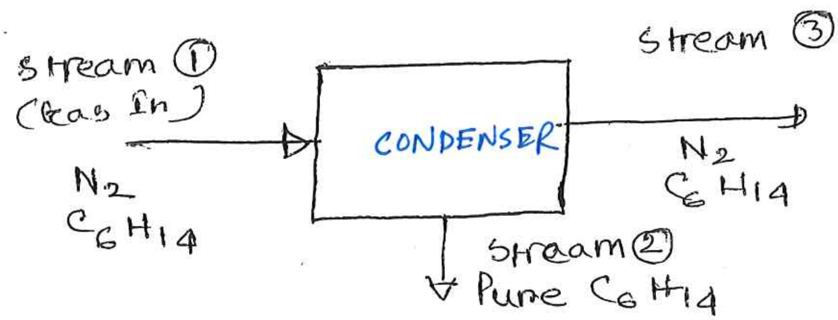
Last Name: Instructor solution (L01/ Dr. Sumon) **Frist Name:**

Tutorial # 2

A gas stream contains 18 mole% hexane (C_6H_{14}) and the balance nitrogen. The stream flows to a condenser, where its temeprature is reduced and some of the hexane is liquefied. The gas stream leaving the condenser contains 5 mole% hexane. Liquid hexane condensate is recovered at a rate of 1.50 L/min. The process operates at steady-state. The density of hexane is 0.66 g/ml. Atomic weights: H = 1, C = 12.

(a) Draw a schematic of the process, show the input and output streams with arrows. Label the streams: stream 1 is the gas stream entering the condenser, stream 2 is the liquid leaving the condenser and stream 3 is the gas leaving the condenser.



(b) Let the total flow rate of gas stream (stream 1) into the condenser is F (mol/min). Determine the flow rate of hexane and nitrogen into the condenser through this stream in terms of F.

Hexane flow rate (mol/min) into the condenser = $(0.18)F$

Nitrogen flow rate (mol/min) into the condenser = $(0.82)F$

(c) What is the molar mass of hexane?

$$M = (6\times12)+(1\times14) = 86 \text{ g/mol}$$

(d) What is the mass flow rate of hexane (g/min) in stream 2? Mass flow rate = volumetric flow rate × density

$$= \left(\frac{1.5\text{ L}}{\text{min}}\right)\left(\frac{1000\text{ mL}}{\text{L}}\right)\left(\frac{0.66\text{ g}}{\text{mL}}\right) = 990 \text{ g/min}$$

(e) What is the molar flow rate of hexane (mol/min) in stream 2? Molar flow rate = mass flow rate/molar mass

$$\left(990 \text{ g/min}\right)\left(\frac{\text{mol}}{86\text{ g}}\right) = 11.51 \text{ mol/min}$$

(f) What is the molar flow rate of nitrogen (mol/min) in stream 2?

0

(g) Let the total flow rate of gas stream (stream 3) that leaves the condenser is V (mol/min). Determine the flow rate of hexane and nitrogen ~~into~~ leaving the condenser through this stream.

Hexane flow rate (mol/min) leaving the condenser = $0.05V$

Nitrogen flow rate (mol/min) leaving the condenser = $0.95V$

(h) Write a balance equation for nitrogen around the condenser unit in terms of F (F = flow rate of gas entering the condenser) and V (V = flow rate of gas out from condenser). Find the ratio V/F.

Mole of N_2 in stream ① = 0.82 F
Mole of N_2 in stream ② = 0
Mole of N_2 in stream ③ = 0.95 V

At steady state,
N_2 balance: N_2 in = N_2 out
$\boxed{0.82F = 0.95V}$
$\Rightarrow \boxed{V/F = 0.863}$

(i) Write a balance equation for the total material around the condenser unit in terms of F and V.

Total material into the condenser through stream ① = F mol/min.
Total material leaving the condenser " " ② = 11.51 mol/min
Total material leaving the condenser " ③ = V mol/min
Total material balance at steady state: Total material in = Total material out
$\boxed{F = 11.51 + V}$

(j) Solve the two equations you obtained in parts (h) and (i) for F (flow rate of gas in) and V (flow rate of gas out).

The equations obtained are:
$$\begin{cases} 0.82F = 0.95V & \text{—— (I)} \\ F = 11.51 + V & \text{—— (II)} \end{cases}$$

From equation (I), $V = \frac{0.82}{0.95}F = 0.863F$

Eliminating V ~~into~~ from equation (II), $F = 11.51 + 0.863F$

$\Rightarrow 0.137F = 11.51$

$\Rightarrow \boxed{F = 84.01 \text{ mol/min}}$

$\Rightarrow V = (0.863 \times 84.01)$

$\boxed{V = 72.5 \text{ mol/min}}$

Note: Now, using the values of F and V you can calculate all the flow rates.

Question # 2

In a process involving diffusion, the dimensionless terms, $k\left(\frac{\rho}{\mu g}\right)^{\alpha}$ and $\left(\frac{\mu}{\rho D_L}\right)^{-1/2}$ are required, where,

k = mass-transfer coefficient, $\frac{mol}{s.m^2\left(\frac{mol}{m^3}\right)}$

ρ = density

μ = viscosity, $\frac{kg}{m.s}$

g = gravitational acceleration

D_L = the liquid phase diffusion coefficient

(a) Find the dimensions of k

From the given units of k, we obtained its dimensions,

$$[k] = \frac{[mol][L]^3}{[t]\,[L]^2\,[mol]} = \frac{[L]}{[t]} = \boxed{[L][t]^{-1}}$$

(b) Find value of the exponent α

$$[\rho] = \left[\frac{M}{L^3}\right], \quad [\mu] = \left[\frac{M}{L.t}\right], \quad [g] = \left[\frac{L}{t^2}\right]$$

$$\left[\frac{\rho}{\mu g}\right] = \left[\frac{M}{L^3} \cdot \frac{1}{\frac{M}{L.t} \cdot \frac{L}{t^2}}\right] = \left[\frac{t^3}{L^3}\right]$$

$$\left[k\left(\frac{\rho}{\mu g}\right)^{\alpha}\right] = \left[\frac{L}{t} \cdot \frac{t^{3\alpha}}{L^{3\alpha}}\right] = \left[\frac{t^{3\alpha-1}}{L^{3\alpha-1}}\right]$$

From the term $\left[k\left(\frac{\rho}{\mu g}\right)^{\alpha}\right]$ to be dimensionless the exponent, $3\alpha - 1 = 0 \Rightarrow \boxed{\alpha = \frac{1}{3}}$

(c) Find the dimensions of D_L, the liquid phase diffusion coefficient.

For the term $\left(\frac{\mu}{\rho D_L}\right)^{-1/2}$ to be dimensionless, $\frac{\mu}{\rho D_L}$ must be dimensionless.

Then, $\left[\frac{\mu}{\rho D_L}\right] = 1 \Rightarrow [D_L] = \left[\frac{\mu}{\rho}\right] = \left[\frac{M}{L.t} \cdot \frac{L^3}{M}\right] = \left[\frac{L^2}{t}\right]$

$= \boxed{[L]^2[t]^{-1}}$