An Insight into Chemical Engineering

Through Instant Notes, Objective Types and Problems

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Through Instant Notes, Objective Types and Problems

(Useful for GATE and other Aptitude Tests)

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To Almighty

FOREWORD

Competitive examinations have become inevitable nowadays for admission to graduate courses and placement in chemical and allied industries, for undergraduate students in chemical engineering. For such examinations, apart from a wide knowledge of all aspects of unit operations of chemical engineering a quick wit to solve the questions/problems is absoluteley essential. Exhaustic revision of all these operations studied in earlier semesters is a tedious procedure. A quick **insight** into the same along with solutions to short answer objective questions or problems is necessiated. With this objective in view, the author has made an attempt to prepare this monograph after going through many question papers of this type from several universities along with an intensive study of the operations covered.

I had the oppurtunity of revising the text and providing academic advice wherever necessary. I am confident this effort of the author will be well received by the budding chemical engineers taking their first degree from engineering colleges.

Dr. N. SUBRAMANIAN
Former Professor & Head
Department of Chemical Engineering
Indian Institute of Technology Madras

Chennai
October 5, 2003

PREFACE

For competitive examinations to pursue higher studies or get jobs, depth of knowledge in problem solving and answering objective type questions should be the essential qualities of a successful Chemical Engineer.

A set of instant notes are given for various important topics in the core subjects of Chemical Engineering. I hope this set of topics detailed in this book will be of extreme use to the undergraduate students and practicing engineers for enhancing and checking their knowledge in the core concepts of the subject. In any competitive examination due weightage is being given to objective type questions. In this book I have also given objective type questions which will be useful for the chemical engineers and students for their preparation.

By lecturing for the past few years in core subjects of Chemical engineering like Fluid Mechanics, Thermodynamics and Process Control at Department of Chemical Engineering, Sri Venkateswara College of Engineering (SVCE), Sriperumbudur I have found that the students need additional input for applying theoretical knowledge for solving the problems. In this book a comprehensive set of problems in each of the nine subjects of Chemical Engineering are given with the steps in solving the same from the first principles which could be understood easily by a novice in the field also. Most of the problems are questions that were asked in GATE (Graduate Aptitude Test in Engineering) and in University examinations.

I extend my heartful thanks to **Dr.N.Subramanian** (Visiting Professor, SVCE — Former Professor in Indian Institute of Technology Madras, Chennai) for sparing his valuable time to review this book and provide technical guidance whenever needed.

I sincerely acknowledge the management of SVCE for their support.

I am grateful to Dr.V.Ravichandran (Assistant Professor, Dept. of Computer Applications, SVCE) for introducing and enthusing me to learn LaTeX software, with which this book is typeset. Also he helped me in solving the objective type questions of Mathematics.

Mr.B.Nedumaran (Assistant Professor, Dept. of Chemical Engineering, SVCE) was always helpful in conducting GATE coaching to students of SVCE, that initiated me to prepare these materials.

Always my affection and thanks lie with my students who extended their interest to the fullest. Also I thank the Chemical Engineering community allover the world for their encouragement through my website http://www.svce.ac.in/∼msubbu for the study materials provided in the website.

My thanks are due to my wife Mrs.S.Panchi for her suggestions in publishing this book and providing administrative assistance. I thank my dear parents and relatives for their emotional support during these years.

I thank the publisher for bringing out this edition at the earliest.

Awaiting for your valuable ideas, to be posted at http://www.msubbu.com

Chennai
October 15, 2003

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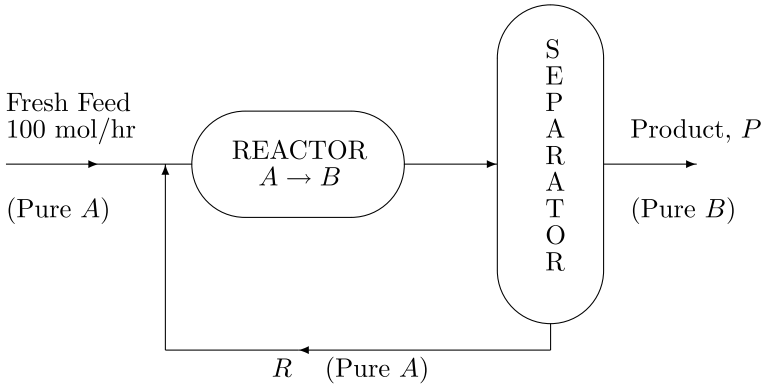
(M. SUBRAMANIAN)

Contents

11. The flowsheet is given in figure.



If the single-pass conversion (once-through conversion) of A to B is 20%, then the rate of recycle R (mol/hr) is (GATE-1997-2.05)

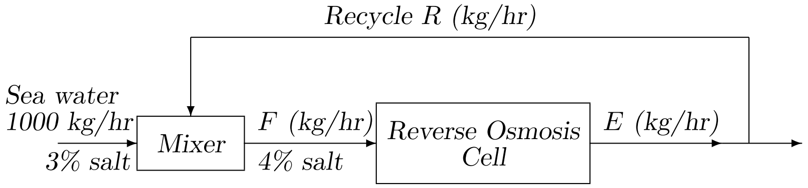
(a) 300 (b) 400 (c) 500 (d) 600

Answer: **(b)** $A \rightarrow B$. By overall balance, product $P = 100$ mol/hr.
Since conversion within the reactor is only 20%,

$$\begin{aligned} \text{mixed feed to the reactor} &= 100/0.2 = 500 \text{ mol/hr} \\ \text{recycle rate } R &= 500 - 100 = 400 \text{ mol/hr} \end{aligned}$$

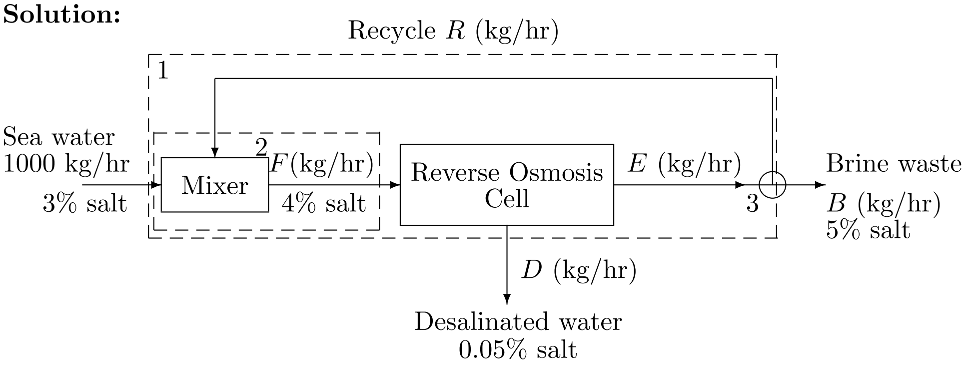
1.3.12 Recycle Ratio in Reverse Osmosis Desalination

Sea water is desalinated by reverse osmosis as shown in figure.



All compositions are on mass basis. Calculate R/E. (GATE-1997-12)

Solution:



Mass balance around boundary 1:
Overall:

$$1000 = B + D \tag{1.1}$$

Balance on salt:

$$1000 \times 0.03 = \frac{0.05}{100} \times D + 0.05 \times B \tag{1.2}$$

Solving Eqns.(1.1) and (1.2), $D = 404$ kg/hr; $B = 596$ kg/hr.
Mass balance around boundary 2:
Overall:

$$F = 1000 + R \tag{1.3}$$

Balance on salt:

$$0.03 \times 1000 + 0.05 \times R = 0.04 \times F \tag{1.4}$$

Solving Eqns.(1.3) and (1.4), $R = 1000$ kg/hr.
From overall mass balance at junction 3,

$$E = B + R = 596 + 1000 = 1596 \text{ kg/hr}$$

Therefore $R/E = 1000/1596 = 0.627$

2.1.4 Flow Meters

- **Venturi meter**:
    - The shape of the converging and diverging sections of venturi meter minimizes losses by eddy formation. Experimental measurements show that for Re > 10000 the frictional loss over the venturi meter is about 10 percent of ΔP. Where ΔP is pressure drop measured by the manometer connected between the upstream and throat sections of venturi meter. (Re is calculated based on the pipe diameter)
    - For Re > 10000, C_d of venturi meter is constant at about 0.98. For smaller Reynolds numbers the coefficient decreases rapidly. This effect is partially caused by the non-uniform velocity distribution across the diameter in laminar flow (in the length of venturi meter). (Re is calculated based on the pipe diameter)
- **Orifice meter**
    - The orifice plate can easily be changed to accommodate widely different flow rates, where as the throat diameter of a venturi meter is fixed.
    - The orifice meter has a large permanent loss of pressure because of the presence of eddies on the downstream side of the orifice plate. The shape of the venturi meter prevents the formation of these eddies and greatly reduces the permanent loss.
    - There are a number of customary positions of the pressure taps which lead to the manometer such as pipe taps, flange taps and vena contracta taps out of which, flange tapes are the most common.
    - The coefficient of discharge of orifice C_d is dependent on the location of the pressure taps.
    - For Re > 10000, C_d of orifice meter is constant at 0.61. At lower Reynolds numbers the orifice coefficient becomes a strong function of Re. (Re is calculated based on the diameter of orifice opening)
    - The orifice discharge coefficient is significantly affected by flow disturbances which originates in valves, bends, and other fittings located upstream from the orifice. It is less affected by downstream disturbances. As a general rule, the meter should be placed 50 pipe diameters downstream and 10 pipe diameters upstream from any disturbances. The upstream distance can often be reduced by placing straightening vanes in the pipe.
- **Rotameter**: In the case of venturi and orifice meters the area of constriction remains constant and the pressure drop varies with flow rate; in the rotameter, the pressure drop remains nearly constant and the area of constriction varies.

26. A rotameter, through which air at room temperature and atmospheric pressure is flowing, gives a certain reading for a flow rate of 100 cc/s. If helium (Molecular weight 4) is used and the rotameter shows the same reading, the flow rate is (GATE-1996-2.02)

    (a) 26 cc/s (b) 42 cc/s (c) 269 cc/s (d) 325 cc/s

    Answer: **(c)** From Bernoulli's equation, $v \propto \sqrt{\Delta P/\rho}$. For variable area meters, ΔP = const. Therefore $v \propto \sqrt{1/\rho}$. For gases $\rho \propto M$; where M is the molecular weight. Therefore

    $$\frac{v_2}{v_1} = \sqrt{\frac{\rho_1}{\rho_2}} = \sqrt{\frac{29}{4}}$$

    i.e., $v_2 = v_1\sqrt{29/4} = 100 \times \sqrt{29/4} = 269$ cc/s.

2.3.9 Flow Rate for a given Pressure Drop

Nikuradse developed a semi theoretical correlation for f *vs. Re for steady turbulent flow in smooth pipes* ($10^5 < Re < 10^7$)*:* $1/\sqrt{f} = 1.75\ln(Re\sqrt{f}) - 0.4$*. Toluene* ($\rho = 866$ kg/m^3, $\mu = 0.0008$ Ns/m^2) *is to be conveyed through a 100 m pipe -line of diameter 0.2 m. What is the maximum flow rate of toluene in kg/sec that can be maintained, if the frictional pressure loss is not to exceed 10 kN/m^2?* (GATE-1990-12i)

Solution:

$$\Delta P = \frac{2fL\rho v^2}{D}$$

rearranging,

$$v^2 = \frac{\Delta PD}{2fLL\rho}$$

Substituting the known values,

$$v^2 = \frac{10000 \times 0.2}{2 \times f \times 100 \times 866} = \frac{0.01155}{f}$$

That is, from the pressure drop relation,

$$v^2 = \frac{0.01155}{f} \tag{2.5}$$

Nikuradse relation for f (given):

$$1/\sqrt{f} = 1.75\ln(\mathrm{Re}\sqrt{f}) - 0.4$$

Rearranging,

$$\begin{aligned}
\ln(\mathrm{Re}\sqrt{f}) &= \frac{0.4 + 1/\sqrt{f}}{1.75} \\
\ln \mathrm{Re} &= \frac{0.4 + 1/\sqrt{f}}{1.75} - \ln\sqrt{f} \\
\ln(0.2 \times v \times 866/0.0008) &= \frac{0.4 + 1/\sqrt{f}}{1.75} - \ln\sqrt{f}
\end{aligned}$$

$$\ln v = \frac{0.4 + 1/\sqrt{f}}{1.75} - \ln\sqrt{f} - 12.285 \tag{2.6}$$

Equations (2.5) and (2.6) are solved by trial and error to get the value of v, and calculations are given below:

SlNo	Assumed value of f	v from Eqn.(2.5)	v from Eqn.(2.6)
1	0.004	1.70	0.77
2	0.0035	1.817	1.537
3	0.0034	1.843	1.796
4	0.0033	1.871	2.112
5	0.00338	1.848	1.854

Since for the value of $f = 0.00338$, v from the two equations are approximately equal (differering only in the third decimal), v shall be taken as 1.85 m/sec.
Volumetric flow rate(Q):

$$Q = (\pi/4)\,D^2 v = (\pi/4) \times 0.2^2 \times 1.85 = 58.1 \times 10^{-3}\ \text{m/sec}$$

Mass flow rate($\dot{m}$):

$$\dot{m} = Q\rho = 58.1 \times 10^{-3} \times 866 = 50.3\ \text{kg/sec}$$

19. A suspension of uniform particles in water at a concentration of 500 kg of solids per cubic meter of slurry is settling in a tank. Density of the particles is 2500 kg/m^3 and terminal velocity of a single particle is 20 cm/s. What will be the settling velocity of suspension? Richardson-Zaki index is 4.6 (GATE-1995-2.k)

    (a) 20 cm/s (b) 14.3 cm/s (c) 7.16 cm/s (d) 3.58 cm/s

    Answer: **(c)** Volume of solids $= m/\rho_s = 500/2500 = 0.2$ m^3. Void fraction (ϵ) = (total volume − volume of solids)/(total volume) $= (1 - 0.2)/1 = 0.8$. $u/u_t = \epsilon^n$; Therefore, $u = 20 \times 0.8^{4.6} = 7.16$ cm/s.

4. Air enters an adiabatic compressor at 300 K. The exit temperature for a compression ratio of 3, assuming air to be an ideal gas ($\gamma = C_P/C_V = 7/5$) and the process to be reversible, is (GATE-2001-2.07)

   (a) $300(3^{2/7})$ (b) $300(3^{3/5})$ (c) $300(3^{3/7})$ (d) $300(3^{5/7})$

   Answer: **(a)** For reversible adiabatic process PV^γ = constant. From ideal gas law $PV = RT$. Therefore, $P^{1-\gamma}T^\gamma$ = constant. Given: $P_2/P_1 = 3$. $T_2/T_1 = \frac{P_2^{(\gamma-1)/\gamma}}{P_2^{(\gamma-1)/\gamma}}$ which gives $T_2 = 300(3^{2/7})$

4.3.13 Joule-Thomson Expansion

A pure gas flows at a low rate through a well insulated horizontal pipe at high pressure and is throttled to a slightly lower pressure. The equation of state for the system is given as $P(V-c) = RT$*, where* c *is a positive constant. Kinetic energy changes are negligible. Prove whether or not the gas temperature rises or falls due to throttling by using the following equation for Joule-Thomson coefficient,* μ_H*,* (GATE-1989-16i)

$$\mu_H = \left(\frac{\partial T}{\partial P}\right)_H = \frac{T\left(\dfrac{\partial V}{\partial T}\right)_P - V}{C_P}$$

Solution:
For the equation of state $P(V-c) = RT$,

$$\begin{aligned} V - c &= \frac{RT}{P} \\ V &= \frac{RT}{P} + c \\ \left(\frac{\partial V}{\partial T}\right)_P &= \frac{R}{P} \end{aligned}$$

Therefore

$$\begin{aligned} \mu_H &= \frac{T\left(\dfrac{\partial V}{\partial T}\right)_P - V}{C_P} \\ &= \frac{T(R/P) - V}{C_P} = \frac{-c}{P} \end{aligned}$$

Since c is positive, μ_H is negative.
For the pressure difference ΔP at constant H,

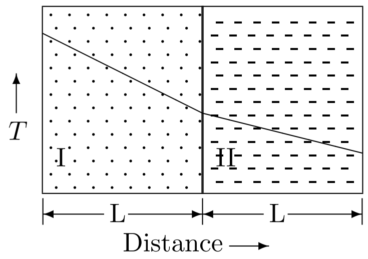
$$\frac{\Delta T}{\Delta P} = \mu_H$$

Therefore

$$\Delta T = \mu_H \Delta P$$

During throttling, pressure is reduced. i.e., $\Delta P(= P_2 - P_1)$ is negative. Therefore $\Delta T(= T_2 - T_1$ is positive. In other words, $(T_1 - T_2)$ is negative. Therefore temperature increases during expansion. (1 refers to inlet and 2 refers to outlet conditions)

8. At steady state, the temperature variation in a plane wall, made of two different solids I and II is shown below:



Then, the thermal conductivity of material I (GATE-1997-2.09)

(a) is smaller than that of II
(b) is greater than that of II
(c) is equal to that of II
(d) can be greater than or smaller than that of II

Answer: **(a)** $q = kdT/dx = k \times \text{slope} = \text{const}$. Here $\text{slope}_I > \text{slope}_{II}$. Therefore $k_I < k_{II}$

6.1.7 Distillation

- Separation by distillation is accomplished by partial vaporization and partial condensation.
- **Vapor-liquid equilibrium relationship**
  - $y = Kx$, where K is the equilibrium ratio.
  - The equilibrium ratio for any component depends on temperature, on pressure and on compositions of the liquid and vapor. Because higher temperatures favor vaporization and higher pressure retard it, equilibrium ratios generally become larger as the temperature is raised or as pressure is reduced.
- First drop of liquid vaporizes at bubble point and last drop at dew point.
- **Relative Volatility** (α)
  - This is the ratio of A and B in one phase to that in the other and is a measure of the separability.

    $$\alpha = \frac{y^*/(1-y^*)}{x/(1-x)} = \frac{P_{satA}}{P_{satB}}$$
  - If $\alpha = 1$, no separation is possible.
  - The relative volatility and hence the separability usually becomes less at high pressures.
  - Volatility of different materials generally approach each other as temperature is raised. Because increasing the pressure on any system raises its boiling temperature, relative volatilities become smaller as pressures are raised.
  - **Equilibrium relation**

    $$y^* = \frac{\alpha x}{1 + x(\alpha - 1)}$$
  - Relative volatility varies with the temperature.
  - As the pressure is increased, the relative volatility decreases.
- **Ideality of solutions**
  - A liquid or vapor mixture constitutes an ideal solution if there are no interactions when its components are mixed, no heat is evolved and volumes are additive. By this definition, vapor mixtures that obey perfect gas law must constitute ideal solutions.
  - In ideal solutions, volatilities are independent of composition.
- Because distillation conditions are usually close to isobaric, equilibrium diagrams are drawn for constant-pressure conditions.
- **Positive deviations from ideality**

  - A mixture whose total pressure is greater than that computed for ideality is said to show positive deviations from Raoult's law. Most mixtures fall in this category. In these cases, the partial pressures of each component are larger than the ideal.
  - Since the activity coefficient γ is greater than unity in these cases $\log \gamma$ is positive, and hence the name positive deviations from ideality.

- **Minimum boiling azeotropes**
  - When positive deviations from ideality are sufficiently large and the vapor pressures of the components are not too apart, then minimum boiling azeotropes will form.
  - Azeotropic mixtures of this sort are very common. One of the most important is ethanol-water azeotrope which at 1 atm occurs at 89.4 mole percent of ethanol and 78.2°C. Azeotropism disappears in this system at pressures below 70 mm Hg.

- **Partial liquid miscibility**: *Heteroazeotropes*
  - Example: Isobutanol-water system. In this azeotropic composition lies inside the limits of solubility at the bubble point.
  - In relatively few instances the azeotropic composition lies outside the limits of solubility, as in the systems of methyl ethyl ketone-water and phenol-water.
  - Heterogeneous azeotropes are always minimum boiling mixtures because activity coefficients must be significantly greater than 1 to cause splitting into two phases.

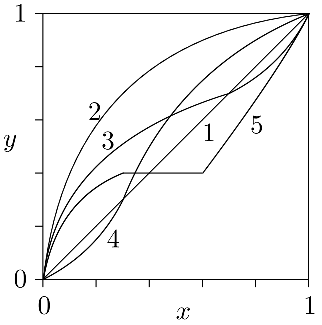
- When the components have a very large difference in their boiling points, no azeotrope can form, as for ammonia-toluene, and carbondioxide-water.

- **Insoluble liquids**: *Steam distillation*
  - Mutual solubility of liquids is so small.
  - If the liquids are completely insoluble, the vapor pressure of either component cannot be influenced by the presence of the other and exerts its true vapor pressure at the prevailing temperature. When the sum of the seperate vapor pressure equals the total pressure, the mixture boils, and the vapor composition is readily computed, assuming the applicability of ideal gas law.

$$\begin{aligned} P_A + P_B &= P_t \\ y^* = \frac{P_A}{P_t} & \end{aligned}$$

  - By this method of distillation with steam, so long as liquid water is present, the high boiling organic liquid can be made to vaporize at a temperature much lower than its normal boiling point without the necessity of a vacuum pump.
  - For the greatest economy in steam distillation, the still should be heated from an external source of energy to the highest allowable temperature, and should be operated under as high a vacuum as the cooling water will permit.

- **Negative deviations from ideality**
  - When the total pressure of a system at equilibrium is less than the ideal value, the system is said to deviate negatively from *Raoult's law*.
- **Maximum boiling azeotropes**
  - Maximum boiling azeotropes are less common than the minimum type.
  - Examples: acetone-chloroform, HCl-water systems.
- $x - y$ **diagrams**:



1. Stereoisomers, $\alpha = 1$
2. Ideal solutions
3. Minimum boiling azeotropes
4. Maximum boiling azeotropes
5. Heteroazeotropes

  - With systems of type 1, ($y = x$) no seperation is possible by distillation. Examples: stereoisomers, H_2O-D_2O system.
  - Those systems having curves of type 3, which crosses the diagonal, possess minimum boiling points at the intersection, while the systems of type 4 (curves with steeper slopes than the disgonal at the point of intersection) are mixtures that possess maximum boiling points at the point where $y = x$.
- **Differential or simple distillation**
  - *Rayleigh's Equation*:

$$\ln\frac{F}{W} = \int_{x_W}^{x_F} \frac{dx}{y^* - x}$$

  - For constant α:

$$\ln\frac{F x_F}{W x_W} = \alpha \ln\frac{F(1 - x_F)}{W(1 - x_W)}$$

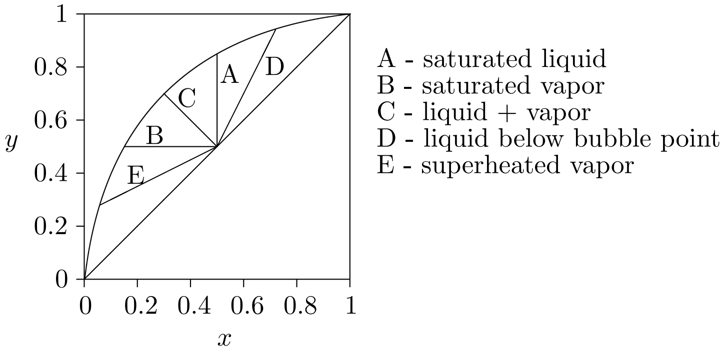
- **Reflux ratio** R
  - $R = \dfrac{L}{D}$
  - At the minimum reflux ratio, column requires an infinite number of trays, and consequently the fixed cost is infinite; but the operating costs (heat for reboiler, condenser cooling water, power for reflux pump) are least.

  - Optimum reflux ratio is about $1.2R_m$ to $1.5R_m$, where R_m is the minimum reflux ratio.

- ***q*-lines**
  - q = heat required to convert 1 mole of feed from its condition h_f to a saturated vapor h_g divided by molar latent heat.

$$q = \frac{h_g - h_f}{h_g - h_l}$$

  - Slope of q-line $= \dfrac{q}{q-1}$



- ***Fenske's equation***
  - To find minimum number of trays N_m at total reflux, for systems of constant relative volatility.

$$N_m + 1 = \frac{\log\left[\frac{x_D}{1-x_D} \cdot \frac{1-x_W}{x_W}\right]}{\log \alpha}$$

- The optimal reflux ratio to minimum reflux ratio is usually in the range of 1.1 to 1.5.

- **Use of open steam**
  - When a water solution in which the nonaqueous component is the more volatile, is fractionated, so that the water is removed as the residue product, the heat required can be provided by admission of steam directly to the bottom of the tower. The reboiler is dispensed with.
  - For a given reflux ratio and distillate composition, more trays will usually be required in the tower.
  - In trays calculation, the enriching section of the tower is unaffected by the use of open steam.

- It is the condensing temperature in a condenser which determines the operating pressure of the distillation column, since the saturation temperature of a vapor varies with its pressure. If the condensing temperature is very close to cooling water range at atmospheric pressure, the distillation pressure must be elevated to permit a larger ΔT.

- **Reboilers**
  - Kettle type reboiler — a theoretical stage.
  - Thermosyphon reboilers: It is safest not to assume that theoretical stage's worth of fractionation will occur with thermosyphon reboilers but instead to provide the necessary stages in the tower itself.

- **Heat losses in the tower**
  - Heat losses increases the internal reflux ratio L_n/G_{n+1}, and for a given condenser heat load, fewer trays for a given sepration are required.
  - For a given reboiler heat load, fewer trays are required for a given separation is the heat losses are eliminated.

- **Use of HETP data for packed-bed distillation**
  - Distillation design methods normally involve dtermination of the number of theoretical equilibirum stages or plates N. Thus when packed columns are employed in distillation applications, it is common practice to rate the efficiency of tower packings in terms of the height of packing equivalent to one theoretical stage (HETP).

6.3.4 Interfacial Gas Concentration

Consider a system in which component A is being transferred from a gas phase to a liquid phase. The equilibrium relation is given by $y_A = 0.75x_A$ *where* y_A *and* x_A *are mole fractions of A in gas and liquid phase respectively. At one point in the equipment, the gas contains 10 mole % A and liquid 2 mole % A. Gas film mass transfer coefficient* k_y *at this point is 10 kmol/(hr.m*^{2}*.*Δy_A*) and 60% of the resistance is in the gas film. Calculate:*

(a) the overall mass transfer coefficient in kmol/(hr.m^2*.*Δy_A*).*

(b) mass flux of A in kmol/(hr.m^2*).*

(c) the interfacial gas concentration of A in mole fraction. (GATE-1990-15iii)

Solution:
Equilibrium composition of gas y_A^* corresponding to $x_A = 0.02$ (i.e., 2 mole %):

$$y_A^* = 0.75x_A = 0.75 \times 0.02 = 0.015$$

Since individual gas film resistance $1/k_y$ is 60% of overall resistance $1/K_y$,

$$\begin{aligned} 0.6\frac{1}{K_y} &= \frac{1}{k_y} \\ K_y &= 0.6 \times 10 = 6 \text{ kmol/(hr.m}^2.\Delta y_A) \end{aligned}$$

Mass flux in terms of overall mass transfer coefficient:

$$\begin{aligned} \text{Mass flux} &= K_y(y_A - y_A^*) \qquad (6.7) \\ &= 6(0.1 - 0.015) = 0.51 \text{ kmol/(hr.m}^2) \end{aligned}$$

Mass flux in terms of individual mass transfer coefficient:

$$\text{Mass flux } = k_y(y_A - y_{Ai}) \qquad (6.8)$$

where y_{Ai} = interfacial gas concentration.
Substituting for mass flux, k_y and y_A in Eqn.(6.8),

$$\begin{aligned} 10(0.1 - y_{Ai}) &= 0.51 \\ y_{Ai} &= 0.049 \end{aligned}$$

20. A gaseous reaction $A \rightarrow 2B+C$ takes place isothermally in a constant pressure reactor. Starting with a gaseous mixture containing 50% A (rest inerts), the ratio of final to initial volume is found to be 1.6. The percentage conversion of A is (GATE-1992-2.c)

    (a) 30 (b) 50 (c) 60 (d) 74

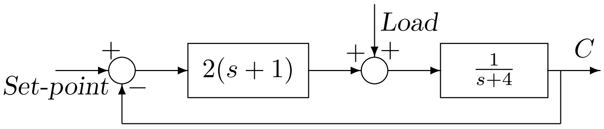
    Answer: **(c)** $\varepsilon_A = \dfrac{V_{X_A=1} - V_{X_A=0}}{V_{X_A=0}} = \dfrac{3-1}{1} = 2$

    $$\frac{V}{V_0} = 1.6 = \frac{\text{volume of inert} + \text{volume of } A}{\text{volume at initial}} = \frac{0.5V_0 + 0.5V_0(1+\varepsilon_A X_A)}{V_0}$$

    Solving $X_A = 0.6$.

8.3.18 Offset in Feedback Control System

A control system is shown below.



(a) Determine the variation of C *with time for a unit step change in the set-point.*

(b) What is the offset? (GATE-1997-8)

Solution:

$$\begin{aligned} C(s) &= \frac{2(1+s)\frac{1}{s+4}}{1+2(1+s)\frac{1}{s+4}}\bar{y}_{sp}(s) \\ &= \frac{2(1+s)}{(s+4)+2(1+s)}\bar{y}_{sp}(s) \\ &= \frac{2(1+s)}{3(s+2)}\bar{y}_{sp}(s) \end{aligned}$$

For unit step change in setpoint, $\bar{y}_{sp}(s) = 1/s$. Therefore

$$\begin{aligned} C(s) &= \frac{2}{3}\frac{1+s}{s+2}\frac{1}{s} \\ &= \frac{2}{3}\left[\frac{1}{s(s+2)} + \frac{1}{s+2}\right] \\ &= \frac{2}{3}\left[\frac{1/2}{s} - \frac{1/2}{s+2} + \frac{1}{s+2}\right] \\ &= \frac{1}{3}\left[\frac{1}{s} + \frac{1}{s+2}\right] \end{aligned}$$

Using inverse Laplace transform,

$$C(t) = (1/3)\left[1 + e^{-2t}\right]$$

This expression gives the variation of C with time for unit step change in setpoint.

$$\begin{aligned} \text{Offset} &= 1 - \lim_{t\to\infty} C(t) \\ &= 1 - 1/3 = 2/3 \end{aligned}$$

9.1.2 Cost Estimation

- Total capital investement = Fixed capital investement + working capital

- Most chemical plants use an working capital accounting to 10 to 20% of the total capital investment.

- **Cost indexes**: for updating cost data from cost data for a particular year.

$$\begin{aligned}\text{Present cost} &= \text{original cost } \times \\ &\left(\frac{\text{index value at present time}}{\text{index value at time original cost was obtained}}\right)\end{aligned}$$

- **Cost scaling**: cost data for a particular size. Normally *six-tenths factor rule* is used. According to this rule, if the cost of a given unit at one capacity is known, the cost of a similar unit with X times the capcity of the first is approximately $X^{0.6}$ times the cost of the initial unit.

$$\begin{aligned}\text{Cost of equipment of } a &= \text{cost of equipment } b \times \\ &\left(\frac{\text{capacity of equipment } a}{\text{capacity of equipment } b}\right)^{0.6}\end{aligned}$$

  However, the application of the 0.6 rule of thumb for most purchased equipment is an oversimplification of a valuable cost concept, since the actual values of the cost-capacity factor vary from less than 0.2 to greater than 1.0. Because of this, 0.6 factor should only be used in the absence of other information. In general, the cost-capacity concept should not be used beyond a tenfold range of capacity.

- **Lang[1] multiplication factors for estimation of fixed-capital investment or total capital investment**
  Factor × delivered equipment cost = fixed-capital investment or total capital investment.

Type of plant	Factor for	
	Fixed-capital investment	Total capital investment
Solid-processing plant	3.9	4.6
Solid-fluid-processing plant	4.1	4.9
Fluid-processing plant	4.8	5.7

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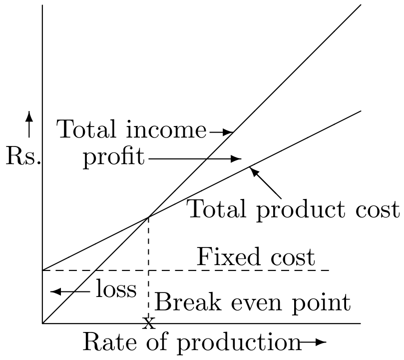
[1] Ref: Plant Design and Economics for Chemical Engineers - Peters & Timmerhaus, McGraw-Hill

- **Break-even point**



The fixed cost remains constant, and the total production cost increases as the rate of production increases. The point where the total product cost equals the total income is known as break-even point.

- Turnover ratio $= \dfrac{\text{gross annual sales}}{\text{fixed capital investment}}$
The reciprocal of turnover ratio is sometimes defined as the capital ratio or investment ratio. For the chemical industry, as a very rough rule of thumb, the turnover ratio can be approximated as 1.

31. Dilute sulfuric acid is handled in vessels made of: (GATE-1989-9.i.a)

    (a) Stainless steel (b) Brass (c) Lead (d) Cast iron

    Answer: **(c)** Lead-chamber process produces $< 70\%$ H_2O_4, as lead is not suitable for high-concentrated sulfuric acid. But at concentrations less than 70% carbon steel is not suitable. In other words lead is suitable for dilute sulfuric acid and carbon steel for concentrated acid and vice versa.

12. $\lim_{x \to \infty} \dfrac{x^3+1}{2x^2+80x+1}$ is (GATE-1997-1.02)

    (a) 0 (b) $\dfrac{1}{2}$ (c) 1 (d) infinity

    Answer: **(d)** Divide numerator and denominator by x^3 to get

$$\lim_{x \to \infty} \frac{1+1/x^3}{(2/x)+(80/x^2)+(1/x^3)} = \frac{1+1/\infty}{0+0+0} = 1/0 = \infty$$