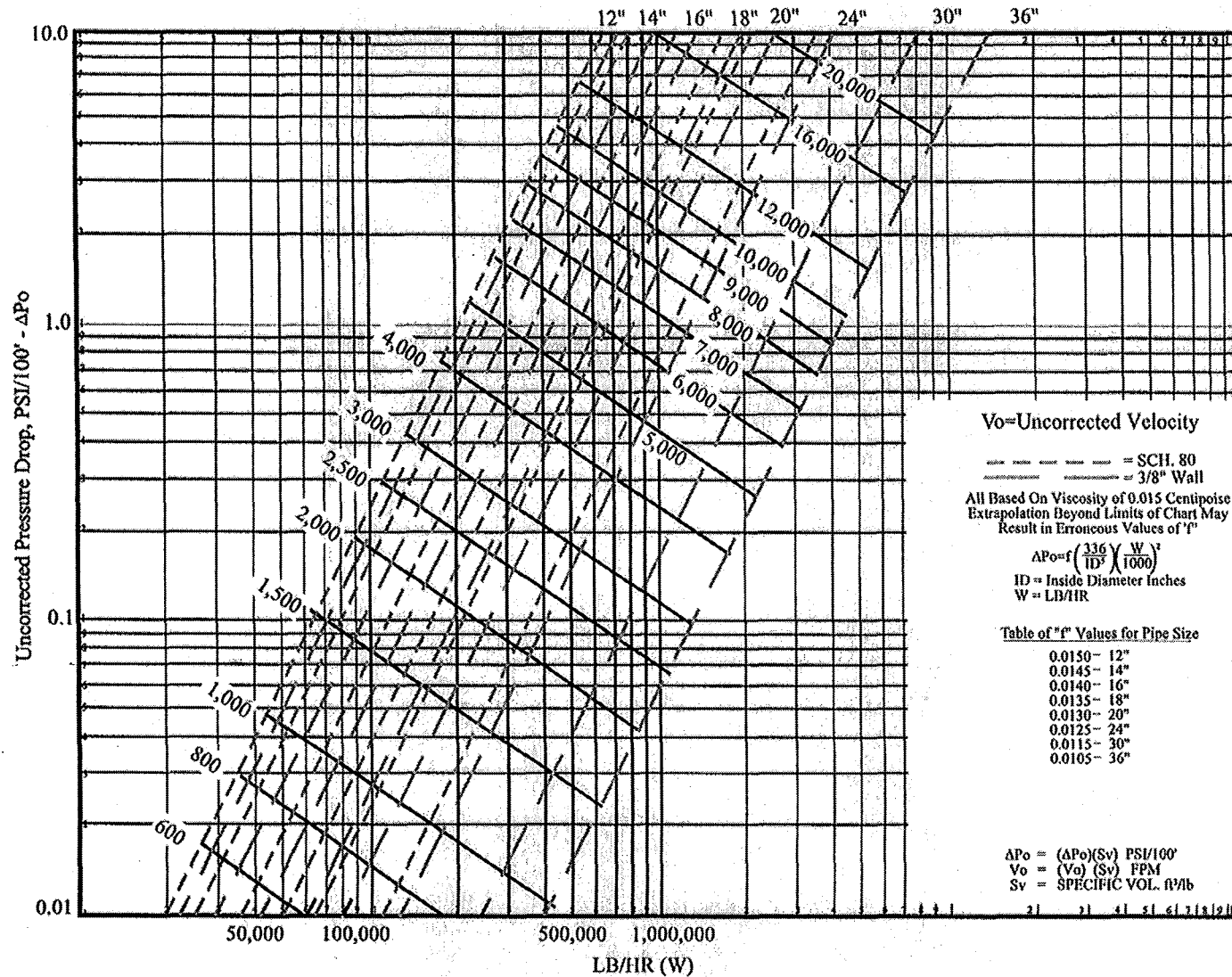
LS-R00-18
 IPD-2004/LS-22

Vapor Flow thru Commercial Steel Pipe

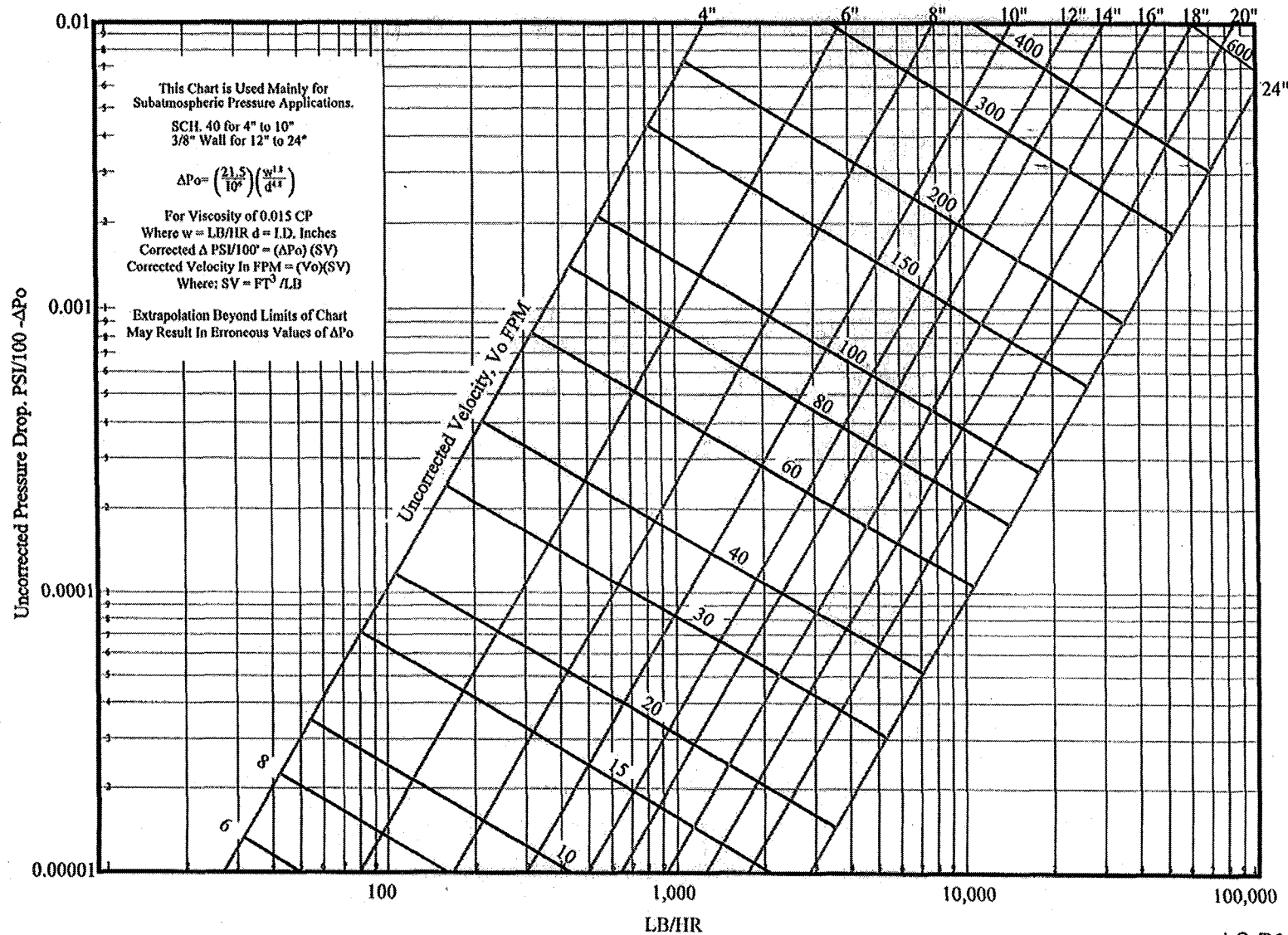


Vapor Flow thru Commercial Steel Pipe

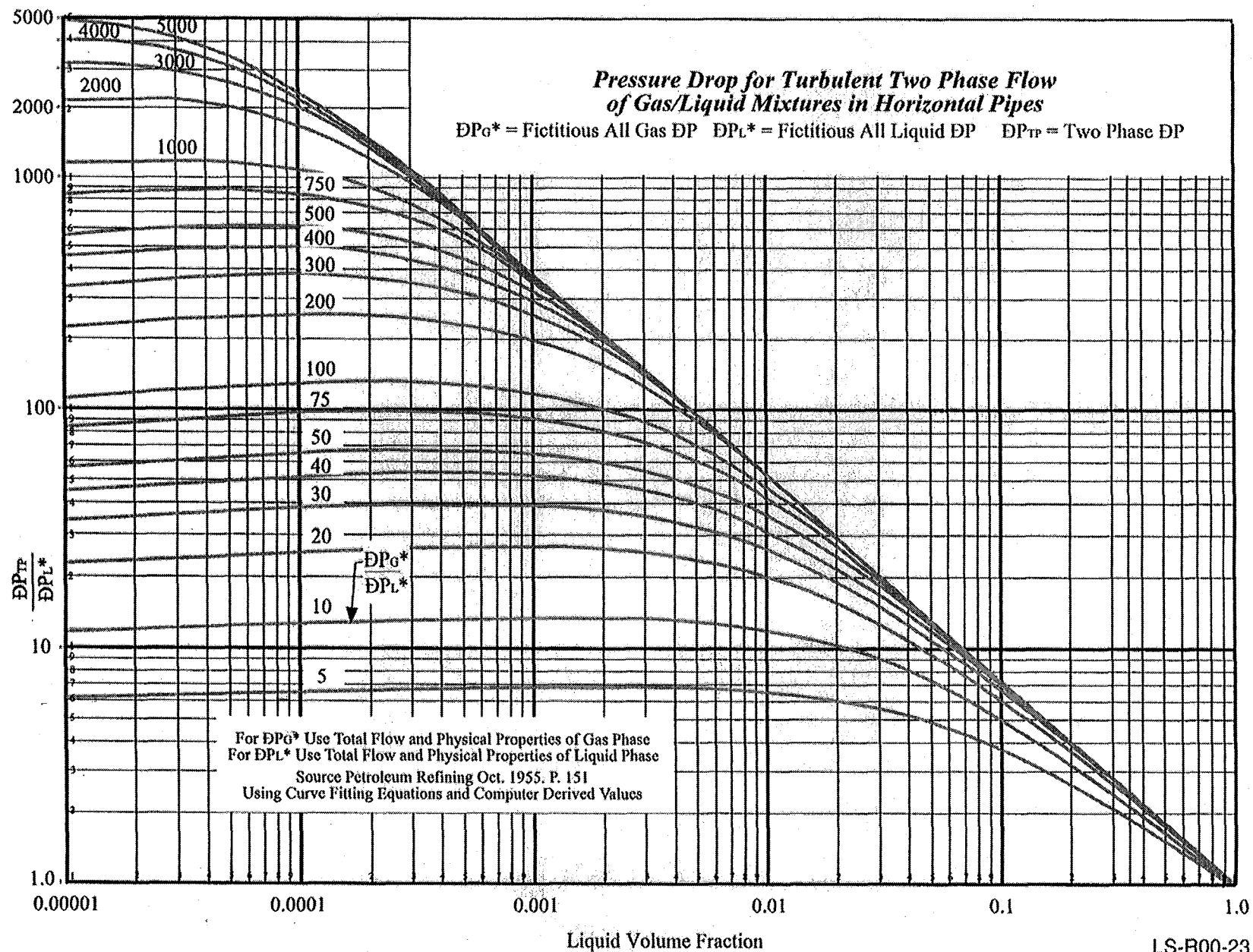
(See Other Chart for Smaller Sizes)



Vapor Flow thru Commercial Steel Pipe

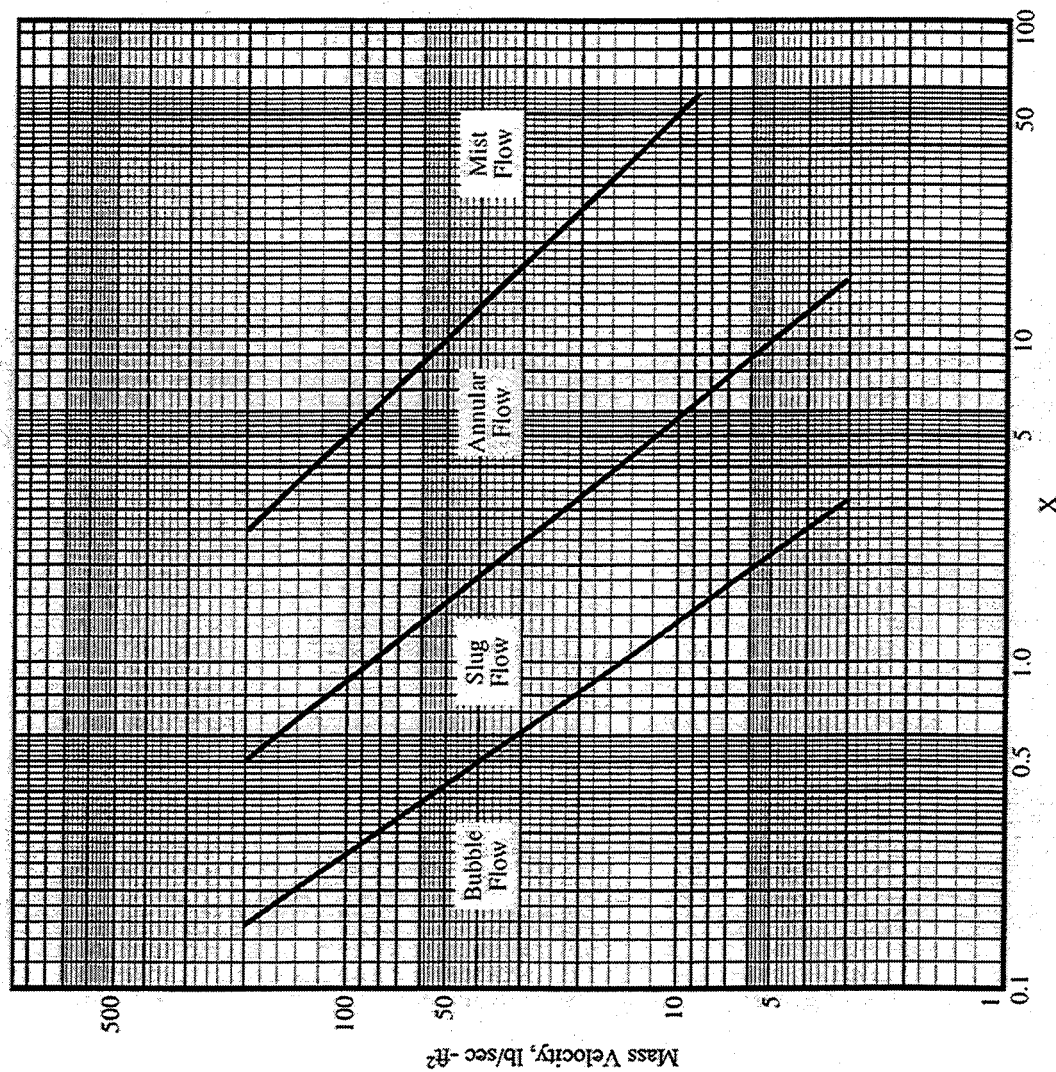


LS-R00-22
 IPD-2004/LS-31



		TWO PHASE FLOW WORKSHEET		PROJECT NO. _____ SHEET _____ OF _____ BY _____ DATE _____	
VAPOR AND LIQUID LINE (TWO PHASE FLOW)					
① LIQUID FLOW USGPM					
② LIQUID FLOWING SP. GR.					
③ LIQUID FLOW LB./HR. $\times 10^3$					
④ VAPOR FLOW LB./HR. $\times 10^3$					
⑤ TOTAL LB./HR. $\times 10^3$					
⑥ VAPOR SP. VOL. CU. FT./LB.					
⑦ LIQUID VOLUME CF/S $= \frac{\text{GPM}}{4.48}$					
⑧ VAPOR VOLUME CF/S					
⑨ TOTAL VOLUME CF/S					
⑩ VOL L/TOTAL VOL. = LVF					
⑪					
⑫ LINE SIZE, INCHES					
⑬ PIPE SCHEDULE					
⑭ IF ALL LIQUID USGPM $\frac{① \times ⑤}{③}$					
⑮ FRICTION PSI/100 FT. (UNCOR.)					
⑯ EP_L° (CORR.) (CORR.) $\frac{⑮ \times ②}{③}$					
⑰ IF ALL GAS LB./HR. $\times 10^3$ $\frac{⑤}{③}$					
⑱ FRICTION PSI/100 FT. (UNCOR.)					
⑲ ΔP_G^* (CORR.) $\frac{⑱ \times ⑥}{③}$					
⑳					
㉑ EP_G° / EP_L° $\frac{⑲}{⑯}$					
㉒					
㉓ $\Delta P_{TP}^* / \Delta P_L^* =$ (FACTOR FROM PD-395A)					
㉔					
㉕ $\Delta P_L^* \times$ (FACTOR) $\frac{⑲ \times ㉓}{③}$ = ΔP_{TP}^* (CORR.)					
㉖					
㉗ VELOCITIES FPM (CORR.)					
ΔP_L^* FICTITIOUS ALL LIQUID ΔP	ΔP_G^* FICTITIOUS ALL GAS ΔP				

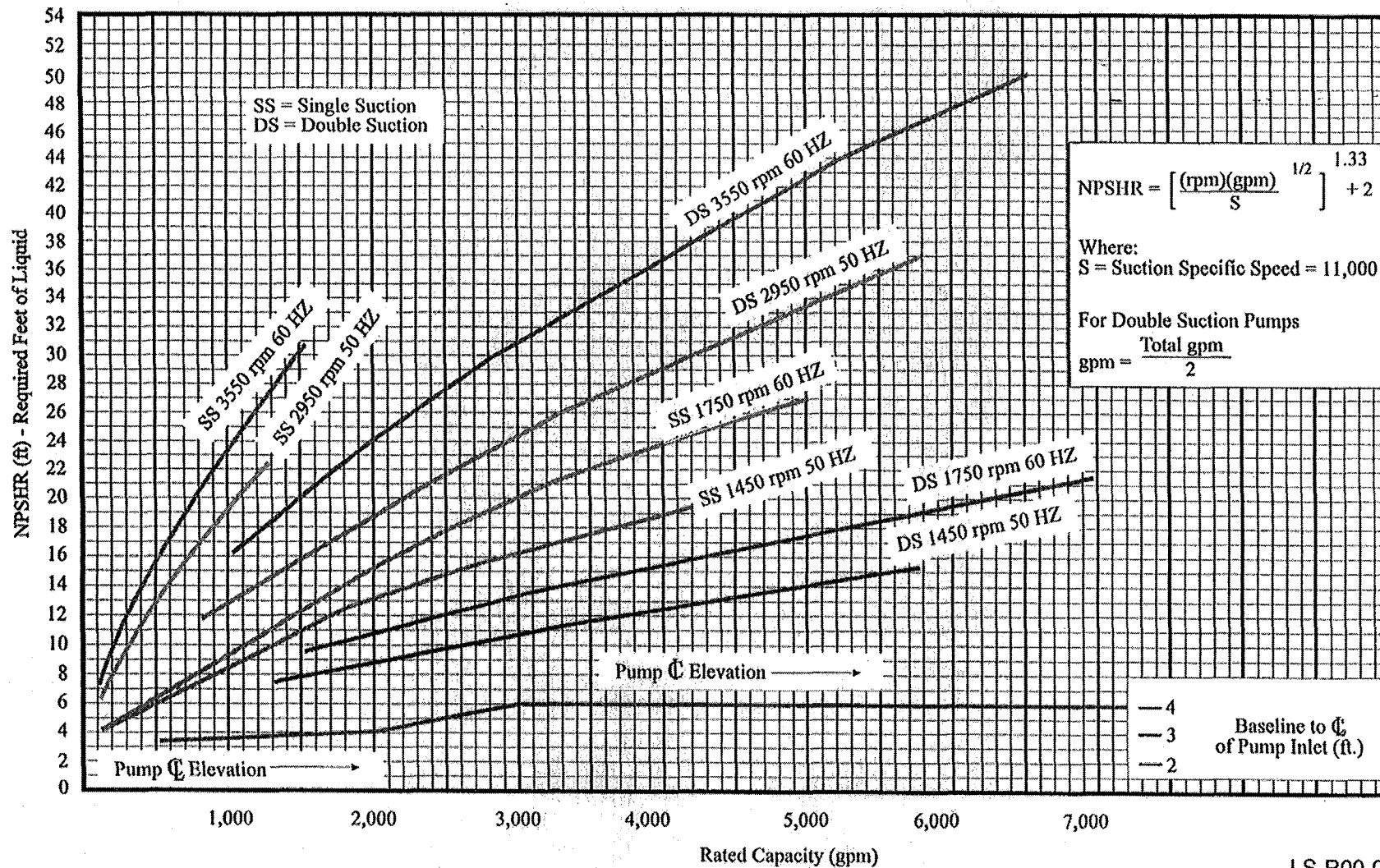
Approximate Two-Phase Flow Patterns (Vertical Upflow)



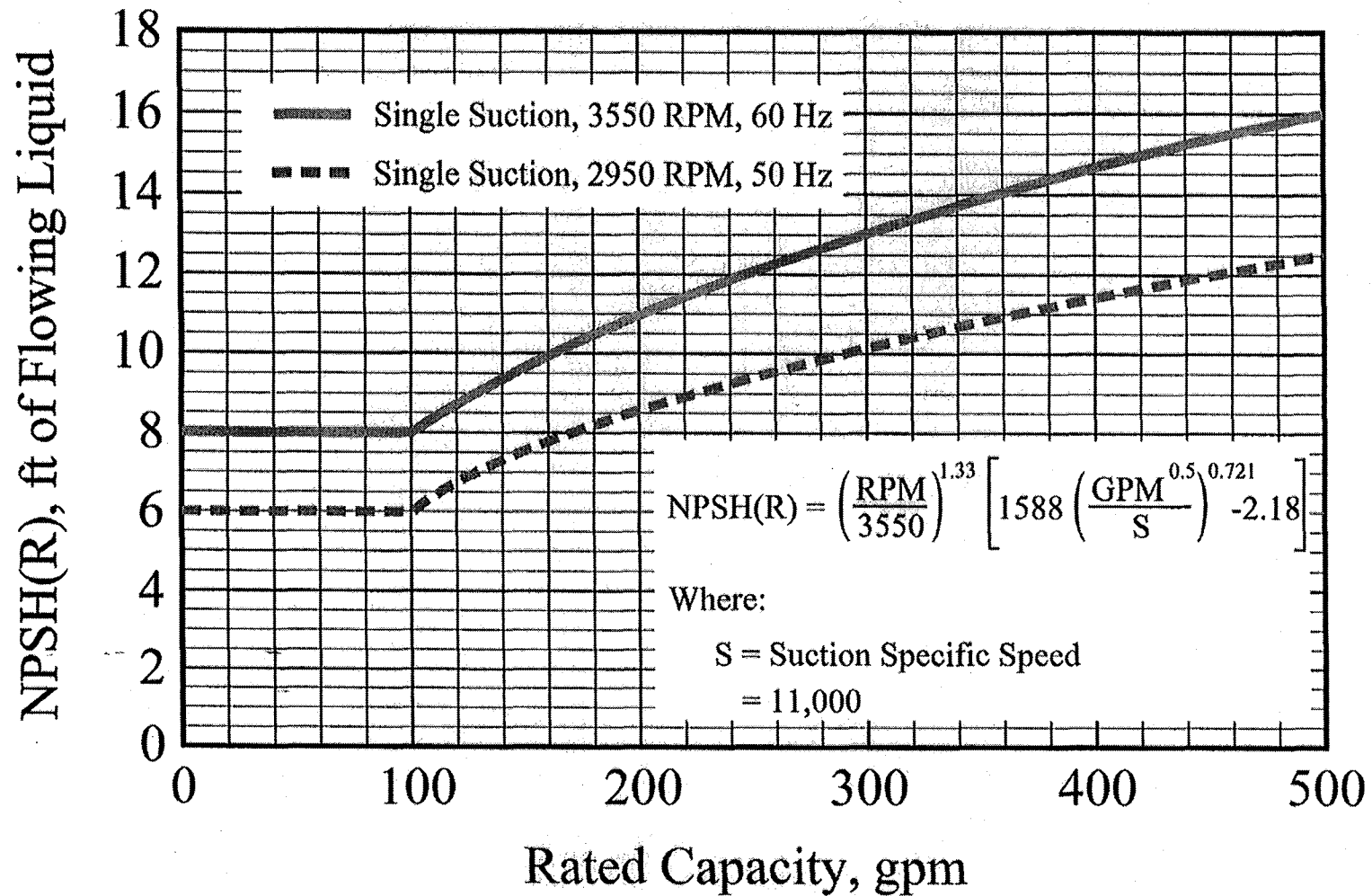
$$X = \frac{1}{\left(\frac{W_L}{W_G}\right)^{0.9} \left(\frac{\rho_G}{\rho_L}\right)^{0.5} \left(\frac{\mu_L}{\mu_G}\right)^{0.1}}$$

W = lb/sec
 ρ = lb/ft³
 μ = centipoise

Single Stage Centrifugal Pumps Minimum Required NPSH



NPSH(R) for Single Centrifugal Pumps



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, 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	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	200
			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 Angel	
	In-Line Ball	2.5 vertical and 0.25 horizontal...Fully open	150	
Foot Valves with Strainer		0.3' ...Fully open	420	
		0.4' ...Fully open	75	
Butterfly Valves (8-inch and larger)			Fully open	40
Cocks	Straight-Through	Rectangular plug port area 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	44
			Flow through branch	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

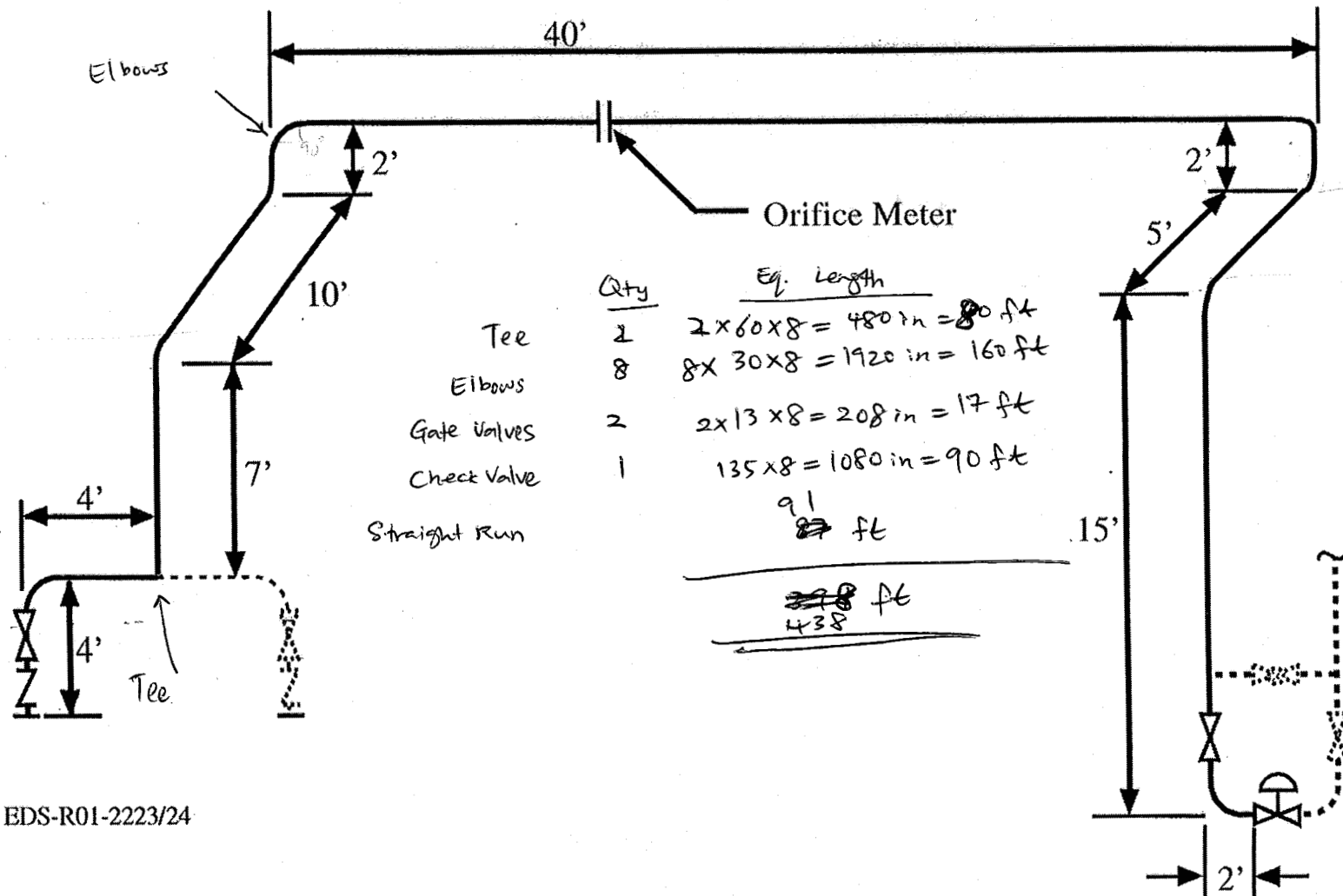
** Exact equivalent length is
equal to the length between
flange faces or welding ends.

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

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

LS-R00-26
IPD-2004/LS-119

Typical Calculation of Piping Equivalent Length - 8" Pump Discharge Line



EDS-R01-2223/24

IPD-2004/LS-120



25 East Algonquin Road Des Plaines, Illinois 60017 U.S.A.

Engineering Department

Heat and Weight Balances

Aromatics Fractionation

Example for Line Sizing Only

Page No. 1
Date _____
Project _____
By _____

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Stream	° API (lb/gal)	K	MW	Flowing Sp. Gr.	°F	psig (MM Hg ABS)	BPSD 640° 10° SCF/D	Flowing GPM (CFS)	Mols per h	lb/h	BTU/ lb	10 ⁶ Btu/h
Aromatics from Storage	(7.28)	10.0	89	0.86	100	-	5000	148	718	63700	18	1.14
Feed - Bottoms Exchanger Duty												1.72
Feed to Column	(7.28)	10.0	89	0.82	160	7	-	155	718	63700	45	2.86
Overhead Vapors to Condenser	-		78	(0.22)	195	5	-	(87)	883	68900	225	15.5
Condenser Duty												14.3
Material to Receiver	(7.37)	9.75	78	0.86	100	0	5340	160	883	68900	17	1.2
Reflux	(7.37)	9.75	78	0.86	100	0	4340	130	718	56000	17	1.0
Benzene Product	(7.37)	9.75	78	0.86	100	0	1000	30	165	12900	17	0.2
Liquid to Reboiler	(7.26)		92	0.76	265	10	26,600	890	3670	338000	97	32.80
Reboiler Duty												16.56
Material from Reboiler	(7.26)		92	-	265	10	-	-	3670	338000	146	49.36
Vapor			92	(0.30)	265	10	(11.15)	(105)	1223	113000	243	27.46
Liquid	(7.28)		92	0.76	265	10	17700	592	2447	225000	97	21.90
Bottoms to Exchanger	(7.28)	10.1	92	0.76	265	-	4000	134	553	50800	97	4.92
Exchanger Duty	(7.28)											1.72
Bottoms to Cooler	(7.28)	10.1	92	0.79	200	-	4000	129	553	50800	63	3.20
Cooler Duty	(7.28)											2.30
Bottoms to Storage	(7.28)	10.1	92	0.85	100	-	4000	119	553	50800	18	0.90

LS-R00-36
IPD-2004/LS-137



Engineering Department

Aromatics Fractionation

Example for Line Sizing Only

Page No. 2

Date _____

Project: _____

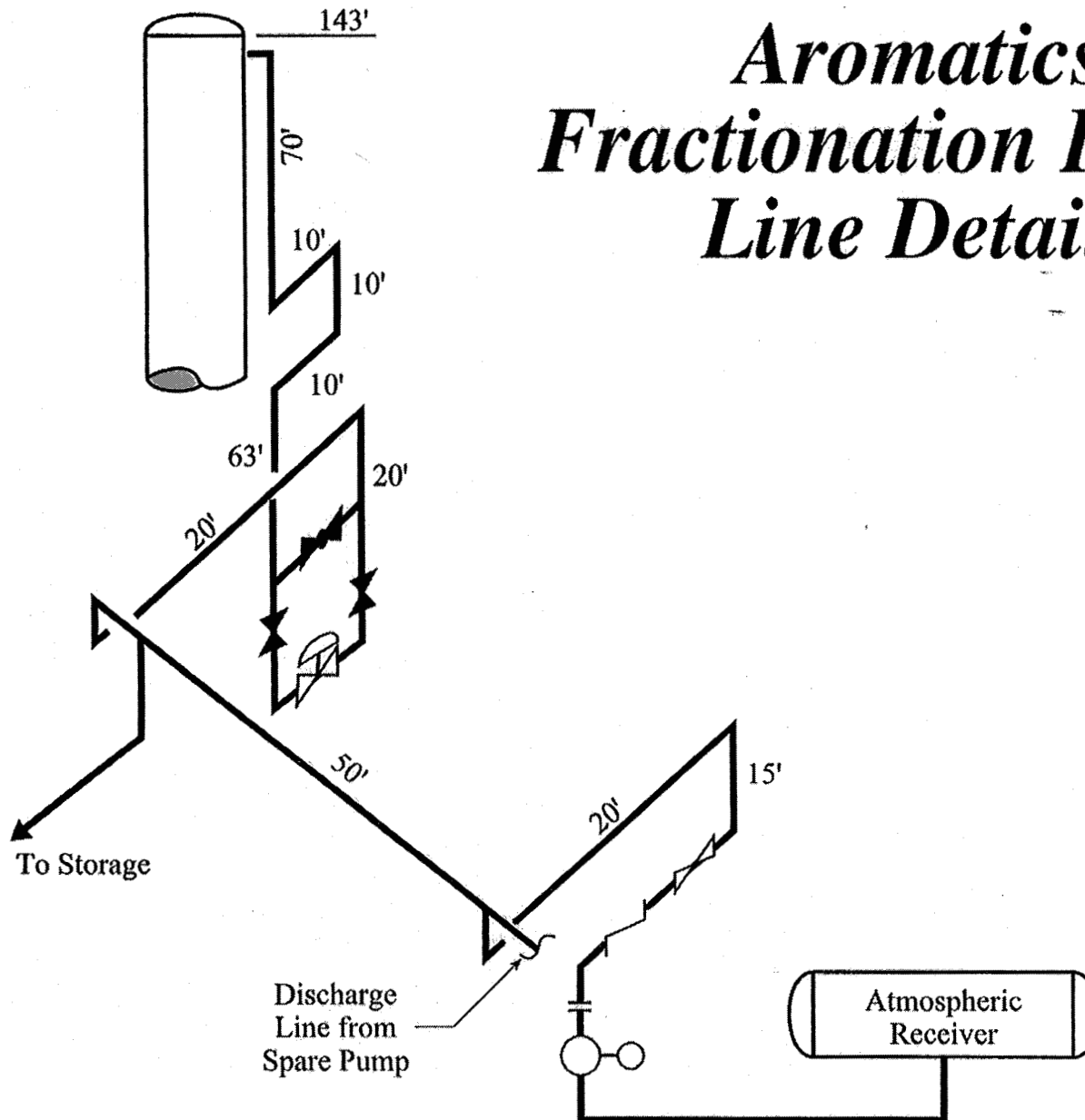
By _____

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LS-R00-37
IPD-2004/LS-138

Aromatics Fractionation Reflux Line Details



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 25 East Algonquin Road Des Plaines, Illinois 60017 U.S.A. HYDRAULIC TABULATION										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 $\div 100$	Description	ΔP psi	Inlet Press psig	ΔP psi	Inlet Press psig	ΔP psi	Inlet Press psig	Design Press psig					
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
11																	
12																	
13																	
14																	
15																	
16																	
17																	
20																	
21																	
22																	
23																	
24																	
25																	

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UOP

25 East Algonquin Road Des Plaines, Illinois 60017 U.S.A.

HYDRAULIC TABULATION
(A)

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 Head 143' ($\frac{.86}{2.31}$)	53.24						
3	3	40	1.46	2.5	Line to Tray 1							
4					6 90° Ells 120 D							
5					1 Tee St 20 D							
6					1 Gate Valve 13 D							
7					Subtotal 153 D							
8					Equivalent Length 38'							
9					Straight Pipe 163'							
10					Total Eq. Length 201'							
11					Say 250'							
12												
13					Control Valve							
14												
15	3	40	1.46	1.0	Line to CV.							
16					4 90° Ells 80 D							
17					1 Tee St 20 D							
20					1 Gate Valve 13 D							
21					Subtotal 113 D							
22					Equivalent Length 28'							
23					Straight Pipe 40'							
24					Total Eq. Length 68'							
25					Say 100'							

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

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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 (Straight) 20 D							
5					1 Check 135 D							
6					1 Gate 13 D							
7					328 D							
8					Equiv. Length 82'							
9					Straight Pipe 85'							
10					167'							
11					Use 200'							
12												
13					Pump							
14					Static (16') ($\frac{.86}{2.31}$)							
15												
16	6	40	0.07	3.0								
17					See 'Hyd. Gen. Comments'							
20					Item 'A-3' NPSH Calc.							
21												
22												
23												
24												
25												

UOP
 25 East Algonquin Road Des Plaines, Illinois 60017 U.S.A.
HYDRAULIC TABULATION
 (A)

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

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[illegible]



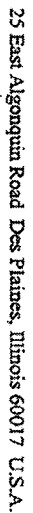
Sheet _____

Project _____

LS-R00-35
IPD-2004/LS-144

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Sheet _____

Project _____

LS-R00-41
IPD-2004/LS-145

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[illegible]

The diagram illustrates a complex refinery process involving two distillation columns, V-1 and V-2, and several heat exchangers (E-1, E-2, E-3, E-4).
Distillation Column V-1: Features sections 1, 9, 10, and 40. It has design pressures of 155 and 180, and an operating pressure of 180. It is equipped with a Level Control (LC) and a Temperature Control (TRC) loop.
Distillation Column V-2: Features sections 18 and 10. It has design pressures of 150 and 185, and an operating pressure of 180. It includes a Pressure Control (PRC) and a Level Control (LIC) loop.
Heat Exchangers:
 - E-1: A horizontal heat exchanger with design pressures of 180 and 185, and an operating pressure of 180.
 - E-2: A vertical heat exchanger with design pressures of 190 and 190, and an operating pressure of 190.
 - E-3: A vertical heat exchanger with design pressures of 215 and 190, and an operating pressure of 190.
 - E-4: A vertical heat exchanger with design pressures of 190 and 190, and an operating pressure of 190.
Process Flow and Controls:
 - Feed enters at the bottom left, passes through E-3, and splits into two paths: one to the bottom of V-1 and another to a surge drum.
 - V-1 bottom product flows through E-4 and then through a control valve (A) to the surge drum.
 - V-1 top product flows through E-1 and then through a control valve (B) to the bottom of V-2.
 - V-2 top product flows through a control valve (C) to the recovery section.
 - V-2 bottom product flows through E-2 and then through a control valve (D) to the surge drum.
 - The surge drum feeds into E-3.
 - Fuel gas enters at the bottom right, passes through a control valve (F), and is used for heating in V-1 and V-2.
 - The recovery section includes a control valve (C) and a control valve (D).
 - The diagram also shows various control loops: FRCAL, FRC, and TRC.

EDS-R00-2239
IPD-2004/LS-146

MIXED PHASE LINE SIZING

$$\text{Liquid Volume Fraction} = \frac{V_L}{V_L + V_G} = \frac{\frac{W_L}{S.G. \times 62.5}}{\frac{W_L}{S.G. \times 62.5} + \frac{W_G}{\#/\text{Ft}^3}}$$

$$= \frac{\frac{\quad}{\times 62.5}}{\frac{\quad}{\times 62.5} + \frac{\quad}{\quad}}$$

$$= \frac{\quad}{\quad} = \frac{\quad}{\quad} = \quad$$

$$\text{Total Flow Gas} = W_L + W_G = \quad + \quad = \quad \#/\text{HR}$$

$$\text{Total Flow Liquid} = \frac{W_L + W_G}{S.G. \times 500} = \frac{\quad}{\quad \times 500} = \quad \text{GPM}$$

Try ____" Line

$$\frac{\text{Total Flow } \Delta P_G}{\text{Total Flow } \Delta P_L} = \frac{\Delta P_{G0} \times \frac{1}{\#/\text{Ft}^3}}{\Delta P_{L0} \times S.G.} = \frac{\quad \times \frac{1}{\quad}}{\quad \times \quad} = \quad = \quad$$

$$\Delta P_{G0} = f \times \frac{336}{d^5} \times \left(\frac{W}{1000} \right)^2 = \frac{x 336 x}{x 10^6} =$$

$$\Delta P_{TP} = \text{Total Flow } \Delta P_L \times \text{Factor} = \underline{\hspace{1cm}} \times \underline{\hspace{1cm}} =$$

Try ____" Line

$$\frac{\text{Total Flow } \Delta P_G}{\text{Total Flow } \Delta P_L} = \frac{\Delta P_{G0} \times \frac{1}{\#/\text{Ft}^3}}{\Delta P_{L0} \times \text{S.G.}} = \frac{x \frac{1}{x}}{x} = \underline{\hspace{1cm}} =$$

$$\Delta P_{G0} = f \times \frac{336}{d^5} \times \left(\frac{W}{1000} \right)^2 = \frac{x 336 x}{x 10^6} =$$

$$\Delta P_{TP} = \text{Total Flow } \Delta P_L \times \text{Factor} = \underline{\hspace{1cm}} \times \underline{\hspace{1cm}} =$$

Use ____" Line

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 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 $\left(\frac{I}{C}\right)$
		Steel		Stain- less Steel Sched. No.				(a) Square Inches	(A) Square Feet					
		Iron Pipe Size	Sched. No.											
1/8	0.405	---	---	10S	.049	.307	.0548	.0740	.00051	.00088	.19	.032	.106	.00437
		STD	40	40S	.068	.269	.0720	.0568	.00040	.00106	.24	.025	.106	.00523
		XS	80	80S	.095	.215	.0925	.0364	.00025	.00122	.31	.016	.106	.00602
1/4	0.540	---	---	10S	.065	.410	.0970	.1320	.00091	.00279	.33	.057	.141	.01032
		STD	40	40S	.088	.364	.1250	.1041	.00072	.00331	.42	.045	.141	.01227
		XS	80	80S	.119	.302	.1574	.0716	.00050	.00377	.54	.031	.141	.01395
3/8	0.675	---	---	10S	.065	.545	.1246	.2333	.00162	.00586	.42	.101	.178	.01736
		STD	40	40S	.091	.493	.1670	.1910	.00133	.00729	.57	.083	.178	.02160
		XS	80	80S	.126	.423	.2173	.1405	.00098	.00862	.74	.061	.178	.02554
1/2	0.840	---	---	5S	.065	.710	.1583	.3959	.00275	.01197	.54	.172	.220	.02849
		---	---	10S	.083	.674	.1974	.3568	.00248	.01431	.67	.155	.220	.03407
		STD	40	40S	.109	.622	.2503	.3040	.00211	.01709	.85	.132	.220	.04069
		XS	80	80S	.147	.546	.3200	.2340	.00163	.02008	1.09	.102	.220	.04780
		---	160	---	.187	.466	.3836	.1706	.00118	.02212	1.31	.074	.220	.05267
		XXS	---	---	.294	.252	.5043	.050	.00035	.02424	1.71	.022	.220	.05772
3/4	1.050	---	---	5S	.065	.920	.2011	.6648	.00462	.02450	.69	.288	.275	.04667
		---	---	10S	.083	.884	.2521	.6138	.00426	.02969	.86	.266	.275	.05655
		STD	40	40S	.113	.824	.3326	.5330	.00371	.03704	1.13	.231	.275	.07055
		XS	80	80S	.154	.742	.4335	.4330	.00300	.04479	1.47	.188	.275	.08531
		---	160	---	.219	.612	.5698	.2961	.00206	.05269	1.94	.128	.275	.10036
		XXS	---	---	.308	.434	.7180	.148	.00103	.05792	2.44	.064	.275	.11032
1	1.315	---	---	5S	.065	1.185	.2553	1.1029	.00766	.04999	.87	.478	.344	.07603
		---	---	10S	.109	1.097	.4130	.9452	.00656	.07569	1.40	.409	.344	.11512
		STD	40	40S	.133	1.049	.4939	.8640	.00600	.08734	1.68	.375	.344	.1328
		XS	80	80S	.179	.957	.6388	.7190	.00499	.1056	2.17	.312	.344	.1606
		---	160	---	.250	.815	.8365	.5217	.00362	.1251	2.84	.230	.344	.1903
		XXS	---	---	.358	.599	1.0760	.282	.00196	.1405	3.66	.122	.344	.2136
1 1/4	1.660	---	---	5S	.065	1.530	.3257	1.839	.01277	.1038	1.11	.797	.435	.1250
		---	---	10S	.109	1.442	.4717	1.633	.01134	.1605	1.81	.708	.435	.1934
		STD	40	40S	.140	1.380	.6685	1.495	.01040	.1947	2.27	.649	.435	.2346
		XS	80	80S	.191	1.278	.8815	1.283	.00891	.2418	3.00	.555	.435	.2913
		---	160	---	.250	1.160	1.1070	1.057	.00734	.2839	3.76	.458	.435	.3421
		XXS	---	---	.382	.896	1.534	.630	.00438	.3411	5.21	.273	.435	.4110
1 1/2	1.900	---	---	5S	.065	1.770	.3747	2.461	.01709	.1579	1.28	1.066	.497	.1662
		---	---	10S	.109	1.682	.6133	2.222	.01543	.2468	2.09	.963	.497	.2598
		STD	40	40S	.145	1.610	.7995	2.036	.01414	.3099	2.72	.882	.497	.3262
		XS	80	80S	.200	1.500	1.068	1.767	.01225	.3912	3.63	.765	.497	.4118
		---	160	---	.281	1.338	1.429	1.406	.00976	.4824	4.86	.608	.497	.5078
		XXS	---	---	.400	1.100	1.885	.950	.00660	.5678	6.41	.42	.497	.5977
2	2.375	---	---	5S	.065	2.245	.4717	3.958	.02749	.3149	1.61	1.72	.622	.2652
		---	---	10S	.109	2.157	.7760	3.654	.02538	.4992	2.64	1.58	.622	.4204
		STD	40	40S	.154	2.067	1.075	3.355	.02330	.6657	3.65	1.45	.622	.5606
		XS	80	80S	.218	1.939	1.477	2.953	.02050	.8679	5.02	1.28	.622	.7309
		---	160	---	.344	1.687	2.190	2.241	.01556	1.162	7.46	.97	.622	.979
		XXS	---	---	.436	1.503	2.656	1.774	.01232	1.311	9.03	.77	.622	1.104
2 1/2	2.875	---	---	5S	.083	2.709	.7280	5.764	.04002	.7100	2.48	2.50	.753	.4939
		---	---	10S	.120	2.635	1.039	5.453	.03787	.9873	3.53	2.36	.753	.6868
		STD	40	40S	.203	2.469	1.704	4.788	.03322	1.530	5.79	2.07	.753	1.064
		XS	80	80S	.276	2.323	2.254	4.238	.02942	1.924	7.66	1.87	.753	1.339
		---	160	---	.375	2.125	2.945	3.546	.02463	2.353	10.01	1.54	.753	1.638
		XXS	---	---	.552	1.771	4.028	2.464	.01710	2.871	13.69	1.07	.753	1.997
3	3.500	---	---	5S	.083	3.334	.8910	8.730	.06063	1.301	3.03	3.78	.916	.7435
		---	---	10S	.120	3.260	1.274	8.347	.05796	1.822	4.33	3.62	.916	1.041
		STD	40	40S	.216	3.068	2.228	7.393	.05130	3.017	7.58	3.20	.916	1.724
		XS	80	80S	.300	2.900	3.016	6.605	.04587	3.894	10.25	2.86	.916	2.225
		---	160	---	.438	2.624	4.205	5.408	.03755	5.032	14.32	2.35	.916	2.876
		XXS	---	---	.600	2.300	5.466	4.155	.02885	5.993	18.58	1.80	.916	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 per foot of pipe	External Surface Sq. Ft. per foot of pipe	Section Modulus ($\frac{I}{O.D.}$)
		Steel		Stain- less Steel Sched. No.				Internal Area						
		Iron Pipe Size	Sched. No.					(c) Square Inches	(d) Square Feet					
3½	4.000	---	---	SS	.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	---	---	SS	.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	---	---	SS	.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	---	---	SS	.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	---	---	SS	.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	---	---	SS	.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	---	---	1.000	8.750	30.63	60.13	.4176	367.8	104.13	26.06	2.814	68.43
		---	140	---	1.125	8.500	34.02	56.75	.3941	399.3	115.64	24.59	2.814	74.29
		---	160	---	---	---	---	---	---	---	---	---	---	---
		12	12.75	---	---	SS	.156	12.438	6.17	121.50	.8438	122.4	20.98	52.65
---	---			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	1.53	96.14	.6677	561.6	107.32	41.66	3.338	88.1
XXS	---			---	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 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 ($\frac{2}{O.D.}$)
		Steel		Stain- less Steel Sched. No.				(e)	(A)					
		Iron Pipe Size	Sched. No.											
14	14.00	---	---	SS	.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	---	---	SS	.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
		XS	40	---	.500	15.000	24.35	176.72	1.2272	731.9	82.77	76.58	4.189	91.5
		---	60	---	.656	14.688	31.62	169.44	1.1766	932.4	107.50	73.42	4.189	116.6
		---	80	---	.844	14.312	40.14	160.92	1.1175	1155.8	136.61	69.73	4.189	144.5
		---	100	---	1.031	13.938	48.48	152.58	1.0596	1364.5	164.82	66.12	4.189	170.5
		---	120	---	1.219	13.562	56.56	144.50	1.0035	1555.8	192.43	62.62	4.189	194.5
		---	140	---	1.438	13.124	65.78	135.28	.9394	1760.3	223.64	58.64	4.189	220.0
		---	160	---	1.594	12.812	72.10	128.96	.8956	1893.5	245.25	55.83	4.189	236.7
18	18.00	---	---	SS	.165	17.670	9.25	245.22	1.7029	367.6	31.43	106.26	4.712	40.8
		---	---	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	30	---	.375	17.250	20.76	233.71	1.6230	806.7	70.59	101.18	4.712	89.6
		---	40	---	.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
		---	60	---	.562	16.876	30.79	223.68	1.5533	1171.5	104.67	96.93	4.712	130.1
		---	80	---	.750	16.500	40.64	213.83	1.4849	1514.7	138.17	92.57	4.712	168.3
		---	100	---	.938	16.124	50.23	204.24	1.4183	1833.0	170.92	88.50	4.712	203.8
		---	120	---	1.156	15.688	61.17	193.30	1.3423	2180.0	207.96	83.76	4.712	242.3
		---	140	---	1.375	15.250	71.81	182.66	1.2684	2498.1	244.14	79.07	4.712	277.6
---	160	---	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	---	---	SS	.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
		---	20	---	.375	19.250	23.12	290.04	2.0142	1113.0	78.60	125.67	5.236	111.3
		STD	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	128.11	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	---	---	SS	.188	21.624	12.88	367.25	2.5503	766.2	43.80	159.14	5.760	69.7
		---	---	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
		---	20	---	.375	21.250	25.48	354.66	2.4629	1489.7	86.61	153.68	5.760	135.4
		STD	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	403.09	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
		---	160	---	---	---	---	---	---	---	---	---	---	---

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 ($\frac{I}{O.D.}$)
		Steel		Stain- less Steel Sched. No.				Internal Area						
		Iron Pipe Size	Sched. No.					(a) Square Inches	(A) Square Feet					
24	24.00	...	...	SS	.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	...	...	SS	.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.

LINE SIZING

When faced with the time limitations of production engineering, the design engineer must have available to him various guidelines and rules of thumb to reduce the time consumed in line sizing. Although optimization of line sizing should not be ignored, the available increments of pipe size normally encountered make the expenditure of an extensive amount of time involved in line size optimization very questionable. UOP employs a computer program with built-in optimization procedures to assist the design engineer in the performance of his line sizing job. However, for this discussion, we will approach line sizing without the aid of the computer and rely upon good judgement and experience to reduce the time required and still provide a reasonable approach to optimization.

Following are some general comments to keep in mind as we proceed through this discussion:

- Line sizing will be based on "normal" flow rates and "normal" pressures as developed by the process design. However, the engineer should keep in mind the effect of "design" flow rates, maximum flow rates and start-up, shutdown and upset conditions that may have a significant influence on the plant pressure profile. It is generally helpful to develop a simple sketch of the plant or system piping arrangement to indicate the normal pressure profile and to record the results of investigations of alternate considerations. The sketch also provides a good means to visualize the possible effect of static head on pressure considerations used in line sizing.
- The principle criterion for line size selection will be pressure drop, expressed as pounds per square inch (psi) per 100 equivalent feet of pipe. Velocity, expressed in feet per minute, will also be an important factor.
- Additional properties used in our line sizing procedures will be specific gravity, vapor density and vapor specific volume. Specific gravity will normally refer to a liquid and is a dimensionless number determined as the ratio of the density of the liquid at flowing temperature to the density of water at the temperature of its maximum density. Vapor

density will be expressed in pounds per cubic foot. Vapor specific volume will be expressed as cubic feet per pound.

- In certain line sizing problems, such as vacuum heater transfer lines and pressure relief piping, limitations due to sonic velocity must be observed. In a pipe of constant diameter, a compressible fluid cannot move faster than the speed of sound in that fluid. This speed, for a typical C_p/C_v of 1.1, is equal to:

$$14,000 \sqrt{\frac{\text{Temperature } ^\circ R}{\text{Molecular Weight}}}$$

Sonic velocity is expressed in feet per minute and is proportional to $\sqrt{C_p/C_v}$. The sonic velocity limitation can be easily overlooked, resulting in a calculated pressure drop lower than that which actually exists. When sonic velocity is exceeded in a pipe, the downstream pressure in the pipe will build up until the increased density permits the flow to be exactly at sonic velocity. This built-up downstream pressure would then be used in a total pressure drop calculation rather than some lower pressure in a vessel connected to the pipe.

- If the specific volume of the vapor in a line changes significantly due to line pressure drop, certain corrections should be made in the pressure drop calculation. As a general rule, if the pressure drop for a known length of line is less than 10% of the upstream absolute pressure, either the upstream or downstream specific volume can be used in the pressure drop calculation. If the total pressure drop is between 10 and 40% of the upstream pressure, use the average specific volume. If the total pressure drop is greater than 40% of the upstream pressure, divide the line into sections for calculation purposes.
- For strength considerations, good practice limits the minimum permissible line size to 1" nominal for pipe rack runs and pipe spans between supports. In order to reduce purchasing and detailing problems and to minimize inventory requirements, pipe sizes such as 1¼, 2½,

3½ and 5 inch will normally be avoided. Schedule 80 minimum is recommended for 2 inch and smaller pipe size.

- Pipe sizes have a constant outside diameter. Therefore, as the wall thickness increases, the flowing area will be reduced. The engineer should keep this point in mind when working in piping systems at high pressure or when high corrosion allowances are required.
- When considering the wall thickness for pressure requirements or corrosion allowance, remember that the wall thickness tolerance is "12½% thru 24" seamless pipe size. The wall thickness tolerance is normally reduced to ± 0.01 inch for welded pipe and sizes greater than 24" when fabricated from rolled plate.
- Although most of the information contained in this discussion is directed toward new piping, the engineer should keep in mind that the economics and decision factors involved in revamps are different. Consequently, smaller line sizes can often be used on revamps compared to new construction.
- Chart LS-R00-18 is used to determine the sizing of lines for liquid flow. The engineer enters the chart with the appropriate flowing gpm at the bottom and proceeds upward, selecting the proper line size to suit the pressure drop or velocity criteria, which will be discussed later. Note that for the smaller line sizes, this chart indicates separate lines for different pipe schedules or wall thicknesses. The indicated chart ΔP should be multiplied by the flowing specific gravity to determine actual ΔP . Chart LS-R00-18 is based on a liquid having a kinematic viscosity of 0.6 centistoke. For more viscous materials, the chart ΔP should be multiplied by the correction factor $\left(\frac{\mu}{0.6}\right)^{0.2}$ where μ is in centistokes.

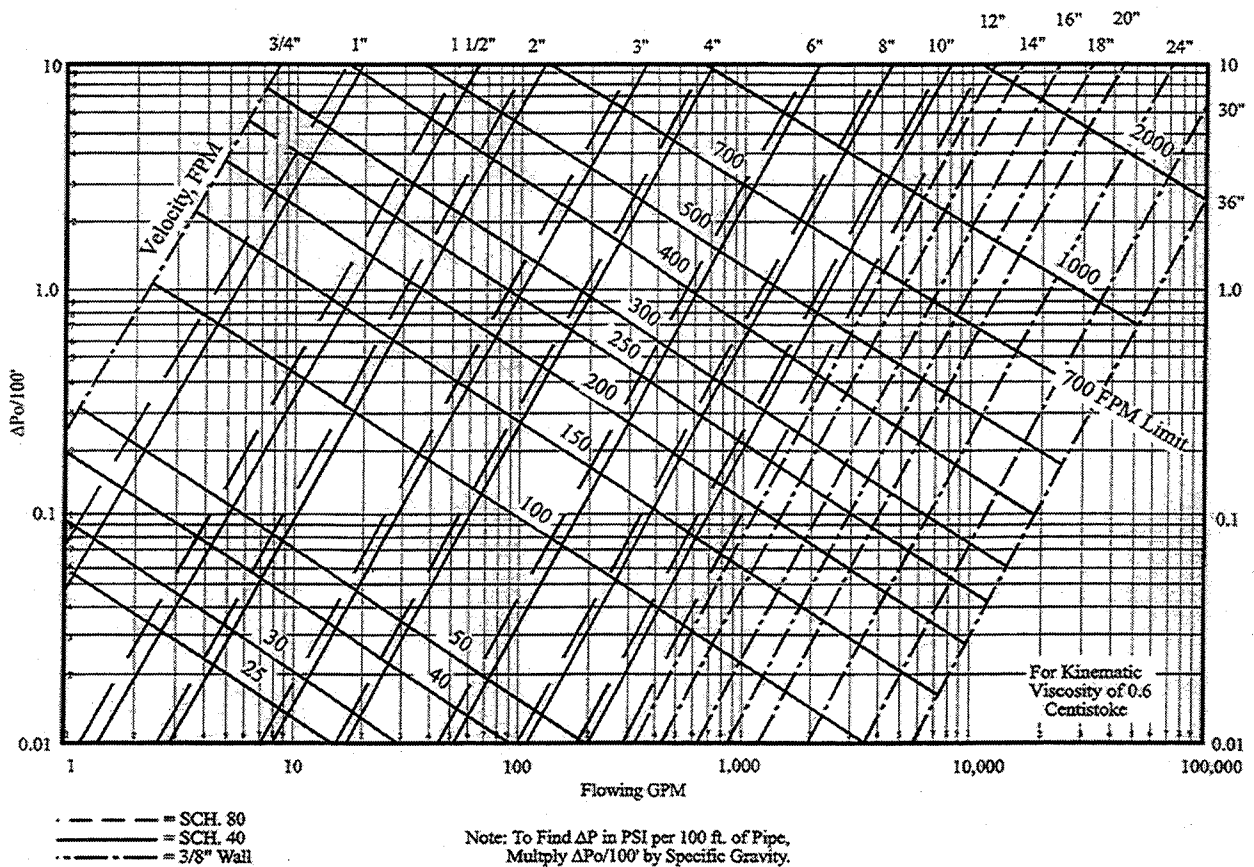
For example, a flowing liquid having a viscosity of 20 centistokes will have a line pressure drop approximately twice as great as would be indicated by the chart. This factor applies for turbulent flow (Reynolds number greater than 2000) only.

- Charts LS-R00-20, 21, and 22 are used to determine the sizing of lines for vapor flow. These charts are used in much the same manner as LS-R00-18 above. The chart ΔP should be multiplied by the specific volume to determine actual ΔP and the chart velocity should be multiplied by specific volume to determine actual velocity.
- For pressure drop calculations involving two-phase flow, chart LS-R00-23 is used. This chart is based on a method developed for horizontal flow. However, practically all of the two-phase flow applications encountered in process piping for refinery units are in the relatively high velocity flow regimes of annular, spray or froth flow. Therefore, it is felt that frictional pressure drops and type of flow regime are not much affected by pipe orientation at these velocities.
- When designing two-phase upflow lines, such as column feeds, reboiler returns and condenser rundowns, the flowing velocity should be kept high enough to prevent slug flow. Annular or mist flow is usually assured if the velocity in ft/sec is approximately equal to 60 divided by the square root of the mixed phase density in lbs/ft^3 . The chart "Approximate Two-Phase Flow Patterns" may also be used to determine the approximate flow condition.
- At UOP, the engineers use hydraulic tabulation forms to assist in their line sizing work. These forms simplify the work of the engineer and provide a convenient means to communicate the hydraulic information to specialty equipment engineers. Three examples are as follows:
 - Form LS-R00-41 is a form used for single-phase line sizing, vapor or liquid, and for pump and control valve information. The form is used in conjunction with the pressure drop charts.
 - Form LS-R00-25 is a form used for two-phase line sizing and is used in conjunction with chart LS-R00-23. This form provides a convenient means for tabulating the two-phase flow line sizing data.

- An additional form which defines the two-phase sizing procedure in equation form. Some engineers may prefer to use this method to record their line sizing calculations. See problem solutions for an example of this form.

Figure VIII-1

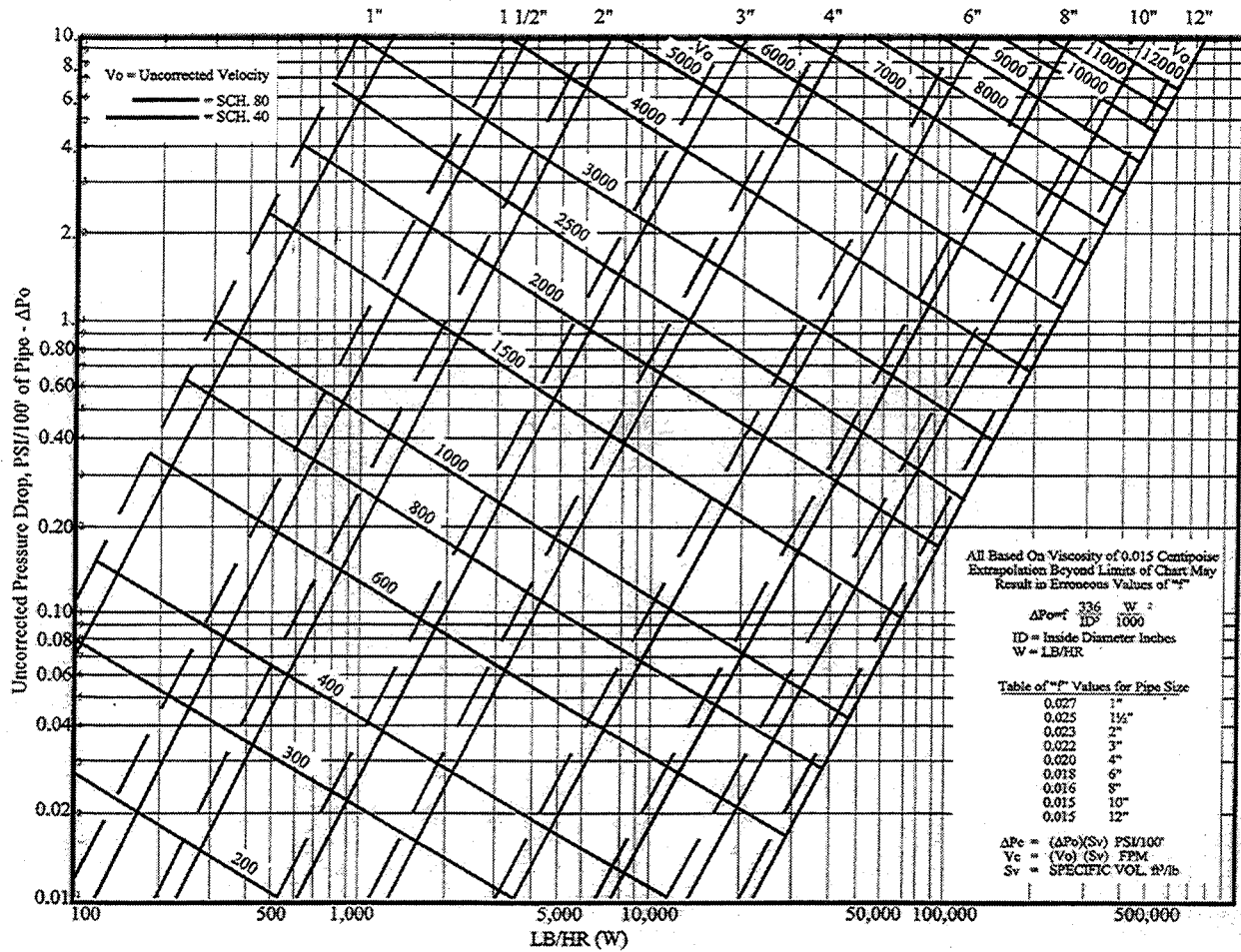
Liquid Flow Thru Commercial Steel Pipe



LS-R00-18

Figure VIII-2

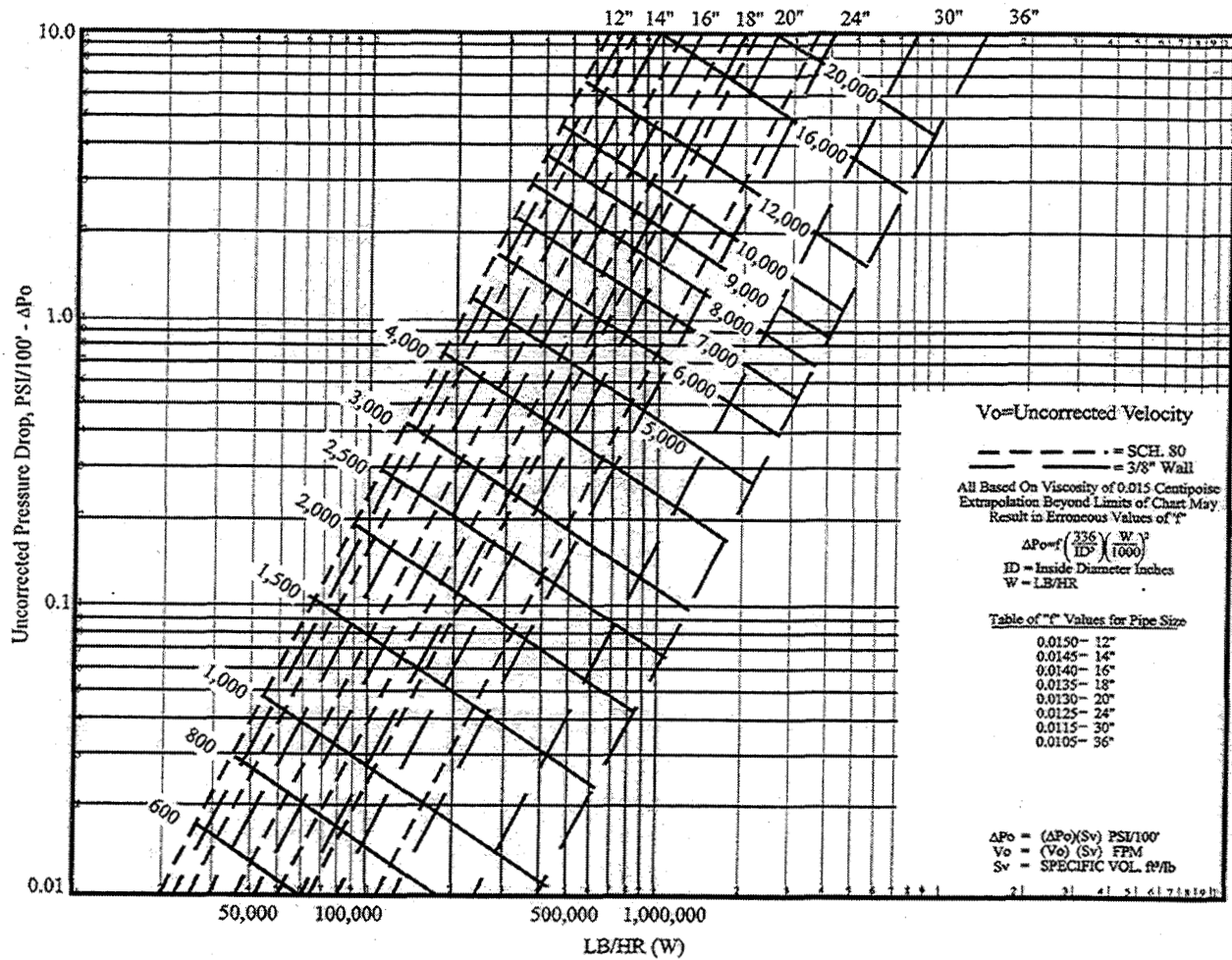
Vapor Flow Thru Commercial Steel Pipe



LS-R00-20

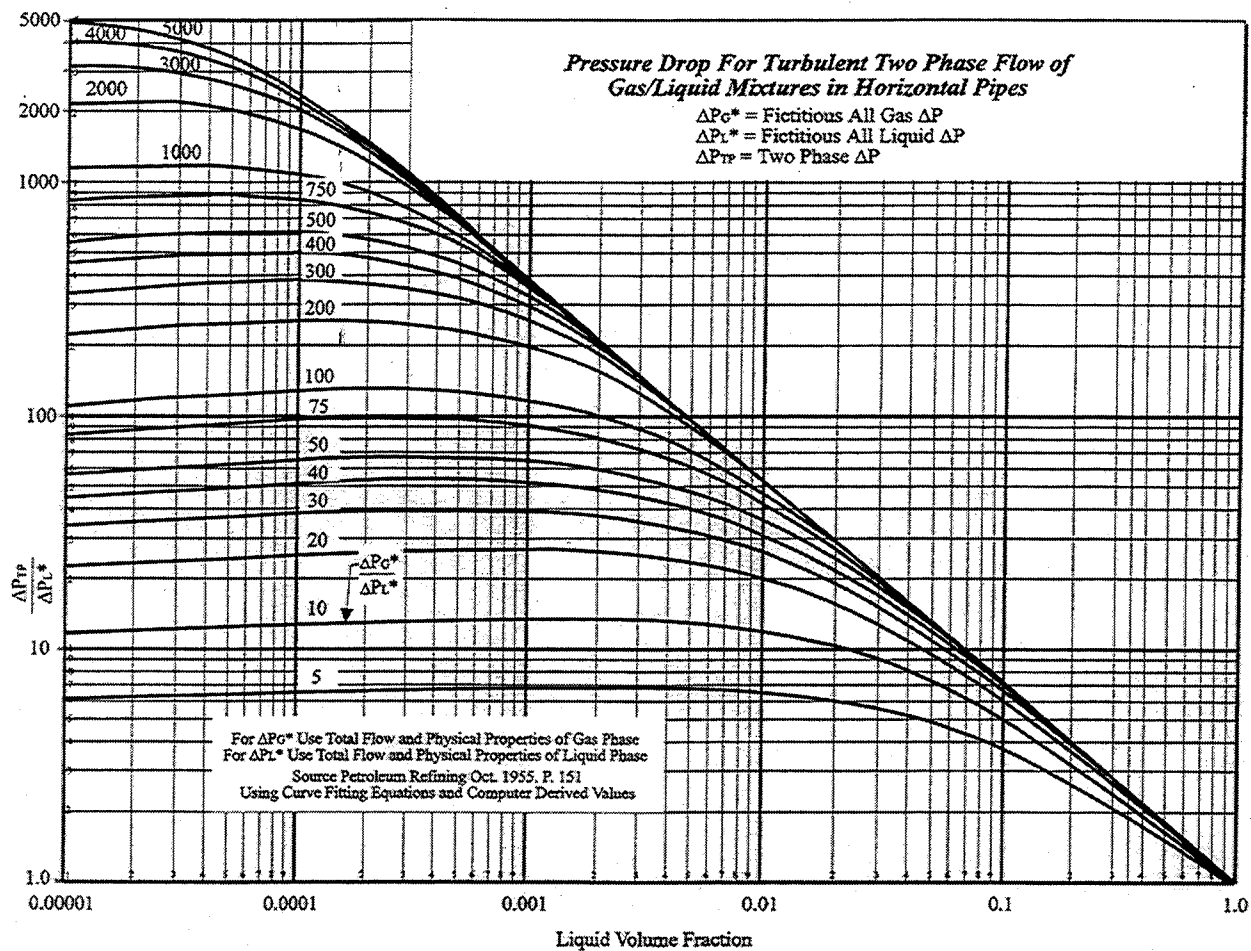
Figure VIII-3

Vapor Flow Thru Commercial Steel Pipe
(See Other Chart for Smaller Sizes)



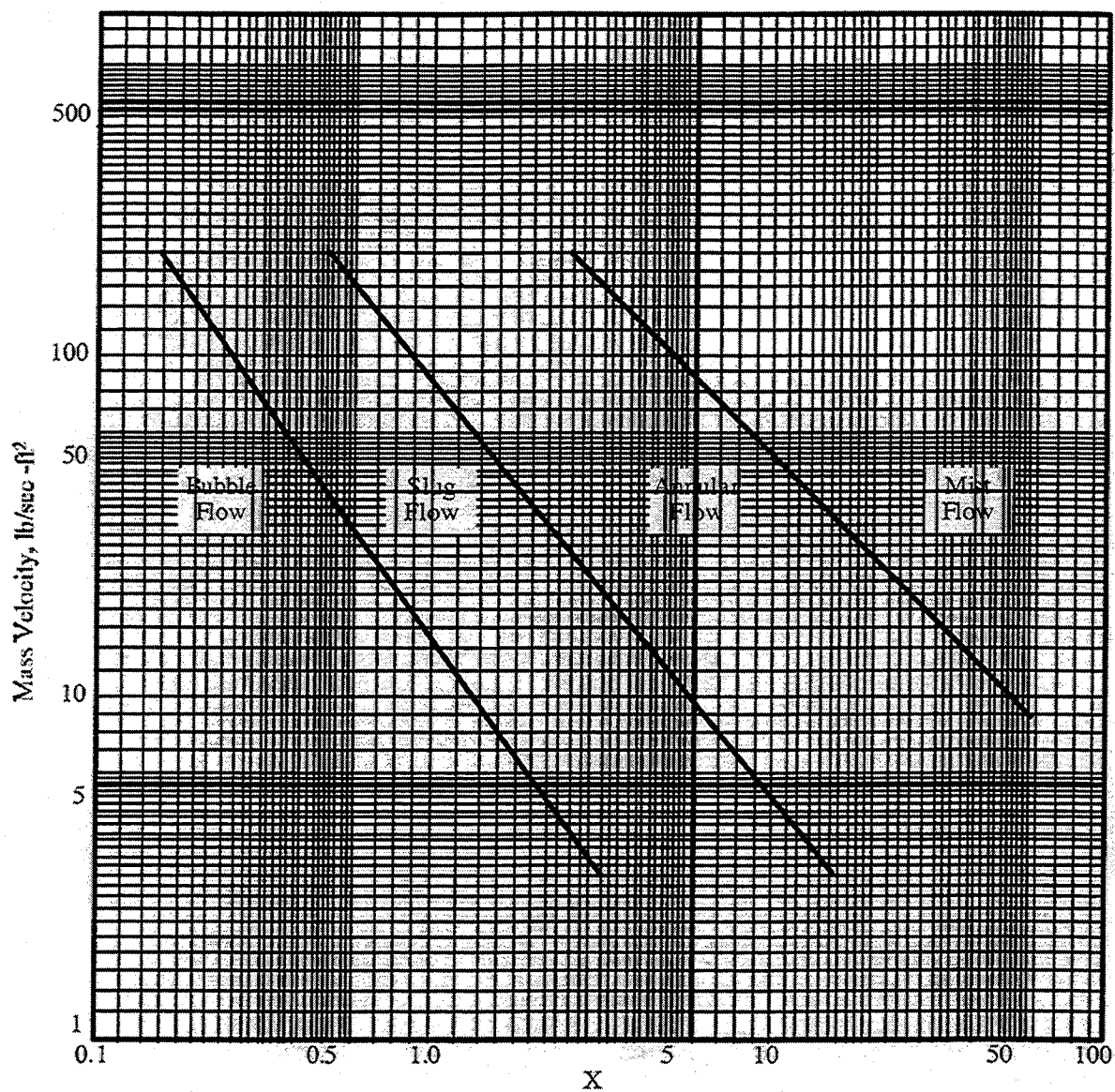
LS-R00-21

Figure VIII-4



LS-R00-23

Figure VIII-5



$$X = \frac{1}{\left(\frac{W_L}{W_G}\right)^{0.9} \left(\frac{\rho_G}{\rho_L}\right)^{0.5} \left(\frac{\mu_L}{\mu_G}\right)^{0.1}}$$

W = lb/sec

ρ = lb/ft³

μ = centipoise

Figure VIII-6

NOTE - These data are confidential and the property of UOP and shall not be disclosed to others or reproduced in any manner or used for any purpose whatsoever except by written permission or as provided in a signed agreement with UOP relating to such data.

 25 East Algonquin Road Des Plaines, Illinois 60017 U.S.A. HYDRAULIC TABULATION								Sheet _____ Project _____ Cust. No. _____			
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/h 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											

LS-R00-41

Figure VIII-7

		TWO PHASE FLOW WORKSHEET		PROJECT NO. _____ SHEET _____ OF _____ BY _____ DATE _____	
VAPOR AND LIQUID LINE (TWO PHASE FLOW)					
①	LIQUID FLOW USGPM				
②	LIQUID FLOWING SP. GR.				
③	LIQUID FLOW LB./HR. $\times 10^3$				
④	VAPOR FLOW LB./HR. $\times 10^3$				
⑤	TOTAL LB./HR. $\times 10^3$				
⑥	VAPOR SP. VOL CU. FT./LB.				
⑦	LIQUID VOLUME CF/S $= \frac{\text{GPM}}{448}$				
⑧	VAPOR VOLUME CF/S				
⑨	TOTAL VOLUME CF/S				
⑩	VOLL/TOTAL VOL. = LVF				
⑪					
⑫	LINE SIZE, INCHES				
⑬	PIPE SCHEDULE				
⑭	IF ALL LIQUID USGPM $\text{①} \times \text{⑤} / \text{③}$				
⑮	FRICTION PSI/100 FT. (UNCOR.)				
⑯	ΔP_L° (CORR.) (CORR.) $\text{⑮} \times \text{②}$				
⑰	IF ALL GAS LB./HR. $\times 10^3$ ⑤				
⑱	FRICTION PSI/100 FT. (UNCOR.)				
⑲	ΔP_G^* (CORR.) $\text{⑱} \times \text{⑥}$				
⑳					
㉑	$\Delta P_G^\circ / \Delta P_L^\circ$ $\text{⑲} / \text{⑯}$				
㉒					
㉓	$\Delta P_{TP}^* / \Delta P_L^* = (\text{FACTOR FROM PD-395A})$				
㉔					
㉕	$\Delta P_L^* \times (\text{FACTOR})$ $= \Delta P_{TP}^* \text{ (CORR.)}$ $\text{⑲} \times \text{㉓}$				
㉖					
㉗	VELOCITIES FPM (CORR.)				
ΔP_L^* FICTITIOUS ALL LIQUID ΔP		ΔP_G^* FICTITIOUS ALL GAS ΔP			

Figure VIII-8

**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, 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	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	200
			One-quarter open	1200
Conduit Pipe Line Gate, Ball, and Plug Valves			Fully open	3**
Check Valves	Conventional Swing	0.5' ...Fully open	135	Same as Globe Same as Angel
	Clearway Swing	0.5' ...Fully open	50	
	Globe Lift or Stop; Stem Perpendicular to Run or Y-Pattern	2.0' ...Fully open		
	Angle Lift or Stop	2.0' ...Fully open		
	In-Line Ball	2.5 vertical and 0.25 horizontal ...Fully open	150	
Foot Valves with Strainer		0.3' ...Fully open	420	
		0.4' ...Fully open	75	
Butterfly Valves (8-inch and larger)			Fully open	40
Cocks	Straight-Through	Rectangular plug port area 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.

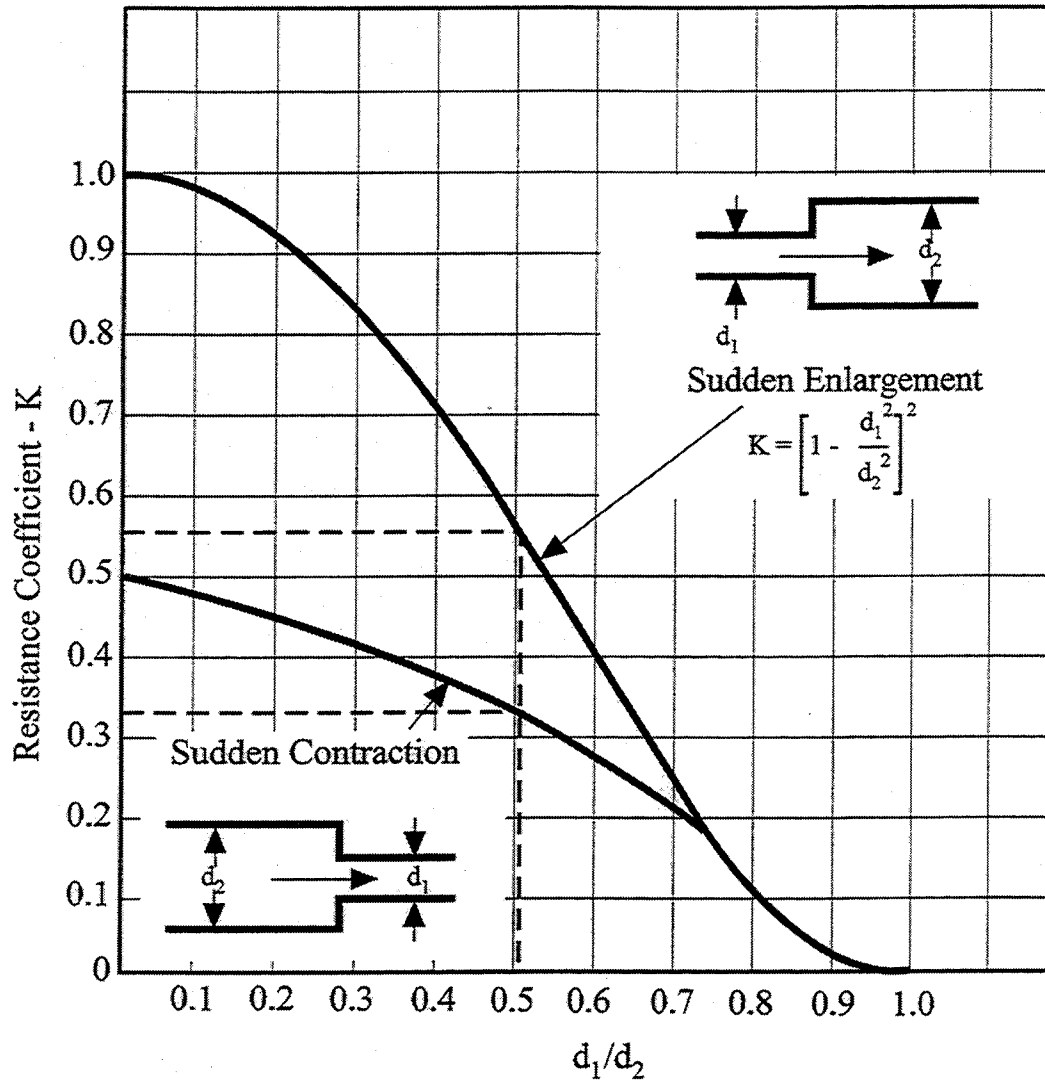
¹ Minimum calculated pressure
drop (psi) across valve to provide
sufficient flow to lift disc fully.

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

LS-R00-26

Figure VIII-9

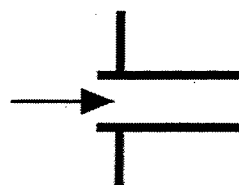
*Resistance Due to Sudden Enlargements
and Contractions*



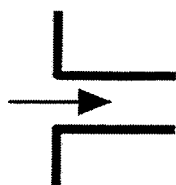
LS-R00-29

Figure VIII-10

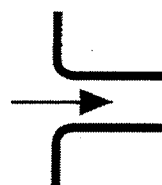
Resistance Due to Pipe Entrance and Exit



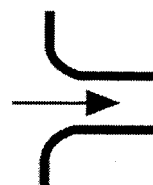
$K = 0.78$
Inward
Projecting
Pipe
Entrance



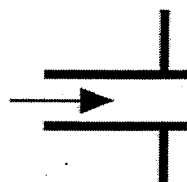
$K = 0.50$
Sharp
Edged
Entrance



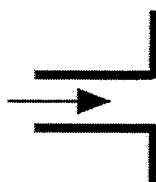
$K = 0.23$
Slightly
Rounded
Entrance



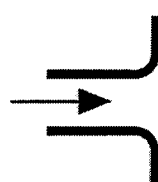
$K = 0.04$
Well
Rounded
Entrance



$K = 1.0$
Projecting
Pipe
Exit



$K = 1.0$
Sharp
Edged
Exit



$K = 1.0$
Rounded
Exit

LS-R00-30

HYDRAULICS

Line sizing is only a part of the overall subject of hydraulics. Other areas of hydraulics effect the sizing of lines, particularly in so far as the determination of available pressure drop is concerned. The following presents a discussion of some of the more important hydraulic systems and considerations with which the engineer should be familiar.

PUMP NPSH

Every centrifugal pump has a minimum positive pressure requirement at the eye of the impeller to prevent vaporization of the pumped liquid, which in turn causes cavitation. This pressure requirement is called "Net Positive Suction Head" (NPSH) and is expressed as the feet of liquid head, in excess of the fluid vapor pressure, required at the suction flange of a specific pump in order to overcome the internal pressure drop in the pump suction nozzle and passage to the eye of the impeller. The NPSH required is determined by the manufacturer as a characteristic of the pump and will set the elevation of many of the vessels in the process unit.

NPSH – Calculations

Pump NPSH calculations can be approached from two different viewpoints. A contractor's calculation is basically a check of the system to determine if the specified suction vessel elevation is sufficient to overcome the frictional loss of the detailed piping arrangement and still provide the pump NPSH requirement as defined by the pump supplier. All details of the system and equipment are usually known at the time the contractor makes this check.

On the other hand, the goal of a design engineer's calculation is the determination of the suction vessel elevation before details of the system and equipment are known. The following considerations and estimates should be taken into account in the engineer's calculation:

1. Estimate the minimum pump NPSH requirement, in feet of liquid, by means of the attached chart. This chart is based upon approximate NPSH requirements that would permit a range

of pump suppliers to be able to quote pumps that are economical in both capital cost and efficiency. The estimated NPSH requirement should be based on the pump design capacity. The chart is limited to single stage pumps with maximum differential heads of 1400 feet at 60 Hz and 1000 feet at 50 Hz. A pump vendor should be consulted for the NPSH requirements to suit unusual cases or services beyond the range of the attached chart.

2. Estimate the elevation of the pump centerline above the base line. The attached chart may be used to estimate the distance from the bottom of the base plate to the centerline of the pump. Add one additional foot for the assumed foundation projection above the base line to arrive at the estimated pump centerline elevation above the base line.
3. Estimate the friction loss, in feet of liquid, in the suction piping between the vessel and pump suction flange.

The piping friction loss is based on the pump design capacity and on clean pipe friction factors. The calculated friction loss per hundred feet must be multiplied by the estimated suction pipe equivalent length in hundreds of feet.

For normal suction piping arrangements from process vessels, the following equivalent lengths may be assumed:

For a **single pump** (with spare) service:

$$L = 50 + 500 D + 50 D^{1/2}$$

For **multiple pump** services (with spares) with common suction piping or for a pump service with a piping split to a reboiler or other service:

From suction vessel to piping split:

$$L = 10 + 150 D + 20 D^{1/2}$$

From the piping split to the pump suction:

$$L = 40 + 400 D + 40 D^{1/2}$$

Where: L = estimated equivalent feet of suction pipe

D = pipe I.D. in feet

Keep in mind that the pump suction valve may be one size smaller than the suction line where the suction connection on the pump is two or three sizes smaller than the line. Since the pump suction connection is not known during the engineering work, the engineer must use good judgment in determining if the smaller valve size will add a significant additional pressure drop.

Since pump suction systems are provided with permanent pump suction strainers or the temporary pump suction strainer is not removed, the additional pressure drop of the strainer must be accounted for in the liquid head. In most cases, the type of strainer to be installed is not known during the engineering work, but the engineer can compensate for the pump suction strainer pressure drop by adding the friction loss of 300 additional feet of piping.

4. Investigate the system absolute pressure on the liquid in the suction vessel to determine if the minimum pressure under all operating conditions exceeds the vapor pressure of the liquid at the pump suction temperature.

Any additional system pressure above the vapor pressure of the liquid at the pump suction temperature can be considered as NPSH available. This situation is most likely to exist in liquid full systems or at pumps handling sub-cooled materials, such as from storage tanks or surge drums or in systems containing a cooler in the pump suction piping.

5. Next, consider the elevation of the minimum liquid level above the bottom tangent of a vertical vessel.

The minimum controlled liquid level should be used to set NPSH availability. The engineer should consider if it is ever likely to have an operation at the pump design capacity with the liquid level below the minimum controlled level. In such cases, the NPSH availability should be taken from the lowest liquid level at which the pump is expected to operate at the design capacity.

6. Finally, the need for and amount of contingency must be evaluated. Consider the following when determining the amount of NPSH contingency to be provided:

Additional piping loss if the suction piping system has a tendency to become dirty or fouled in operation.

The possibility of greater pump capacity due to a larger impeller or motor.

In any event, a standard contingency factor of 15% of the estimated pump NPSH requirement, with a minimum of two feet, should be added to the vessel elevation. Greater contingency should be added if indicated by the above considerations. The engineer's calculation should clearly record the amount and reason(s) for the contingency provided.

7. The suction vessel elevation necessary to satisfy the estimated pump NPSH requirements can now be determined by adding the feet of flowing liquid from Items 1, 2, 3, and 6.

From this total, deduct the feet of flowing liquid from Items 4 and 5. The net result is the minimum elevation above the base line for the bottom of a horizontal suction vessel or the bottom tangent line of a vertical suction vessel to suit NPSH requirements. Mechanical and physical requirements should also be considered before setting the final vessel elevation.

THERMOSYPHON REBOILER SYSTEMS

The hydraulic design of a Thermosyphon reboiler system requires very careful consideration since the driving force is derived only from the difference in densities between the inlet liquid and the mixed phase outlet. For a typical maximum vaporization of 30%, the engineer can use the following approximate method to arrive at a first trial line size:

For inlet piping: $12 < d^2/Q < 15$, or $d = \sqrt{Q}(12 \text{ to } 15)$

For outlet piping: $24 < d^2/Q < 30$, or $d = \sqrt{Q}(24 \text{ to } 30)$

Where: d = nominal pipe size in inches

Q = reboiler duty in millions of Btu per hour

With these trial line sizes or sizes determined in the previous section, the engineer can now proceed to a more accurate analysis of the system.

The following pressure drops are all additives in determining the liquid head requirements.

1. Entrance loss (psi) = $(0.5 V^2/2g_c) * (\text{Sp.Gr.}/2.31)$

V = Velocity, ft/sec

Sp.Gr. = liquid specific gravity

g_c = Newton's-law proportionality factor = 32.174 ft-lb/lb_f-sec²

2. Line loss to Exchanger = (psi/100 ft) * (equivalent length/100)

3. Line loss to Column = (psi/100 ft) * (equivalent length/100)

4. Exchanger loss = specified loss in psi

5. Exit loss (psi) = $(V^2/2g_c) * (Sp.Gr./2.31)$

V = Velocity, ft/sec

Sp.Gr. = liquid specific gravity

g_c = Newton's-law proportionality factor = 32.174 ft-lb/lbf-sec²

6. Static loss to Column (psi) = $H * (Sp.Gr./2.31)$

H = estimated vertical length of return line, ft

Sp.Gr. = composite specific gravity

7. Contingency estimated between 1/2 and 1 psi or equal to line loss.

The sum of the above pressure drops is now converted to the feet of liquid head required.

$$\text{Head} = \frac{\text{Total psi} * 2.31}{\text{Sp.Gr.}} = \text{feet}$$

Sp.Gr. = liquid specific gravity

This head is now the required driving head in feet as determined from the minimum liquid level in the vessel to the centerline of the reboiler. This procedure can be used for vertical Thermosyphon reboilers if the centerline of the exchanger is considered to be the mid-point of the tube length.

HEATER PRESSURE DROPS

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

The following 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

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 judgment 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

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

- 25 psi minimum

- 50% of system friction pressure drop

- 10% of pump differential

Most other control valves are allotted pressure drops 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.

LINE SIZING/HYDRAULICS – ANSWERS

LIQUID LINE ΔP

Flowing GPM = 500

Viscosity (centistokes) = 0.6

Flowing Sp. Gr. = 0.75

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

$$\Delta P = 0.88 \times 0.75 = 0.66 \text{ psi}/100'$$

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

$$\Delta P = 0.185 \times 0.75 = 0.14 \text{ psi}/100'$$

C. Find velocity in 8" Sch 40 pipe

$$\text{Velocity} \approx 200 \text{ fpm}$$

D. Find corrected $\Delta P/100'$ in 6" Sch 80 pipe if $v = 50$ centistokes

$$\Delta P = 0.88 \times 0.75(50/0.6)^{0.2} = 1.60 \text{ psi}/100'$$

E. What size pipe would result in a $\Delta P/100' = 0.28$ if flow is 4000 gpm; Sp. Gr. = 0.80 and $v = 0.6$ cSt?

$$\Delta P_0 = 0.28/0.80 = 0.35 \text{ psi}/100'$$

16" - 3/8" wall

VAPOR LINE ΔP

Flowing Quality = 40,000 lb/hr

Specific Volume = 0.9 cu.ft./lb

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

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

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

$$\Delta P = 0.275 \times 0.9 = 0.25 \text{ psi}/100'$$

C. Find velocity in 8" Sch 40 pipe

$$\text{Velocity} \approx 1950 \times 0.9 = 1430 \text{ fpm}$$

D. What size pipe would result in a $\Delta P/100'$ equal to or less than 0.4 psi if flow is 100,000 lb/h and density is 2 lb/cu.ft.?

What is velocity in line?

$$\text{Spec. Vol.} = \frac{1}{2 \text{ lb/cu.ft.}} = 0.5 \text{ cu.ft./lb}$$

$$\Delta P_0 = 0.4/0.5 = 0.8 \text{ psi}/100'$$

10" Sch 40

$$\text{Velocity} \approx 3000 \times 0.5 = 1500 \text{ fpm}$$

TWO PHASE FLOW

$$\text{Liquid Volume Fraction} = \frac{V_L}{V_L + V_G} = \frac{\frac{W_L}{S.G. \times 62.5}}{\frac{W_L}{S.G. \times 62.5} + \frac{W_G}{\#/ft^3}}$$

$$= \frac{\frac{500 \times 60 \times 8.33 \times 0.75}{0.75 \times 62.5}}{\frac{500 \times 60 \times 8.33 \times 0.75}{0.75 \times 62.5} + \frac{40,000}{1/0.9}}$$

$$= \frac{4000}{4000 + 36,000} = \frac{4000}{40,000} = 0.10$$

$$\text{Total Flow Gas} = W_L + W_G = 187,500 + 40,000 = 227,500 \#/h$$

$$\text{Total Flow Liquid} = \frac{W_L + W_G}{S.G. \times 500} + \frac{227,500}{0.75 \times 500} = 607 \text{ gpm}$$

Try 12" LINE (Schedule 80)

$$\frac{\text{Total Flow } \Delta P_G}{\text{Total Flow } \Delta P_L} = \frac{\Delta P_{GO} \times \frac{1}{\#/ft^3}}{\Delta P_{LO} \times S.G.} = \frac{0.9 \times \frac{1}{1/0.9}}{0.032 \times 0.75} = \frac{0.81}{0.024} = 33.75$$

$$\Delta P_{TP} = \text{Total Flow } \Delta P_L \times \text{Factor} = 0.024 \times 7.0 = 0.168$$

TWO PHASE FLOW

Try 10" LINE (Schedule 80)

$$\frac{\text{Total Flow } \Delta P_G}{\text{Total Flow } \Delta P_L} = \frac{\Delta P_{GO} \times \frac{1}{\#/\text{ft}^3}}{\Delta P_{LO} \times \text{S.G.}} = \frac{2.4 \times \frac{1}{1/0.9}}{0.10 \times 0.75} = \frac{2.16}{0.075} = 28.8$$

$$\Delta P_{TP} = \text{Total Flow } \Delta P_L \times \text{Factor} = \underline{0.075} \times \underline{7} = 0.56$$

Use 10" LINE



HYDRAULIC TABULATION

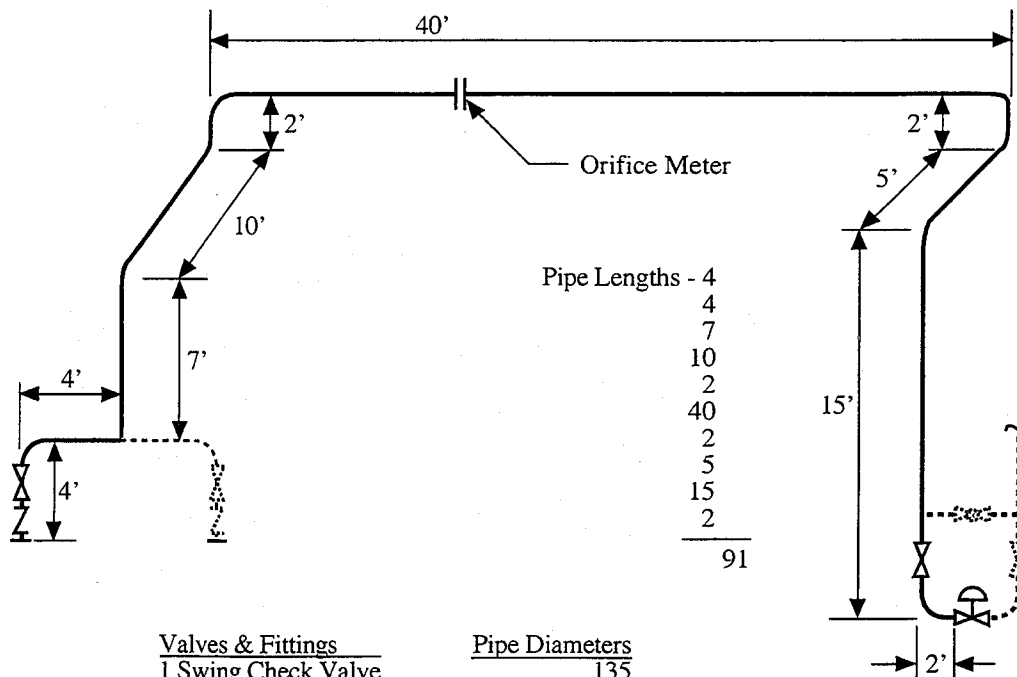
WORKSHEET

PROJECT NO. _____
SHEET _____ OF _____
BY _____
DATE _____

VAPOR AND LIQUID LINE (TWO PHASE FLOW)					
(1) LIQUID FLOW USGPM	500				
(2) LIQUID FLOWING SP. GR.	0.75				
(3) LIQUID FLOW LB./HR. $\times 10^3$	187,500				
(4) VAPOR FLOW LB./HR. $\times 10^3$	40,000				
(5) TOTAL LB./HR. $\times 10^3$	227.0				
(6) VAPOR SP. VOL CU. FT./LB.	0.9				
(7) LIQUID VOLUME CF/S $= \frac{\text{GPM}}{448}$	1.12				
(8) VAPOR VOLUME CF/S	10				
(9) TOTAL VOLUME CF/S	11.12				
(10) VOL L/TOTAL VOL. = LVF	0.10				
(11)					
(12) LINE SIZE, INCHES	10"				
(13) PIPE SCHEDULE	80				
(14) IF ALL LIQUID USGPM $(1) \times (5) / (3)$	607				
(15) FRICTION PSI/100 FT. (UNCOR.)	0.1				
(16) ΔP_L° (CORR.) $(15) \times (2)$	0.075				
(17) IF ALL GAS LB./HR. $\times 10^3$ (5)	227				
(18) FRICTION PSI/100 FT. (UNCOR.)	2.4				
(19) ΔP_G° (CORR) $(18) \times (6)$	2.16				
(20)					
(21) $\Delta P_G^\circ / \Delta P_L^\circ$ $(19) / (16)$	28.8				
(22)					
(23) $\Delta P_{TP}^\circ / \Delta P_L^\circ = (\text{FACTOR FROM PD-395A})$	7				
(24)					
(25) $\Delta P_L^\circ \times (\text{FACTOR})$ $= \Delta P_{TP}^\circ$ (CORR.) $(16) \times (23)$	0.53				
(26)					
(27) VELOCITIES FPM (CORR.)					
ΔP_L° FICTITIOUS ALL LIQUID ΔP		$\Delta P_G^\circ \approx$ FICTITIOUS ALL GAS ΔP			

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Typical Calculation of Piping Equivalent Length. 8" Pump Discharge Line



Valves & Fittings
 1 Swing Check Valve
 2 Gate Valves
 8 90° Elbows
 1 Tee (Branch Flow)
 1 Tee (Through Flow)

Pipe Diameters
 135
 2 x 13 = 26
 8 x 20 = 160
 60
 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.

1 LS-R00-32