Tray Distillation Columns

Efficiency, Flooding
& Weeping

Tray Columns

A tray consist of:

- Overflow or outlet weir
- Downcomer
- Tray Deck

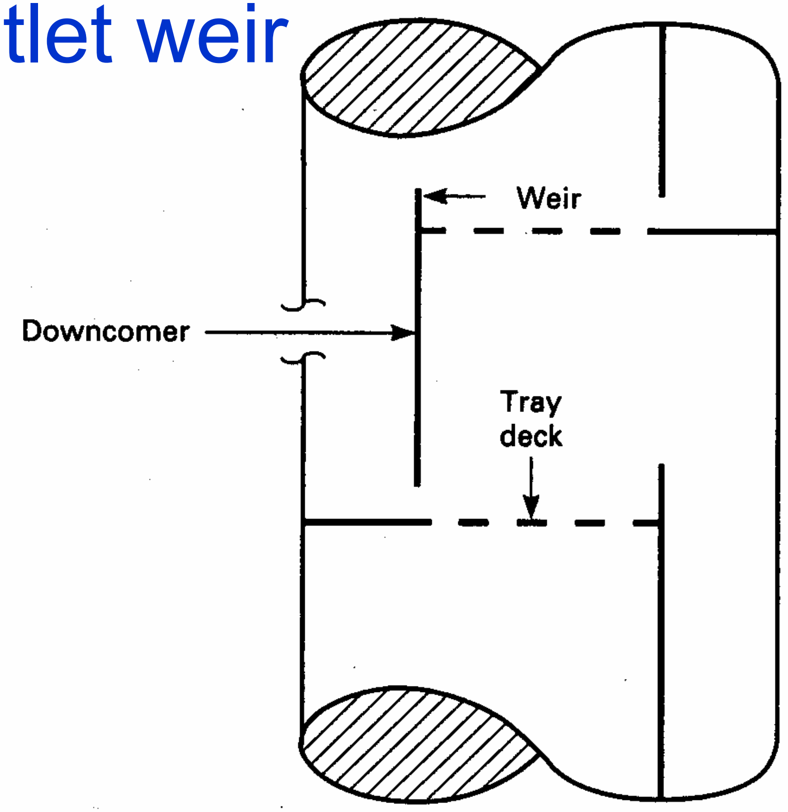

Figure 1.1 Perforated trays.

Tray Efficiency

- Distillation trays in a fractionator operate between 10 and 90 percent efficiency.
- Tray Efficiency : Compare the vapor temperature leaving a tray to the liquid temperature leaving the tray
- Poor Tray Efficiency is caused by:
  - Flooding
  - Dumping

100% Efficiency

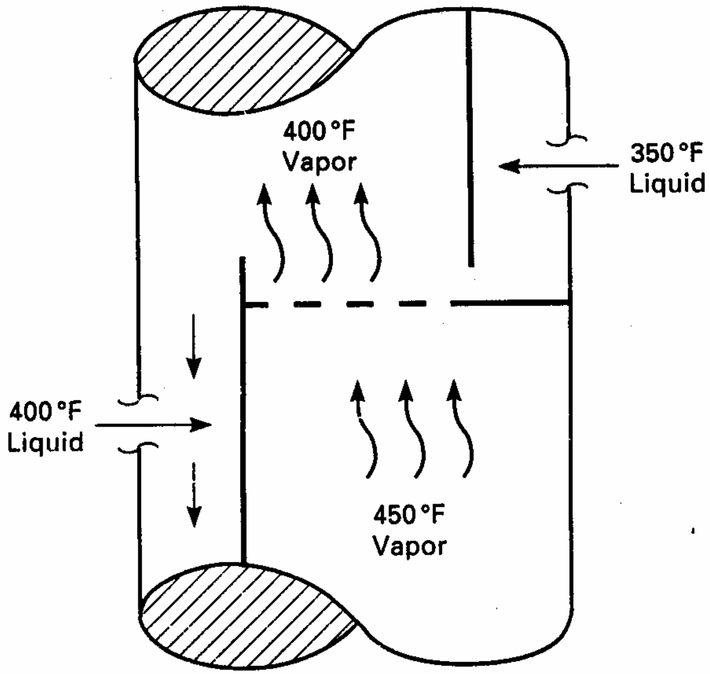

Figure 1.2 Hundred percent tray efficiency.

Zero Percent Efficiency

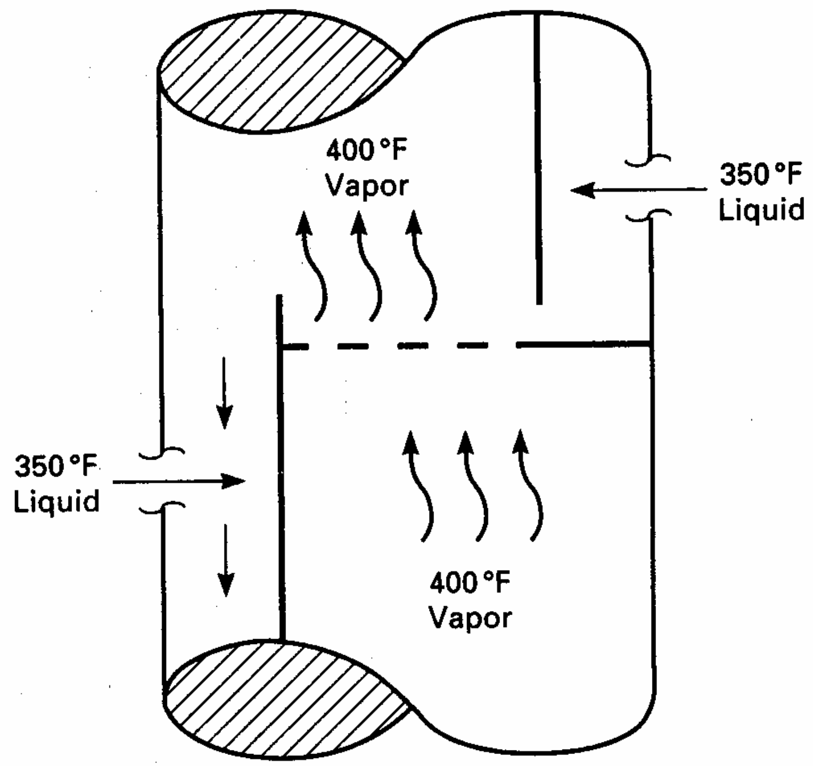

Figure 1.3 Zero percent tray efficiency.

Average Tray Efficiency =10%

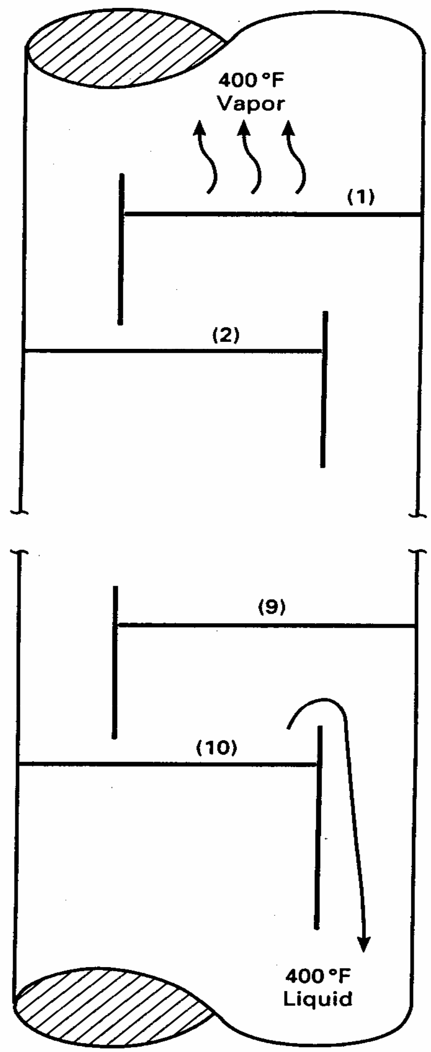

Figure 1.4 Average tray efficiency = 10 percent.

Flooding due to lack of a downcomer clearance

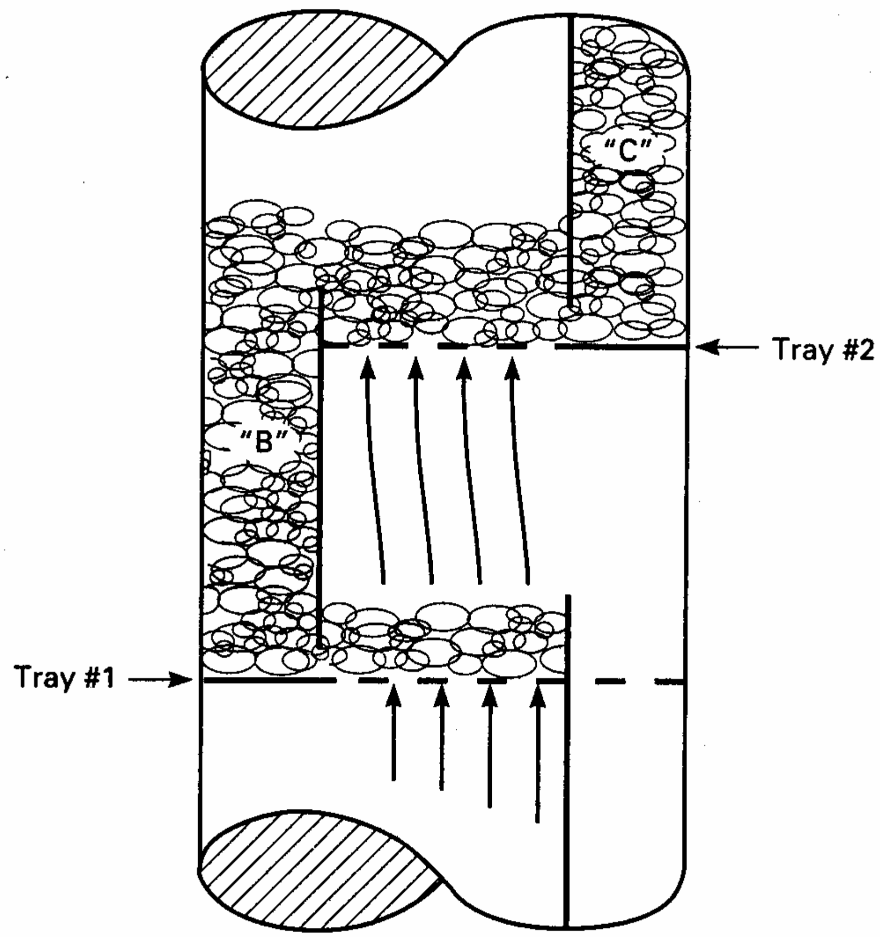

Figure 1.6 Flooding caused by inadequate downcomer clearance.

- When flooding starts on a tray, all the trays above that point will also flood, but trays below that point will go dry .
- An early indication of flooding in a distillation column is loss of liquid level in the bottom of the column.
- If the downcomer clearance-which means the distance between the bottom edge of the downcomer and the tray below-is too great, the downcomer becomes unsealed. Vapor flows up the downcomer, and the trays above flood.
- If the downcomer clearance is too small, then liquid backs up in the downcomer, and the trays above flood. To calculate the height of liquid in the downcomer, due to liquid flowing through the downcomer clearance:

$$\Delta H = 0.6 \times V^2$$

Loss of Downcomer Seal

- When the height of outlet weir is below the bottom edge of the downcomer from the tray above. This permits vapor to flow up downcomer. The upflowing vapor displaces the downflowing liquid → flooding.
- The bottom edge of a downcomer should be about ½ inch below the top edge of the outlet weir.

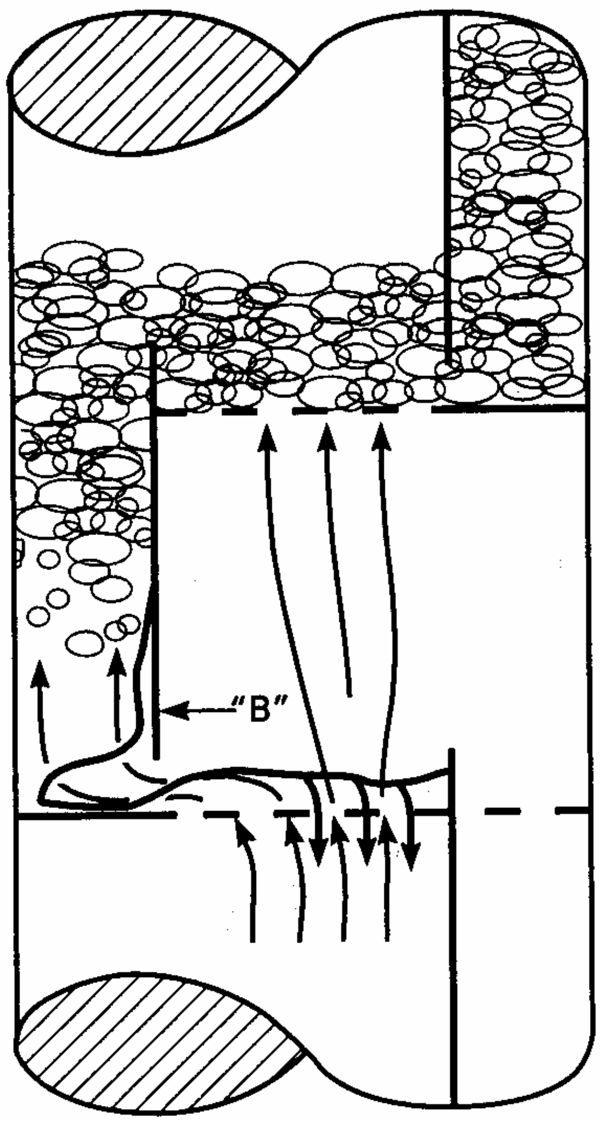

Figure 1.5 Flooding due to lack of a downcomer seal.

Vapor-Flow Pressure Drop

When vapor flows through a tray deck, the vapor velocity increases as the vapor flows through the small openings provided by the valve caps, or sieve holes. The energy to increase the vapor velocity comes from the pressure of the flowing vapor. A common example of this is the pressure drop we measure across an orifice plate. If we have a pipeline velocity of 2 *ftls* and an orifice plate hole velocity of 40 *ftls,* then the energy needed to accelerate the vapor as it flows through the orifice plate comes from the pressure drop of the vapor itself.

Vapor-Flow Pressure Drop

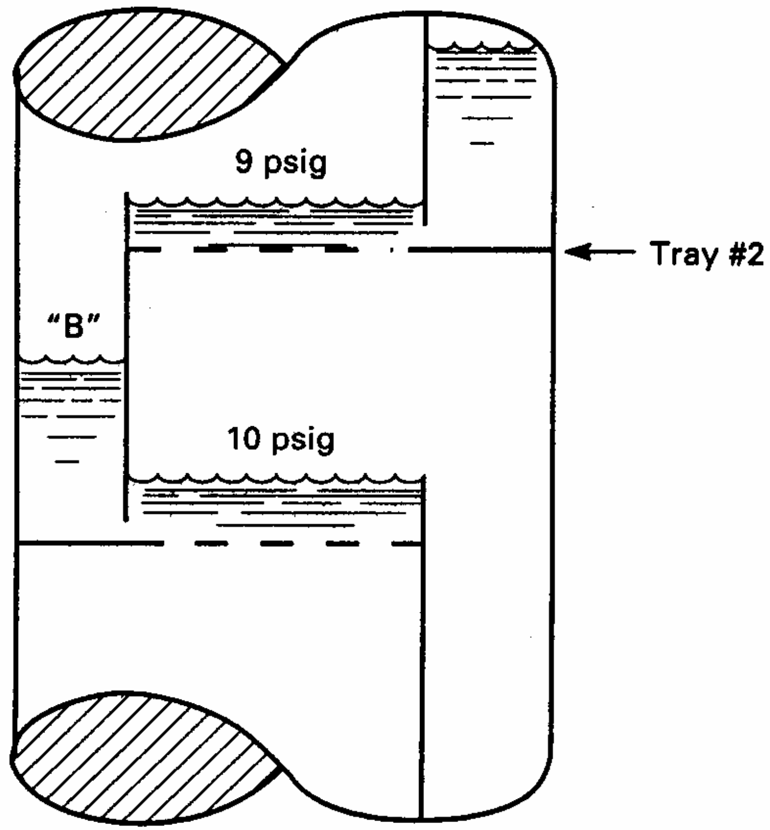

Figure 1.7 Vapor ΔP causes downcomer backup.

- Let us assume that vapor flowing through a tray deck undergoes a pressure drop of 1 psig (lb/in2 gauge). Figure 1.7 shows that the pres- sure below tray deck 2 is 10 psig and the pressure above tray deck 2 is 9 psig. How can the liquid in downcomer B flow from an area of low pressure (9 psig) to an area of high pressure (10 psig)? The answer is gravity, or liquid head pressure.
- The height of water needed to exert a liquid head pressure of 1 psig is equal to 28 in of water. If we were working with gasoline, which has a specific gravity of 0.70, then the height of gasoline needed to exert a liquid head pressure of 1 psig would be 28 in/0.70 = 40 in of clear liquid.

Jet Flood

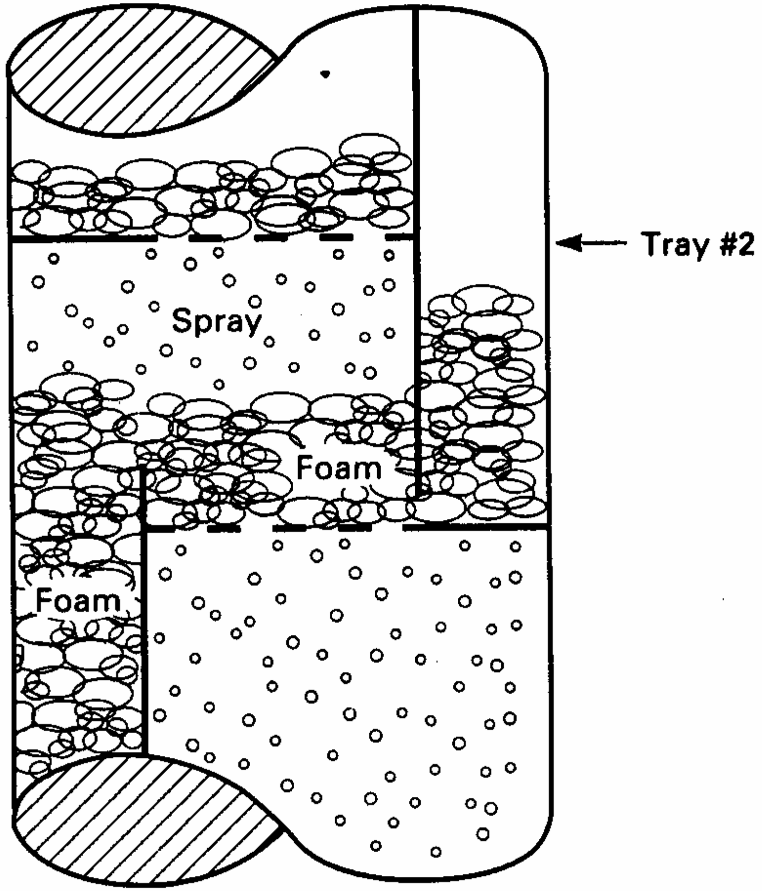

Figure 1.8 Entrainment causes jet flood.

- An increase in vapor flow causes a noticeable increase in the foam height of the tray deck, which then increases the spray height. When the spray height from the tray below hits the tray above, this is called the *incipient flood point,* or the initiation of jet flooding.

- Note, though, that jet flood may be caused by excessive downcomer backup. It is simple to see, in a glass column separating colored water from clear methanol, how tray separation efficiency is reduced as soon as the spray height equals the tray spacing. And while this observation of the onset of incipient flood is straightforward in a transparent tower, how do we observe the incipient flooding point in a commercial distillation tower?

How to observe incipient flood
Example: Depropnaizer

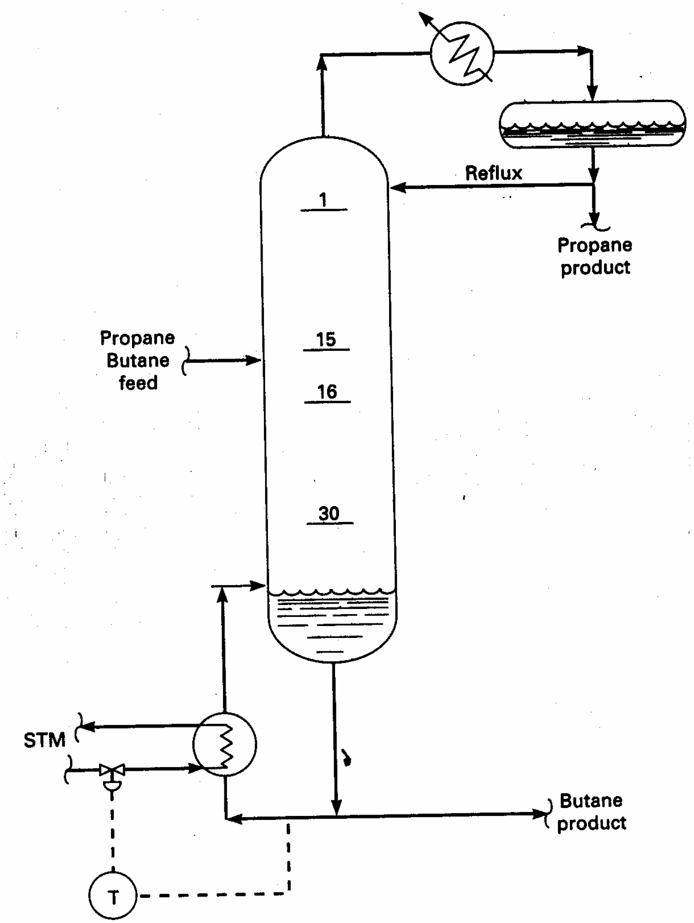

Figure 1.9 A simple depropanizer.

- The tower-top temperature drops
- The amount of butane in the overhead propane product drops
- The tower bottom temperature starts to fall
- The reboiler duty increases, to restore the tower-bottom temperature to its set point
- The weight flow of vapor, and the vapor velocity through the tray, increase

- The spray height, or entrainment, between the trays, increases
- When the spray height from the lower trays, impacts the upper trays, the heavier, butane-rich liquid contaminates the lighter liquid on the upper trays, with heavier butane
- Further increases in the reflux rate, then act to increase, rather than decrease, the butane content of the overhead propane product

Incipient Flood Concept

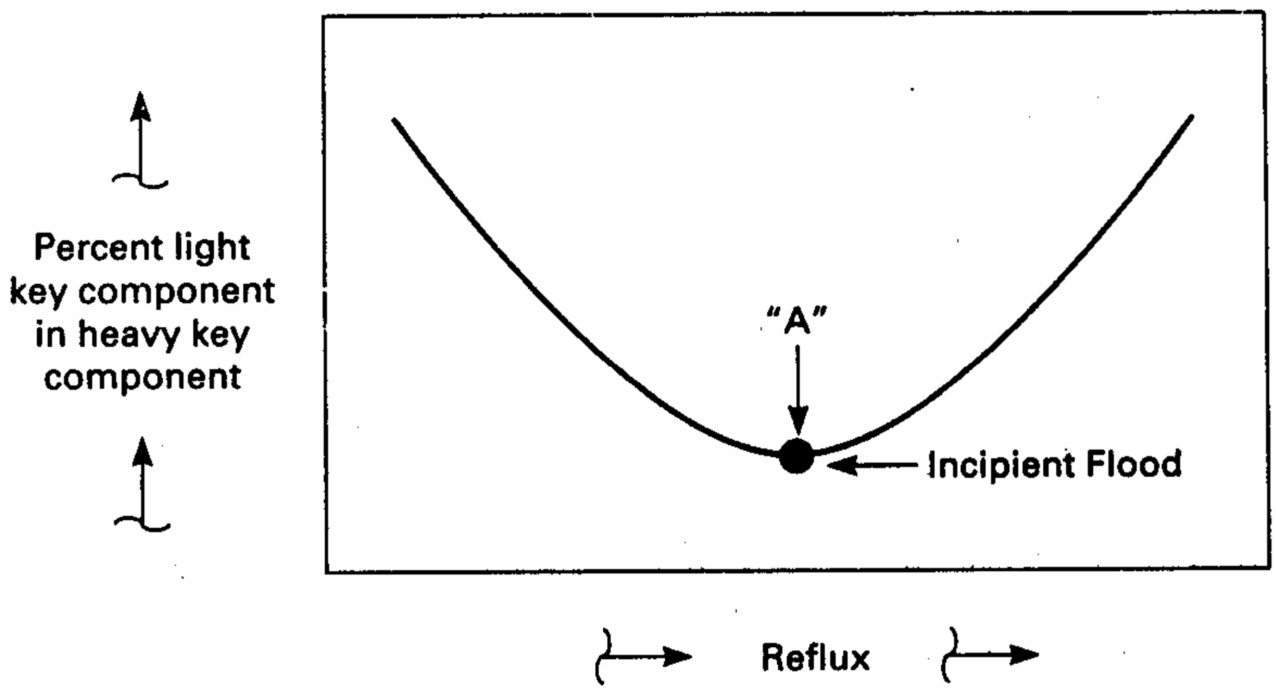

Figure 1.10 Definition of the incipient flood concept.

Tower Pressure Drop and Flooding

- For distillation trays, the incipient flood point corresponds to the best efficiency point.

$$\frac{(\Delta P)(28)}{(NT)(TS)(SG)} = K$$

K=0.18 to 0.25; tray efficiency close to its best efficiency point

K=0.35 to 0.45; tray suffering from entrainment- increase in reflux rate, noticeably reduces tray efficiency

- K>=0.5; tray is in fully developed flood- opening a vent on the overhead vapor line will blow out liquid, with the vapor
- K=0.10 to 0.12; tray deck is suffering from low tray efficiency, due to tray deck leaking
- K=0; the liquid level on the tray is zero, and quite likely the trays are lying in the bottom of the column

Carbon Steel Trays

- Carbon steel trays One of the most frequent causes of flooding is the use of carbon steel trays. Especially when the valve caps are also carbon steel, the valves have a tendency to stick in a partially closed position. This raises the pressure drop of the vapor flowing through the valves, which, in turn, pushes up the liquid level in the downcomer draining the tray. The liq- uid can then back up onto the tray deck, and promote jet flood, due to entrainment.
- Of course, any factor (dirt, polymers, gums, salts) that causes a reduction in the open area of the tray deck will also promote jet flooding.

Weeping Through Tray Decks

- Uneven liquid flow across tray deck causes poor vapor-liquid mixing.
- Uneven vapor flow bubbling-up through the tray deck will promote vapor-liquid channeling ➔ reduce tray efficiency

Solution:

Outlet weir height should be high enough

Tray Pressure Drop

- Dry-tray pressure drop: The pressure drop of the vapor as it accelerates through the sieve hole

$$\Delta P_{dry} = K \frac{Dv}{D_L} V_g^2$$

- Hydraulic tray pressure drop: The weight of liquid on tray created by weir height plus crest height

$$\Delta P_{hyd} = AF \times WH + 0.4(GPM \,/\, \text{outlet weir length})^{0.67}$$

Total Tray Pressure Drop

$$\Delta P_{total} = \Delta P_{dry} + \Delta P_{hyd}$$

- If $\Delta P_{tray} << \Delta P_{hyd}$ ➔ tray will start to leak or weep
- If $\Delta P_{tray} >> \Delta P_{hyd}$ ➔ liquid on tray can blow off of the tray deck (flooding)
- For best efficiency:

  $\Delta P_{tray} = \Delta P_{hyd}$

Distillation Tower Turn Down

- Loss of tray efficiency due to vapor velocity is commonly called *turndown*
- It is opposite to flooding
- If the pressure drop per tray, expressed in inches of liquid, is more than three times the weir height, then the poor fractionation is due to flooding
- If the pressure drop per tray is less than the weir, poor fractionation is due to weeping or dumping

Reflux Rate

- One way to stop trays from weeping is to increase the reflux rate.
- The higher reflux rate increases the reboiler duty which is on automatic temperature control. This will increase the vapor flow through the trays and the dry tray pressure drop.
- Higher reflux however is expensive in terms of energy cost.