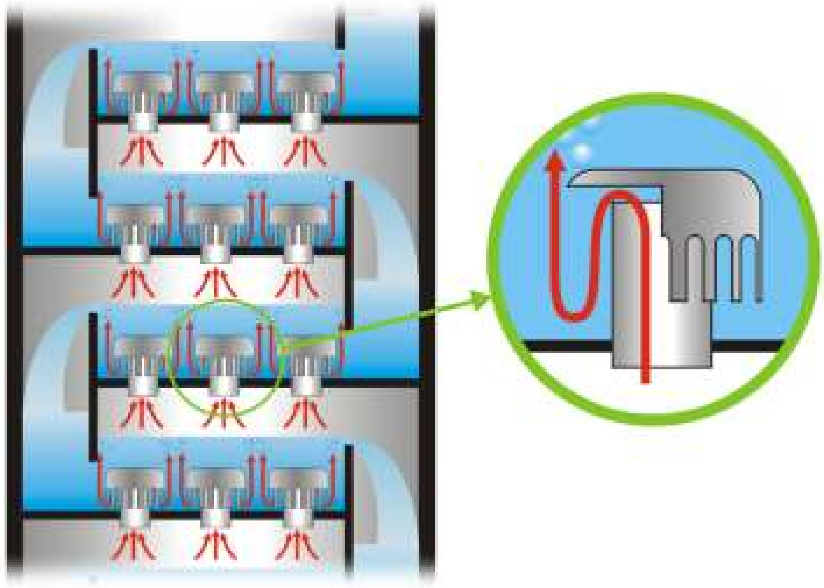

Column Design

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Learning Outcomes

After this lecture you should be able to….

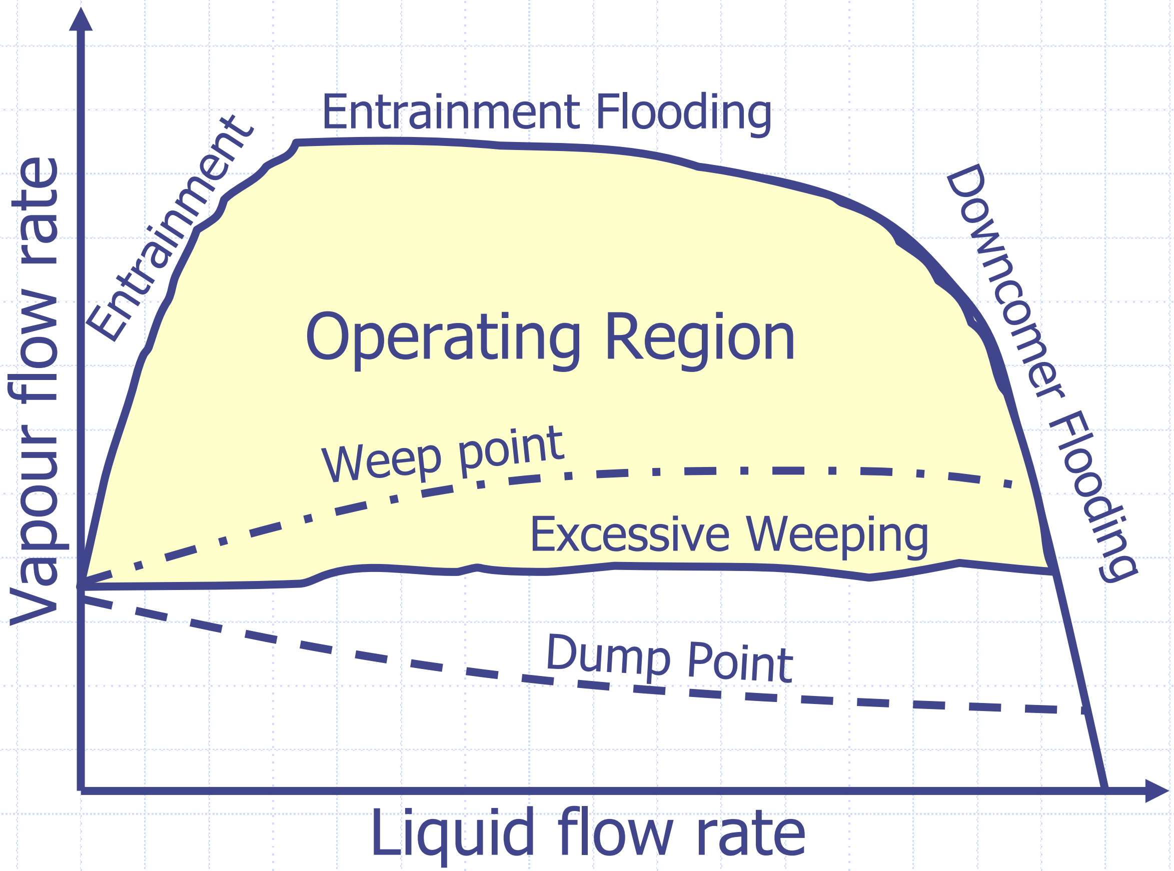
- Explain why the ratio of vapour and liquid velocities is important
- Describe how the vapour velocity can be calculated
- Calculate the volumetric flow of vapour
- Determine the cross sectional area and diameter of the column

Column Design Steps

- Flowrates - Carry out a mass balance to determine mass/molar flowrates of feed, distillate and bottoms and of vapour and liquid in both sections of the column
- Column height - Determine the number of equilibrium stages. Choose a tray or packing and divide number of equilibrium stages by tray efficiency to get actual number of plates or total height of packing. Also, for plates, choose the plate spacing and depth
- Column diameter – determine the vapour velocity and divide vapour flowrate by velocity to give area
- Now have a rough idea as to column size and number of trays or height of packing

Liquid and Vapour flow

Vapour flow rate can cause entrainment and flooding if too high and weeping if too low



Vapour Velocity

Vapour velocities are determined for both the rectifying and stripping sections of the column. They may be different.

If too low, weeping occurs – liquid flows through the holes in the sieve tray, for example.

If too high flooding will occur and liquid will back to the next plate. High velocity can reduce plate efficiency because the contact time between the phases is reduced.

The correct velocity is somewhere in between. The correct velocity depends on the tray type.

Calculate the upper limit for velocity at the point at which flooding occurs.

A design velocity of 80 to 85% of the flooding velocity is then used (ref C&R Vol 6, 11.13).

Flooding Velocity Calculation

For either section, the flooding velocity is estimated from the following equation:

$$u_f = K_1 \sqrt{\frac{\rho_L - \rho_v}{\rho_v}}$$

Where u_f = flooding velocity m/s
K_1 = a coefficient obtained from a chart
ρ_L = liquid density
ρ_v = vapour density

Flooding Velocity contd…

A chart of K_1 versus F_{LV} is available in most books on distillation (McCabe Smith, C & R, etc.). The chart is specific to the type of tray, e.g. sieve. The spacing between the plates must be known. F_{LV} is the liquid vapour flow factor and is given by:

$$F_{LV} = \frac{L_w}{V_w}\sqrt{\frac{\rho_v}{\rho_L}}$$

Where L_w = liquid mass flow rate kg/s
V_w = vapour mass flow rate kg/s
ρ_L = liquid density
ρ_V = vapour density

Some restrictions do apply to this chart such as minimum hole diameter, weir height, non foaming system, liquid surface tension.

Chart of K_1 versus F_{LV}

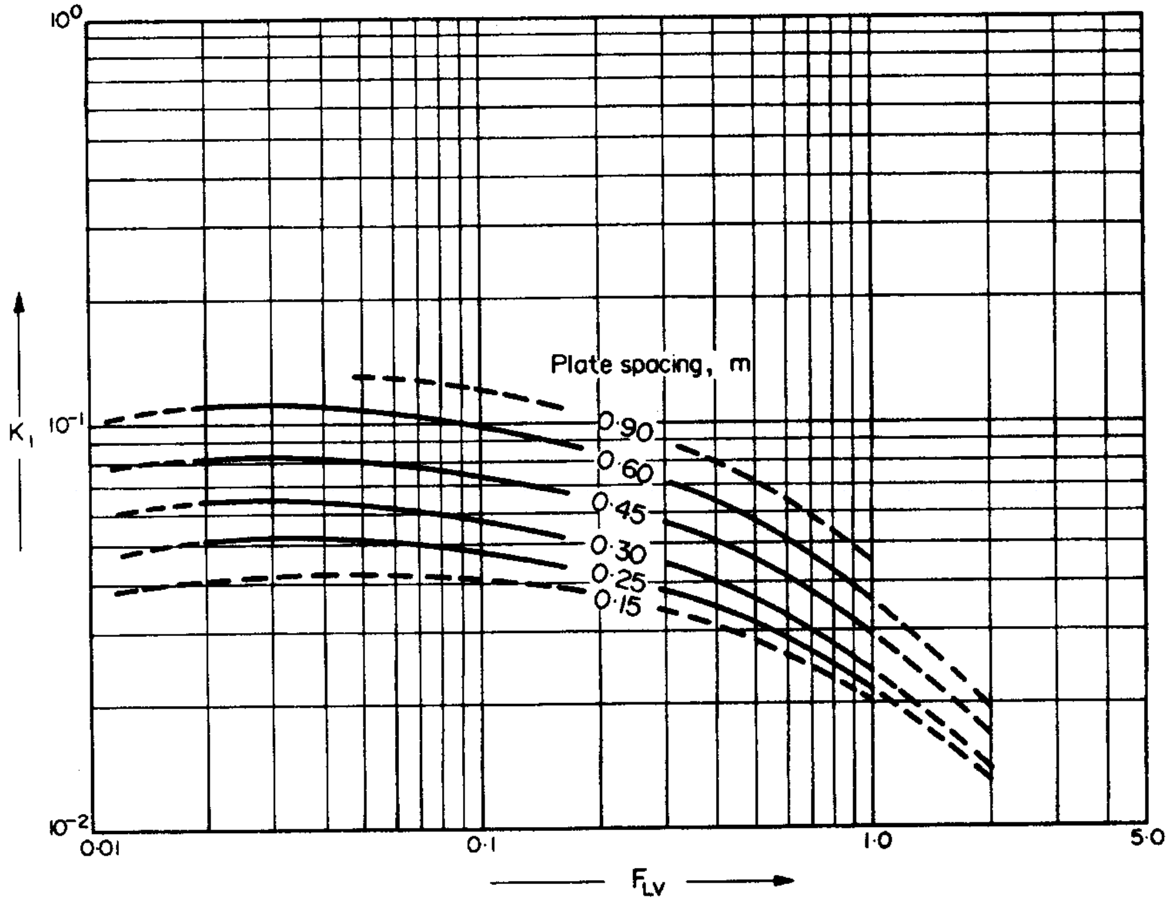


Figure 11.27. Flooding velocity, sieve plates

From C & R, Vol VI, 3rd Ed., p567

Vapour Density Calculation

If the vapour density is unknown, then it can be calculated using the ideal gas law:

$$PV = nRT$$

Where P = column pressure
V = volume of gas (unknown)
n = no. of mols, I.e. the kmol in kmol/hr or can do on a
1 mol basis
R = universal gas constant, 8.314 J/K
T = temperature of vapour

Calculate V using the above equation
Then determine density by multiplying by the molecular weight and dividing by V.

Density calculation example

- What is the density of air outside your airplane window?
- $T = T_o + H.k$
  - T_o = Temp at ground level (25 degC)
  - H = height (m)
  - k is temp gradient over height = -0.0065 degC/m
- $P = P_o(1 + H.k/T_o)^{gM/-Rk}$
  - P_o = atmoshperic pressure
  - g = acceleration due to gravity
  - M = molecular weight
  - R = universal gas constant
- From above we get P and T for air at this elevation
- Now, determine the density
- (Should be about 0.4 kg/m^3 for an elevation of 10,000m)

Column Diameter

The vapour flow rate in either section of the column is obtained from the mass balance in kmol/hr. This is converted to m^3/s as follows:

$$m^3/s = (\text{kmol/hr} \times \text{mol wt.})/(\text{density} \times 3600)$$

From the continuity equation, $q = va$. Since we know the velocity and the flow rate we can determine the cross sectional area and from that the diameter.

Two different velocities will give two different diameters. The same column diameter (the larger) can be used for the entire column to simplify construction.

In this case, the plates in the lower velocity section will have less perforations.

Check for weeping

It is good practice to check that weeping will not occur. For weeping the vapour velocity through the holes in the tray is important.

This is obtained by dividing the minimum vapour flow rate (m^3/s) by the area available for flow, I.e. the total hole area.

This is compared to the vapour velocity at which weeping starts to occur which is given by:

$$u_h = \frac{\left[K_2 - 0.90(25.4 - d_h)\right]}{\sqrt{\rho_v}}$$

Where d_h = hole dimeter and K_2 is obtained from a chart.

The minimum velocity must be greater than the weep velocity.

Tray Spacing

Tray spacing determines the column height.

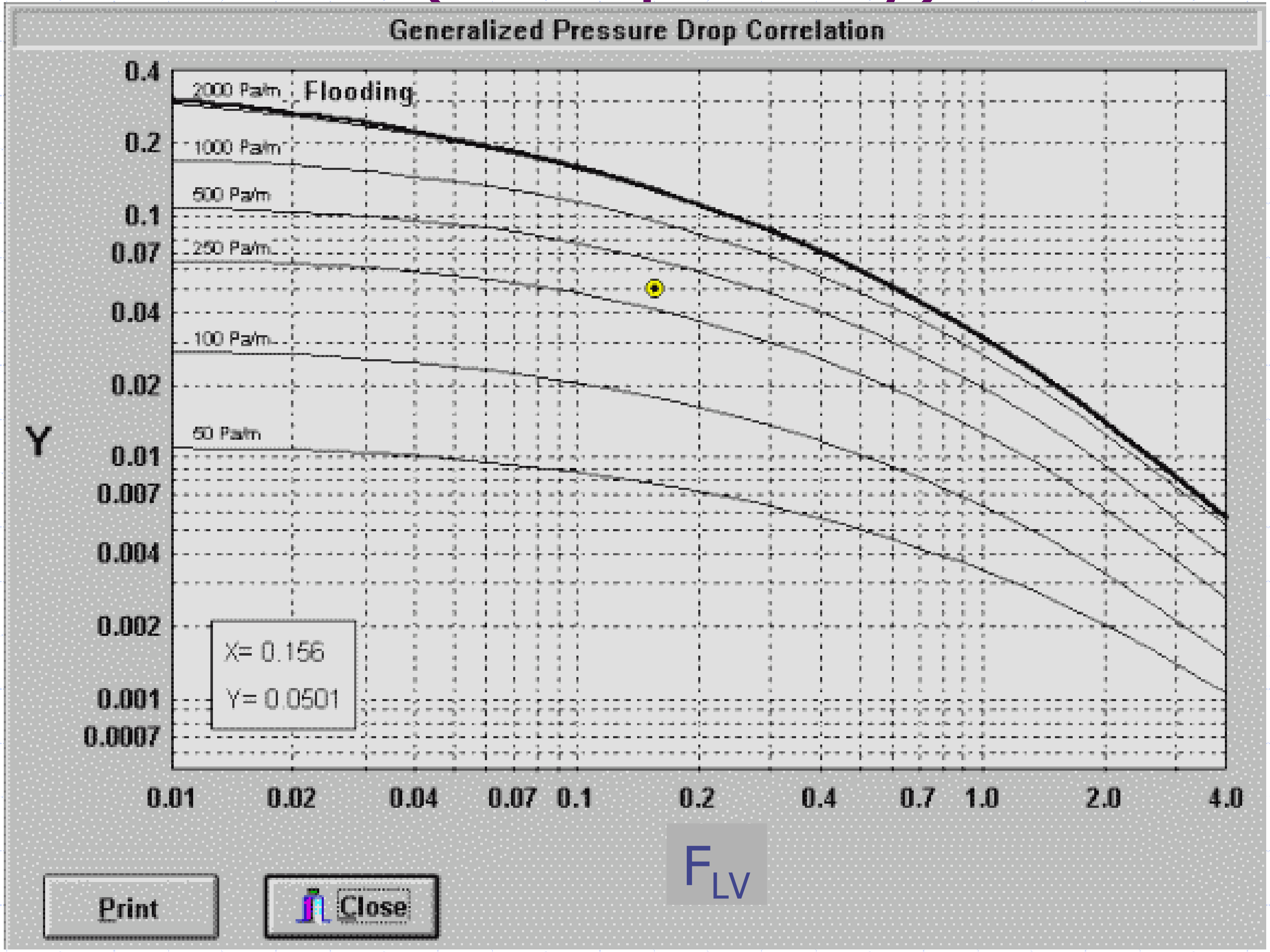
Plates are typically spaced 0.15 to 1m apart

If diameter is > 1m, use a plate spacing of 0.5m

Packed Columns

- Pressure drop < 1000 Pa per m height of packing (1.5" per ft in Seader & Henley, 2nd ed., p233)
- Nominal packing diameter < 1/8th column diameter
- Vapour Liquid flow factor calculated as before (F_{LV})
- Another chart is used of F_{LV} versus Y with lines of constant pressure drop per length of packing
- The Y factor contains the gas velocity we are looking for aswell as correction factors for gas density, liquid density and liquid viscosity (the chart was prepared using data based on trials using water)
- This is known as the Generalised Pressure Drop Correlation, GPDC

GPDC Chart (example only)



Y Factor for packed column

$$Y = \frac{u_o^2 F_P}{g}\left(\frac{\rho_g}{\rho_{H_2O_{(L)}}}\right) f(\rho_L) f(\mu_L)$$

u_o = gas velocity

F_P = packing factor from a table of properties for packings

g = gravity

ρ_g = density of gas

$f(\rho_L)$ = liquid density correction factor

$f(\mu_L)$ = liquid viscosity correction factor

How to calculate column diameter

1. Calculate F_{LV}
2. Decide on flooding pressure drop
3. Read value for Y from chart
4. Rearrange eqn to get $u_{v,f}$
5. Use continuity eqn to get c.s.a. and then diameter

Packed versus Plate Columns

- For D < 0.6m packing is cheaper
- Packing can be made from inert/chem resistant material so good for corrosive
- Good efficiency with low ΔP so good for vacuum
- Packed column copes better with foaming liquid
- Holdup of liquid is low

- Plates can be easier to clean
- Packing can break more easily
- High liquid rates more economical in plate column
- Low liquid rates less of a problem in plate column (incomplete wetting of packing)