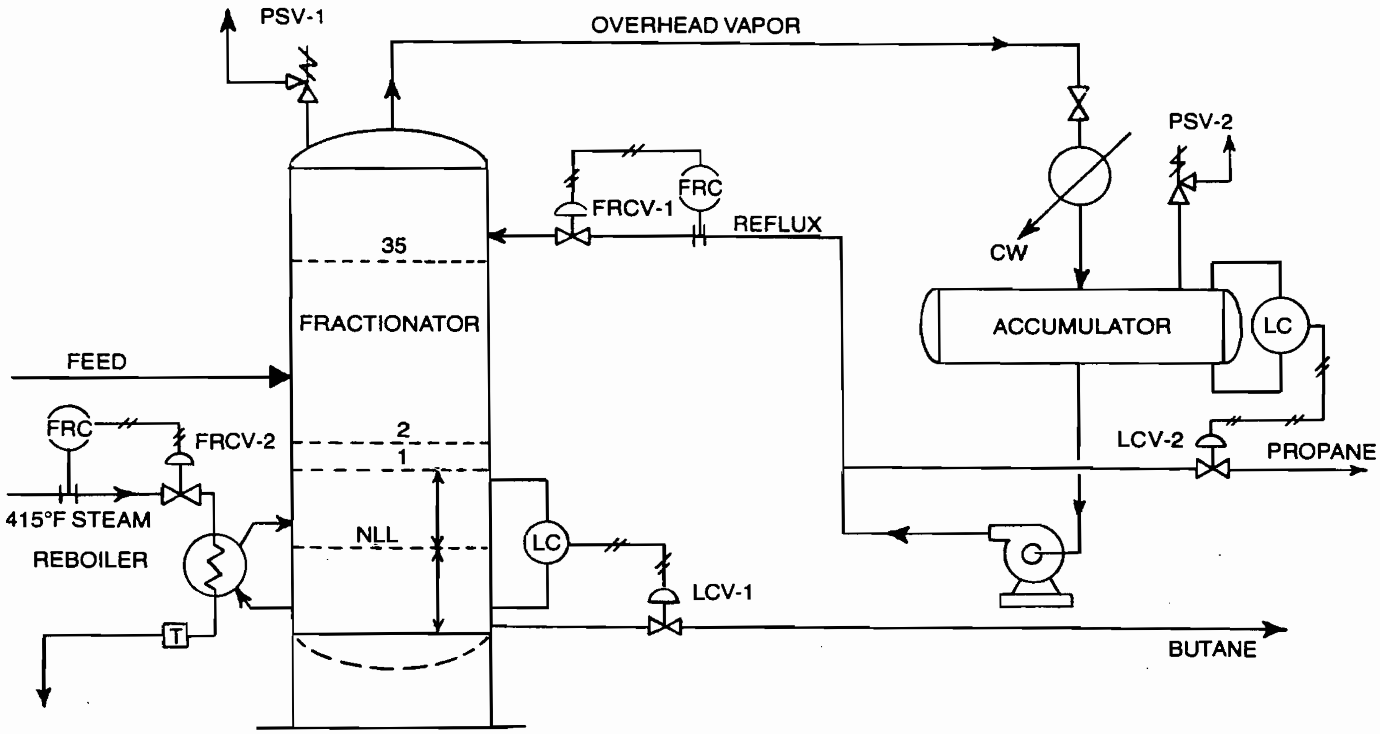

Problem: Safety relief valve sizing calculations for fractionating column.

and reduced temperature is

$$T_r = \frac{T_1}{T_{ca}} = \frac{872}{344} = 2.53$$

The compressibility factor, Z, is now obtained from Chart 3.9, page 166.

$$Z = 1.005$$

Substituting:

$$W = \frac{347.91\,(0.975)\,(0.1789)\,(1{,}169.7)\,\sqrt{16}}{\sqrt{872\,(1.005)}}$$

$$= \underline{\underline{9{,}591 \text{ pph}}}$$

NOTE: Initial factory adjustment specifications should call for the longest blowdown possible without chattering.

PROBLEM: Safety Relief Valve Sizing Calculations for Fractionating Column.

Given

Normal Operating Pressure:	217 Psig
Normal Operating Temperatures:	
(1) Overhead	130°F
(2) Bottoms	220°F
Normal Overhead Vapor Rate:	18,000 pph
Molecular Wt. of Overhead Vapors:	46.9
PSV-1 and PSV-2 Set Pressure:	250 Psig
PSV back pressure:	0 Psig

Factionator Dimensions:

Diameter:	4′-8″ O D
Height:	55′-0″ T-T
Elevation:	6′-0″ Above Grade
Heads:	2:1 Elliptical ASME Code

Insulation:	1½" Thick Calcium Silicate, with aluminum sheet metal cover.
Liquid Level:	4'-0" (bot. of tower)
Tray Spacing:	2'-0" (2½" liquid on ea. tray.)

Reboiler:

Tube I D :	0.584 inch
Steam:	415°F saturated
Heat Duty:	2,160,000 Btu/Hr
Dimensions:	16" OD x 16'-0" T-T
Configuration:	See Sketch above.

Accumulator Dimensions:

Diameter:	4'-0" O.D.
Length:	10'-0"
Heads:	2:1 elliptical ASME Code
Insulation:	None
Elevation:	10'-0" above grade

Calculation of Contingency Relief Rates:

1. Blocked Outlet
If the block valve on the inlet to the condenser is inadvertently closed during normal operation, the total overhead vapor rate must be relieved, i.e., 18,000 pph of 46.9 *MW* vapors. The relieving pressure would be 110% of set pressure (250 x 1.1) + 14.7 = 289.7 psia. If process data is not available to provide the corresponding relief temperature, estimate it from Chart 3.56, page 202 to be 150°F. The temperature may also be estimated from Chart 3.44, page 191 by drawing a parallel vapor pressure line to propane (*MW* = 44.094).

2. Cooling Water Failure
The total overhead vapor rate must be relieved. Relieving pressures and temperatures may be calculated as in Case "A".

3. Loss of Reflux
Normally, loss of reflux because of instrument failure (FRC) will not result in an overpressure of the fractionator. However, if it is possible for loss of reflux to cause flooding of the condenser, the total overhead vapor rate must be relieved. Such a condition could be caused by: (a) LCV valve too small to remove condensed liquid within reasonable operator response time, or (b) loss of reflux pump (with no spare). Each situation must be individually evaluated.

4. Instrument Failure
Failure of FRCV-1 and LCV-2 could result in overpressure due to flooding of the condenser as discussed in Case "C". Normally, failure of LCV-1 would not cause overpressure.
If FRCV-2 were to fail in the full open position, an overpressure could be caused. Additional vapors generated would not normally be as great as the overhead rate, since a large excess of heat transfer area is not normally provided in a reboiler. If inspection of the heat exchanger and control valve specification sheets fail to confirm this, a detailed analysis of the heat transfer in the reboiler loop must be performed.

5. Split Reboiler Tube
In the example given, steam to the reboiler is on flow control. Although the tower would be upset, it is doubtful that an overpressure would occur as a result of a split reboiler tube.

6. External Fire
Calculations must now be made to find the orifice area of a valve which will relieve the vapors generated by a fire occurring around and beneath the fractionator and the overhead accumulator.
The surface area of a vessel exposed to fire which is effective in generating vapor is that area wetted by its internal liquid contents. A valid assumption in this case is that the entire fractionator below the 25'-0" height (API recommendation) should be considered wet. Therefore, only 19'-0" of the fractionator need be considered. However, not all of the fractionator surface is wetted, i.e. only 4' in the bottom and 2½" in each tray. Only the wetted portion must be included. The approximate surface area of the 2:1 elliptical head is calculated by the following formula:

$$A_h = 1.09\,(O\,D)^2$$

The wetted area of the fractionator may be calculated as follows:

No. of trays within 25' of grade = 6

$$A_{wet}\ (3.14 \times 4.667)\left[4.0 + (6)\left(\frac{2.5}{12}\right)\right] + 1.09 \times (4.667)^2 = 100.7 \text{ sq. ft.}$$

The surface of the reboiler may also produce vapors when fractionator bottoms liquid is in the shell rather than in the tubes. Its wetted area is (3.1416 x 1.333 x 16) = 67 sq. ft.

Use the equation $Q = 21{,}000\ FA^{0.82}$ to solve for the total amount of heat absorbed from the fire.

Where

Q = total heat absorption (input) to the wetted surface, in British thermal units per hour.
A = total wetted surface, in square feet.
F = environment factor, values of which are shown in Chart 3.65, page 215, for various types of installations.

Interpolating on Chart 3.65, page 215, the value of F is found to be 0.225.

Caution: The total heat absorption, Q, for the fractionator and from the heat absorbed by the reboiler must be computed separately. Calculations must be of the form $A_1^{0.82} + A_2^{0.82}$, *NOT* $(A_1 + A_2)^{0.82}$!

Solving for heat absorption in the fractionator from the fire

$$Q_f = 21{,}000\ (0.225)(100.7)^{0.82}$$
$$= 207{,}437 \text{ Btu/hr.}$$

Heat absorption in the reboiler from the fire

$$Q_{rf} = 21{,}000\ (0.225)\ (67)^{0.82}$$
$$= 148{,}519 \text{ Btu/hr.}$$

The total additional heat, resulting from a fire engulfing the fractionator and reboiler only, is

$$Q_t = 207{,}437 + 148{,}519 = 355{,}956 \text{ Btu/hr.}$$

Since this additional heat input results in vaporization of overhead material, calculate the additional vapors resulting from the fire (allowing 20% overpressure for fire):

P (relieving) = (250 x 1.2) + 14.7 = 314.7 psia
Estimated T (relieving) is 156°F as discussed under "A."
h_{fg} = 108 Btu/lb. (Chart 3.56) (page 202)
W = 355,956/108 = 3,300 lb./hr.

This is the relief requirement of PSV-1 for the contingency of a fire engulfing the fractionator and reboiler only.

If a fire engulfs the overhead accumulator as well as the fractionator and reboiler, additional relief should be considered for the accumulator. In this example, a block valve is located upstream of the condenser, necessitating a relief valve, PSV-2, to protect the accumulator in case of a fire while blocked in or shut down. If the block valve were omitted, one PSV could be considered for the entire system, provided the pressure drop between the source and PSV did not exceed 3% of set pressure.

For a fire engulfing the overhead accumulator, calculate the relief rate as follows:

A_{vessel} = (3.14)(10) + (1.09)(4.0)^2 = 143 sq. ft.
A_{wet} = (0.5) (143) = 71.5 sq. ft.
F_{bare} = 1.0
Q = (21,000)(1.0)(71.5)$^{0.82}$ = 696,226 Btu/hr.
W = 696,226/108 = 6,446 lb/hr. (relief rate for PSV-2)

Summary of Contingency Relief Rates for PSV-1:

Contingency	M.W.	lb/hr	Temp.,°F	Press., PSIA
A. Blocked Outlet	46.9	18,000	150	289.7
B. Cooling Water Failure	46.9	18,000	150	289.7
C. Loss of Reflux	46.9	18,000	150	289.7
D. Instrument Failure	46.9	18,000	150	289.7
E. Split Reboiler Tube	–	0	–	–
F. External Fire	46.9	3,300	156	314.7

It should be recognized that the approach described above represents a conservative, but practical solution to determining relief rates for a distillation system. Since a distillation column is a dynamic system sensitive to concentration (which varies throughout the column), temperature, pressure and many other variables, the exact relief rate for each contingency would require a very complex study of the system, which is usually not warranted.

Generally, when a distillation column is overpressured, the process temperature in the reboiler rises and the ΔT for heat transfer decreases, resulting in poorer heat transfer, so that the boil-up or overhead vapor rate would not reach the normal rate (18,000 #/hr. in the example). However, each system must be evaluated or judged on the basis of its own control scheme, process variables, etc. Usually the relief rate will not exceed the normal overhead vapor rate.

Calculation of Relief Valve Sizes:

By inspection, contingencies A, B, C and D will determine the valve size.

Safety and safety relief valves in gas or vapor service may be sized by use of one of the following formulas that are modifications of the basic ASME and API formula. Most manufacturers' sizing methods also agree with these forms.

Basic ASME and API Formula

$$W = CKAP_1 \sqrt{\frac{M}{ZT}} \qquad (1)$$

Modifications of Formula (1)

$$W = \frac{CKAP_1 K_b \sqrt{M}}{\sqrt{TZ}}$$

or (M-1)

$$A = \frac{W \sqrt{TZ}}{CKP_1 \ K_b \ \sqrt{M}}$$

$$V = \frac{6.32\, CKAP_1 K_b}{\sqrt{TZM}}$$

or (M-2)

$$A = \frac{V \sqrt{TZM}}{6.32\, CKP_1 K_b}$$

$$V = \frac{1.175\, CKAP_1 K_b}{\sqrt{TZG}}$$

or (M-3)

$$A = \frac{V \sqrt{TZG}}{1.175\, CKP_1 K_b}$$

where

- W = flow through valve, in pounds per hour.
- V = flow through valve, in standard cubic feet per minute at 14.7 psia and 60°F.
- C = coefficient determined by the ratio of the specific heats of the gas or vapor at standard conditions. This can be obtained from Chart 3.78, page 228.
- K = coefficient of discharge, which value is obtainable from the valve manufacturer. The K for a number of nozzle-type valves is 0.975.
- A = effective discharge area of the valve, in square inches.
- P_1 = upstream pressure, in pounds per square inch absolute. This is the set pressure multiplied by 1.10 or 1.20 (depending on the overpressure permissible) plus the atmospheric pressure, in pounds per square inch absolute.
- K_b = capacity correction factor due to back pressure. This can be obtained from Chart 3.80, page 230, which applies to conventional safety relief valves, or from Chart 3.81, page 231, which applies to balanced bellows valves. The correction factor value should be read from the curve specifically applying to the type of valve under consideration. In connection with Chart 3.81, page 231, for set pressures lower than 50 psig, the valve manufacturer should be consulted for the proper value of correction factor K_b.
- M = molecular weight of the gas or vapor. Various handbooks carry tables of molecular weights of materials, but the composition of the flowing gas or vapor is seldom the same as that listed in the tables. This value should be obtained from the process data.
- T = absolute temperature of the inlet vapor, in degrees Rankine (Fahrenheit + 460).
- Z = compressibility factor for the deviation of the actual gas from a perfect gas, a ratio evaluated at inlet conditions. Values of Z for various paraffin hydrocarbons can be obtained from Chart 3.12, page 159.
- G = specific gravity of gas referred to air = 1.00 at 60°F and 14.7 psia.

In chart 3.78, page 228, k is tabulated, where

$$k = \frac{C_p}{C_v}, \text{ i.e.,}$$

the ratio of specific heats of any ideal gas, or the ratio of specific heats of a diatomic actual gas that expands in accordance with the Perfect Gas Laws. Values of k can be determined from the properties of gases as presented in any acceptable reference work.

The tabulation in Table 4.66, page 347, also lists n, where n = isentropic expansion coefficient of an actual gas, such as a paraffin hydrocarbon, expanding through an orifice or nozzle of a safety relief valve in which the upstream pressure is at saturation and the pressure in the throat of the orifice or nozzle is the critical flow pressure.

When k or n cannot be determined, it is suggested to let C = 315.

Establishing Values:

- W = 18,000 pph (contingencies a-d), or 3,300 pph (contingency f)
- C = 306.86 (from Chart 3.78, page 228, since n = 0.93 for 46.9 MW hydrocarbon, Chart 3.80, page 230.
- K = 0.975
- P_1 = (250 + 10%) + 14.7 = 289.7 psia
- K_b = 1.0 (from Chart 3.82, page 232.

M = 46.9
T = 610°R
Z = 0.69 (from Chart 3.12), page 159.

To calculate orifice area,

$$A = \frac{(18{,}000)\ \sqrt{(610)\,(0.69)}}{(306.86)\,(0.975)\,(289.7)\,(1.0)\ \sqrt{46.9}}$$

$$A = \underline{\underline{0.622 \text{ sq. in.}}}$$

An "H" orifice is selected.

Rupture Disc

PROBLEM: Rupture Disc Calculation for Liquid Relief

Given

Relief rate:	6,500 gpm
Relieving specific gravity:	1.5
Liquid viscosity:	30,000 cp
Disc burst pressure:	110 psig
Backpressure developed:	0 psig

The formula used for sizing a rupture disc for liquid relief is

$$a = \frac{0.0438\,Q}{K_v}\sqrt{\frac{S}{\Delta P}}$$

where:

a = required relieving area, sq. in.
K_v = capacity correction factor due to viscosity
ΔP = pressure drop across disc at Q, psid, equal to burst pressure + accumulation (10%) – backpressure
Q = required relieving capacity, gpm
S = specific gravity at relieving temperature

Establishing values:

ΔP = 110(1.1) - 0 = 121 psid
Q = 6,500 gpm
S = 1.5

A value for K_v must be determined from a trial calculation. Using an assumed value of K_v = 1, solve for a trial required area.

$$a' = 0.0438\,(6{,}500)\sqrt{\frac{1.5}{121}}$$
$$= 31.699 \text{ sq. in.}$$

Using area a' as a minimu
transverse internal area is e
Note: If disc assembly inle
the smaller of the two.
schedule 40 pipe is used f
Table 4.57, page 335, ch
whose transverse internal ar

Calculate a value for the R
area and the following form

$$R = \frac{\text{gpm}\ (2{,}800\ G)}{\mu\ \sqrt{a''}}$$

where

a'' = selected area, sq
G = specific gravity
above)
gpm = required relievin
R = Reynolds numb
μ = absolute visco
centipoises

Substituting:

$$R = \frac{6{,}500\ (2{,}800)\ (1.5)}{30{,}000\ \ \ 50.027}$$

Select a value of K_v from

Substituting in the original e

$$a = \frac{0.0438\ (6{,}500)}{0.65}$$
$$= \underline{\underline{48.767 \text{ sq. in.}}}$$

Since this value of a is still
safety head with a sch. 40 bo
is selected.

PROBLEM: Rupture Disc

Given

Relief rate:
Fluid molecular weight:
Isentropic coefficient, n:
Disc burst pressure:
Back pressure developed:

pipe size whose
than this value.
e different, use
ressure services,
bove 2". From
ought steel pipe,
in.

, using the new

ture (same as S

temperature,

7) of K_v = 0.65

e of a", then a
027 sq. in area)

apors or Gases