CE 407 LECTURE NOTES 9/19/2017

PARTIAL CONDENSER

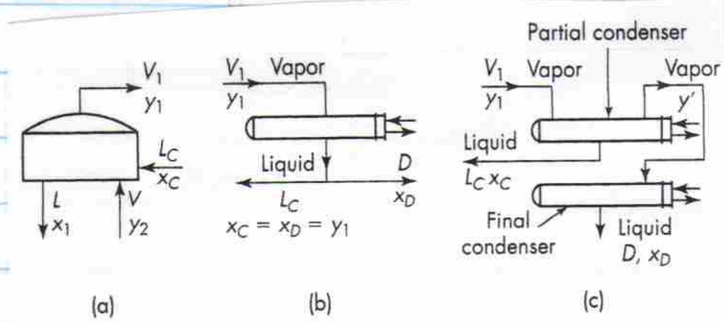


FIGURE 21.7
Material-balance diagrams for top plate and condenser: (*a*) top plate; (*b*) total condenser; (*c*) partial and final condensers.

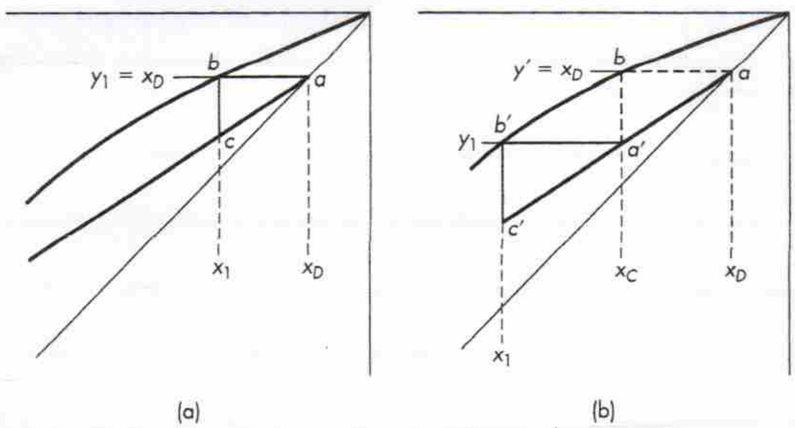


FIGURE 21.8
Graphical construction for top plate: (*a*) using total condenser; (*b*) using partial and final condensers.

FOR TOTAL CONDENSER

MOLE FRACTION IN REFLUX IS EQUAL TO MOLE FRACTION IN PRODUCT IS EQUAL TO MOLE FRACTION IN VAPOR COMING FROM TOP PLATE

FOR PARTIAL CONDENSER

VAPOR LEAVING PARTIAL CONDENSER HAS SAME MOLE FRACTION AS LIQUID LEAVING FINAL CONDENSER.

LIQUID LEAVING PARTIAL CONDENSER IS IN EQUILIBRIUM WITH VAPOR LEAVING PARTIAL CONDENSER

PARTIAL CONDENSER BEHAVES LIKE AN ADDITIONAL THEORETICAL STAGE

NEARLY PURE PRODUCTS

* WHEN EITHER PRODUCT BECOMES NEARLY PURE THE McCABE-THIELE STEPS BECOME TOO SMALL TO ACCURATELY BE DRAWN.

* WITH NEARLY PURE PRODUCT THE MAJOR COMPONENT FOLLOWS RAOULT'S LAW AND THE MINOR COMPONENT FOLLOWS HENRY'S LAW

* ANALYZE THE PROCESS AS FOLLOWS:
  - Choose A HIGH (BUT NOT EXCESSIVELY HIGH) VALUE FOR x_{cutoff} (SAY $x_{cutoff} = 0.9$)
  - USE STANDARD McCABE-THIELE TO DETERMINE # of STAGES TO ACHIEVE PRODUCT EQUAL TO THIS x_{cutoff}
  - DUE TO LOW FRACTION of MINOR COMPONENT THE EQUILIBIUM CURVE IS APPROXIMATELY LINEAR BETWEEN CUTOFF x and x_D
  - WE CAN USE KREMSER EQUATION TO GET THE NUMBER of STAGES BETWEEN CUTOFF x and x_D

$$N = \frac{\ln\left[(y_b - y_b^*)/(y_a - y_a^*)\right]}{\ln\left[(y_b - y_a)/(y_b^* - y_a^*)\right]}$$

EQ 20.24

WHERE y_a is the point on the operating line corresponding to $x_a = x_D$

y_b is point on OP line corresponding to $x_b = x$ cutoff chosen

y_a^* is point on equilibrium line corresponding to $x_a = x_D$

y_b^* is point on equilibrium line corresponding to $x_b = x$ cutoff chosen

☆ y_a and y_b can be obtained from $y = \frac{R_D}{R_D+1} x + \frac{x_D}{R_D+1}$

☆ y_b^* is obtained from Graph, locate value on equilibrium curve for $x = x$ cutoff

Now EQ LINE Passes through (x_{cutoff}, y_b^*) and $(1,1)$ solve $y = mx + b$ for these two points.

☆ Now y_a^* can be calculated to obtain final variable. $y_a^* = m\, x_D + b$

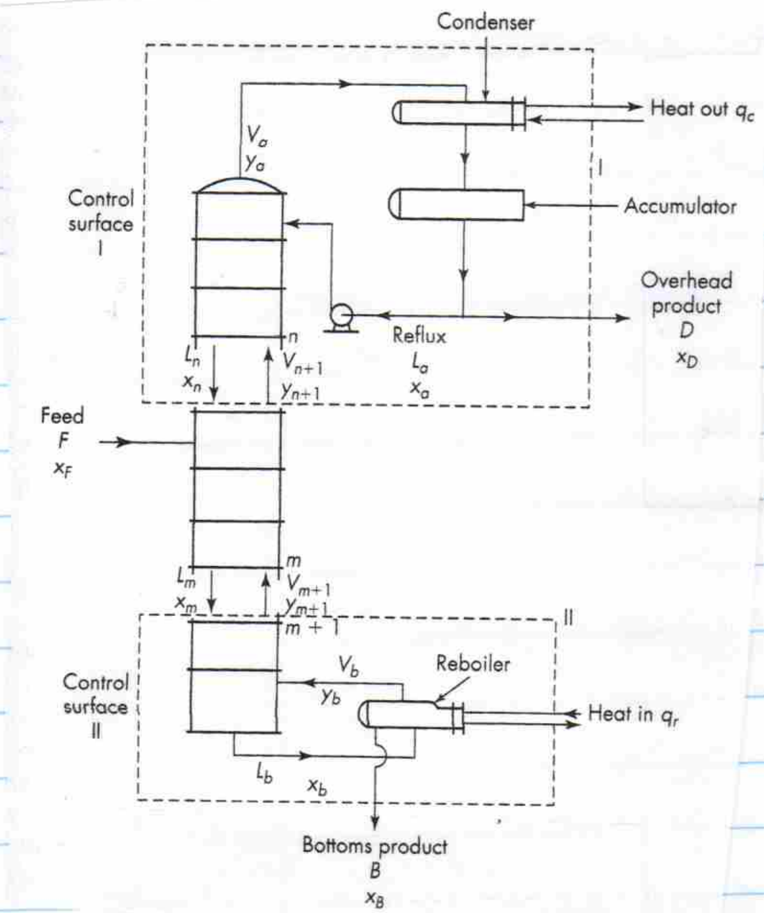
Solve Equation 20.24 with these variables to solve for N = # of stages between x cutoff and x_D

Add N to the number of stages between x_b and x cutoff to obtain total number of stages

ENTHALPY BALANCES

CONSTANT MOLAL OVERFLOW ASSUMES
$\Delta H_{vap\,A} = \Delta H_{VAP\,B}$ AT EACH STAGE

THIS IS A GOOD APPROXIMATION BUT NOT TRULY ACCURATE



ENTIRE SYSTEM $FH_F + q_r = DH_D + BH_B + q_c$

Control Surface I $V_{n+1} H_{y,n+1} = L_n H_{x,n} + DH_D + q_c$

Around Condenser $q_c = V_a H_{y,a} - RH_D - DH_D$

combine these:

$$\boxed{V_{n+1} H_{y,n+1} = L_n H_{x,n} + V_a H_{y,a} - RH_D}$$

EQ 21.51

WE KNOW $V_a H_{y,a}$ and RH_D

WE ARE TRYING TO DETERMINE V_{n+1} and L_n

(we are not assuming constant flows!)

Steps: - Choose value of x_n

- calculate $H_{x,n}$
- ESTIMATE y_{n+1} by assuming $L_N \approx L_0$, $V_{n+1} \approx V_1$ in Eq $y_{n+1} = \frac{L_n x_n}{V_{n+1}} + \frac{D x_D}{V_{n+1}}$

  FROM PHASE DIAGRAM get T

  CALCULATE $H_{y,n+1}$
- solve $V_{n+1} = \frac{V_1 H_{y,1} - L_0 H_0 - D H_{x,n}}{H_{y,n+1} - H_{x,n}}$

- use new value of V_{n+1}, calc L_n

$$L_n = V_{n+1} - D$$

- get improved y_{n+1}

$$y_{n+1} = \frac{L_n x_n}{V_{n+1}} + \frac{D x_D}{V_{n+1}}$$

Do this for several x_n to get curvature of operating line.

$\boxed{\text{WHERE Do the } H\text{'s come FROM !?!}}$

All ENTHALPIES ARE CALCULATE RELATIVE TO A REFERENCE POINT.

CHOOSE SATURATED LIQUID AT THE LOWER BOILING POINT of the TWO COMPONENTS TO BE $H=0$ at $T = T_{A_{BP}}$

LIQUIDS
$$H_{A_x}(T) = \cancelto{0}{H_{A_x}(T_{A_{BP}})} + C_{P_{A,l}}(T - T_{A_{BP}})$$
$$= C_{P_{A,l}}(T - T_{A_{BP}})$$

$$H_{B_x}(T) = \cancelto{0}{H_{B_x}(T_{A_{BP}})} + C_{P_{B,l}}(T - T_{A_{BP}})$$

VAPOR PHASE ENTHALPIES

$$H_{A_y}(T) = \cancel{H_{A_x}(T_{A_{BP}})}^{\,0} + \Delta H_V(T_{A_{BP}}) + C_{p_{A,V}}(T - T_{A_{BP}})$$

liquid at $T_{A_{BP}}$ — PHASE CHANGE Heat of Vaporization at Boiling Point — SENSIBLE HEAT

$$H_{B_y}(T) = \cancel{H_{B_x}(T_{A_{BP}})}^{\,0} + C_{p_{B,l}}(T_{B_{BP}} - T_{A_{BP}}) + \Delta H_V(T_{B_{BP}})$$

liquid at $T_{A_{BP}}$ — heat comp B to it's Boiling point — PHASE CHANGE Heat of vaporization at comp B Boiling Pt

$$+ C_{p,BV}(T_{A_{BP}} - T_{B_{BP}}) + C_{p_{B_V}}(T - T_{A_{BP}})$$

Cool vapor w/o PHASE CHANGE Back to Comp A Boiling Pt — SENSIBLE HEAT

IDEAL SOLUTION : NO HEAT of MIXING

$$H_x = x\, H_{x_A} + (1-x)\, H_{x_B}$$

$$H_y = y\, H_{y_A} + (1-y)\, H_{y_B}$$

DESIGN of COLUMNS

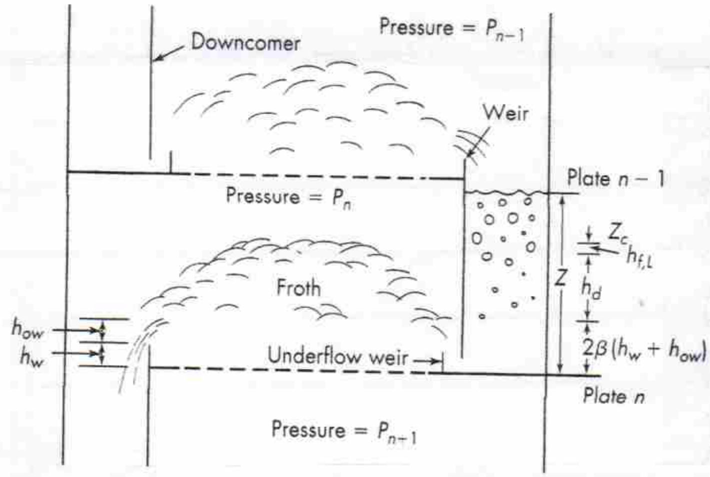
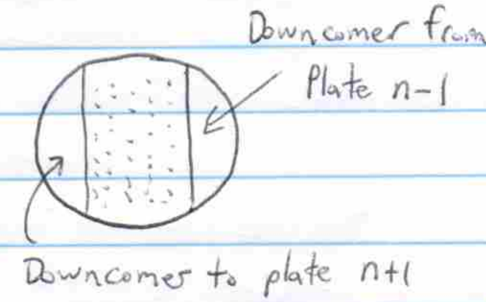


FIGURE 21.24
Normal operation of sieve plate.



SO FAR WE HAVE TALKED ABOUT NUMBER of IDEAL STAGES: WHAT IS A STAGE?

- THE LIQUID NEEDS TO GO DOWN, THE VAPOR NEEDS TO GO UP.
- THE VAPOR NEEDS TO BUBBLE THROUGH THE LIQUID
- THEY NEED TIME TO EQUILIBRATE

  - GRAVITY BRINGS LIQUID DOWN, PRESSURE FROM BOILING PROVIDES FORCE TO DRIVE VAPOR UPWARD
  - $P_{n+1} > P_n > P_{n-1}$
  - THINK of DOWNCOMER SIMILAR TO MANOMETER

WHAT CAN GO WRONG?

* Flooding - Pressure causes liquid to back up the downcomer

* WEEPING - Low Pressure Allows liquid to pass thru holes

* CHANNELING CAUSES LIQUID or VAPOR TO PASS THROUGH IN A NON-UNIFORM MANNER

Vapor Pressure Drop

$$h_t = h_d + h_\ell \qquad \text{mm of liquid}$$

Total ΔP — ΔPressure DUE TO PLATE "DRY" — ΔP due to equivalent head of liquid — ie. the liquid in the column

$$h_d = 51.0\left(\frac{U_o^2}{C_o^2}\right)\left(\frac{\rho_V}{\rho_L}\right) \quad \text{or} \quad 0.186\left(\frac{U_o^2}{C_o^2}\right)\left(\frac{\rho_V}{\rho_L}\right)$$

U_o = vapor velocity through holes m/s or ft/s

h_d mm of liquid or inches of liquid

ρ_V = vapor density

ρ_L = liquid density

C_o = orifice coefficient

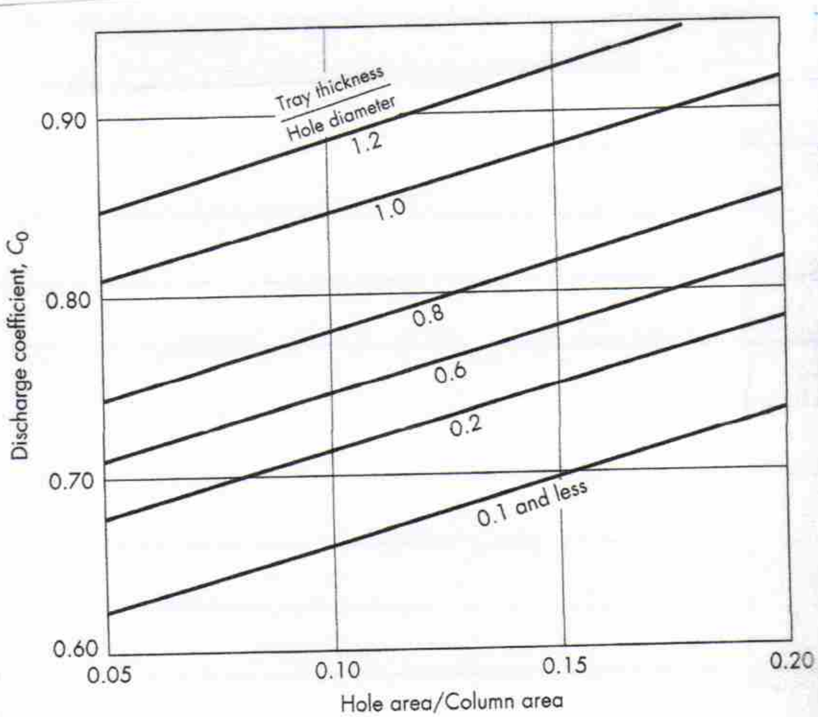


FIGURE 21.25
Discharge coefficients for vapor flow, sieve trays. [*I. Liebson, R. E. Kelley, and L. A. Bullington, Petrol. Refin.*, **36**(2):127, 1957; **36**(3):288, 1957.]

HEAD of LIQUID on PLATE

$$h_l = \beta(h_w + h_{ow})$$ see fig 21.24

h_w is height of weir $\Rightarrow$ design parameter

h_{ow} is how high above weir the liquid level is

$$h_{ow} = 43.4\left(\frac{q_L}{L_w}\right)^{2/3}$$

h_{ow} = height, mm

q = flow rate of clear liquid, m^3/min

L_w = length of weir, m

$$0.4 < \beta < 0.7$$

use $\beta \approx 0.6$

h_d tends to be significantly $> h_l$

Downcomer Level

Will we flood?

$$Z_c = 2\beta(h_w + h_{ow}) + h_d + h_{f,L}$$

h_w = height of weir
h_{ow} = height of liquid above weir
h_d = ΔP through holes
$h_{f,L}$ = ΔP from flow through down comer

(THINK of similarity to Manometer)

Actual level $Z = \dfrac{Z_c}{\phi_d}$ due to entrained air

$\phi_d = 0.5$

FLOODING CORRELATION

MAXIMUM ACCEPTABLE VELOCITY, u_c

$$u_c = K_v \sqrt{\frac{\rho_L - \rho_v}{\rho_v}} \left(\frac{\sigma}{20}\right)^{0.2}$$

u_c = max vapor velocity based on bubbling area $\frac{ft}{s}$

σ = surface tension of liquid, $\frac{dyn}{cm}$

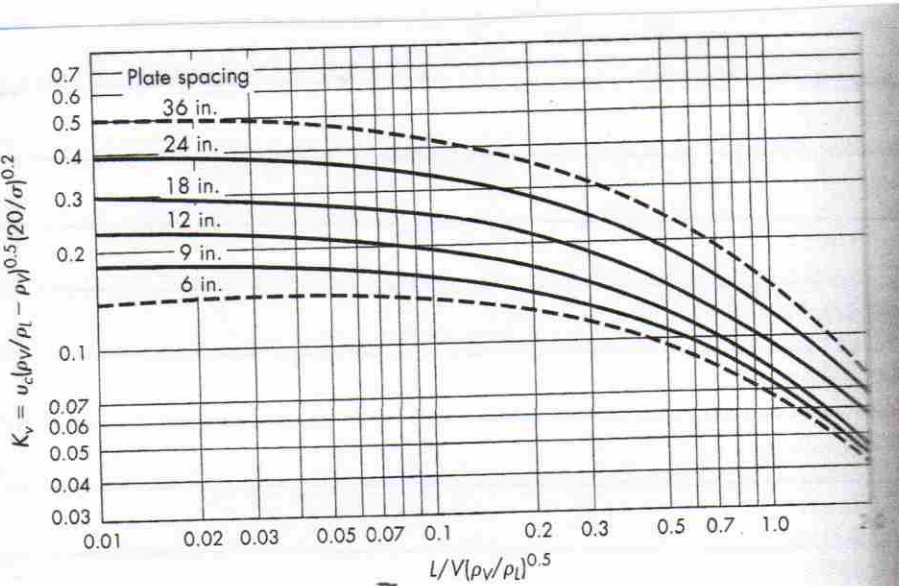


FIGURE 21.26
Values of K_v at flooding conditions for sieve plates; L/V = ratio of mass flow rate of liquid to vapor, u is in feet per second, and σ is in dynes per centimeter. [*J. R. Fair Petrol. Chem. Eng.*, **33**(10):45, 1961. *Courtesy Petroleum Engineer.*]

$$\frac{L}{V}\left(\frac{\rho_v}{\rho_L}\right)^{1/2}$$

With u_c and knowing V and $\bar{V}$ as well as what fraction of plate is open for bubbling, we can calculate Column DIAMETER