

UOP Engineering Design Seminar

FALL 1991

LINE SIZING

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Type 1. Gravity flow

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

Remarks: Can be tighter if line is mostly vertical.

Type 2. Pump Suction

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

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

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

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

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

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

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

Type 3. Pump Discharge

- a. Single line pump discharge

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

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

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

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

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

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

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

Where Q = flowing GPM

d = i.d. (inches)

cstks = flowing viscosity in centistokes

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

Criteria:

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

where ρ_v = flowing density, lb/ft³

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

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

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

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

c. Branches from a pump discharge.

Criteria: Treat as Type 3a.

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

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

Criteria: Treat as Type 3b.

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

Type 4. Liquid to non-pumped reboiler.

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

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

Type 5. Reboiler return to column

Criteria:

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

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

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

Type 6. Column overhead vapor

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

Criteria:

Limiting equations

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

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

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

p = receiver pressure, psia

d = i.d., inches

ρ_v = overhead vapor flowing density, lb/ft³

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

b. FCC main column overhead vapor

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

c. Crude vacuum column overhead

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

Type 7. Column hot vapor by-pass

Criteria: $\Delta P/100'$ (PSI) = 0.5 max.

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

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

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

Type 8. Column overhead condenser rundown.

a. Totally condensing, single phase:

Criteria:

Limiting equations

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

Velocity (FPM) = 200 max.

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

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

Remarks:

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

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

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

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

- c. Partially condensing, vapor and liquid present.

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

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

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

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

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

Type 9. Compressor suction

a. Reciprocating compressor

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

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

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

p = line pressure, psia
MW = gas molecular weight

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

b. Centrifugal compressor

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

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

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

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

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

Type 10. Compressor discharge

a. Reciprocating compressor

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

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

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

p = line pressure, psia
MW = gas molecular weight

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

b. Centrifugal compressor

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

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

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

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

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

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

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

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

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

Type 12. Feed to a column

Criteria and remarks:

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

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

3. If line is other as indicated in 1 or 2, above:

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

- A) If flow is 100% liquid:

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

- B) If flow is 100% vapor:

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

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

Type 13. Vacuum unit heater transfer

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

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

Type 14. Steam

Criteria and remarks:

1. Saturated, 15 psig and less:

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

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

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

2. Saturated, over 15 psig:

Velocity (FPM) = 10,000 max.

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

p = pressure, psia.

3. Superheated, over 200 psig

Velocity (FPM) = 15,000 max.

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

p = pressure, psia.

Type 15. Condensing steam turbine exhaust

The method of sizing is as follows:

Determine equivalent length of the line.

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

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

Velocity (FPM) = $1200/\sqrt{\rho_v}$ max. ρ_v = flowing density of steam at inlet to condenser, lb/ft³Type 16. Liquid at its bubble point to a control valve or steam trapCriteria: $\Delta P/100'$ (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.

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

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

1. With control valve located in steam line.

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

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

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

2. With control valve in condensate line.

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

3. General Remarks, applicable to all cases.

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

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

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

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

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

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

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

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

Type 19. Fuel gas to heaters

Criteria:

1. Before control valve:

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

p = gauge pressure before valve

2. After control valve:

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

p = gauge pressure after valve.

If pressure is not known, the following standard values may be used:

For gas with gross heating value of 500 BTU/SCF or more:
10 psig

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

3. Header:

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

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

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

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

Type 20: Fuel oil to heaters

Criteria:

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

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

Note that this is laminar flow.

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

Type 21: Atomizing steam to heaters

Criteria: Usual steam criteria

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

Type 22: Instrument air piping

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

Branch Header line size:

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

Type 23: Cooling water

Criteria:

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

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

Type 24. Static electricity consideration

Criteria: Velocity (FPM) = 400 max.

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