Module - 6

Adsorption :- Adsorption may be defined as selective concentration or retention of one or more components of ~~from a~~ a fluid mixture on a solid surface. The solid is called adsorbent and component is called adsorbate. Adsorption is surface phenomena whereas absorption is a bulk phenomena. The adsorption process is a result of interaction between the adsorbate molecules and the surface (or pore wall) of the adsorbent.

Types of adsorption :-

Adsorption

Physical adsorption or Physisorption or Van der waals adsorption

reversible phenomenon is the result of intermolecular forces of attraction between molecules of solid and adsorbate

Chemisorption or chemical adsorption or activated adsorption, is result of chemical interaction between the solid and the adsorbate molecules.

Heat of adsorption is much larger than physisorption

May not be reversible.

Same substance may show physisorption at lower temp. and chemisorption at higher temperature, and both phenomena may occur at the same time.

Nature of adsorbents :-

Adsorbent. solids are usually used in granular form, varying in size from roughly 12 mm in diameter to as small as 50 μm. The solids must possess certain engineering properties depending upon the application. If they are used in a fixed bed through which a liquid or gas is to flow, for example they must not offer too great a pressure drop for flow nor must they. easily be carried away by the flowing stream. They must have adequate strength and hardness so as not to be reduced in size during handling or crushed in supporting their own weight in beds of the required thickness. Large surface per unit weight seems essential to all useful adsorbents

Adsorbents :- (i) Fuller's earth, (ii) Activated clays (bentonite)

(iii) bauxite (iv) Alumina, (v) activated carbon etc.

(vi) molecular sieves (zeolite crystals 3 cages) (vii) Silica gel

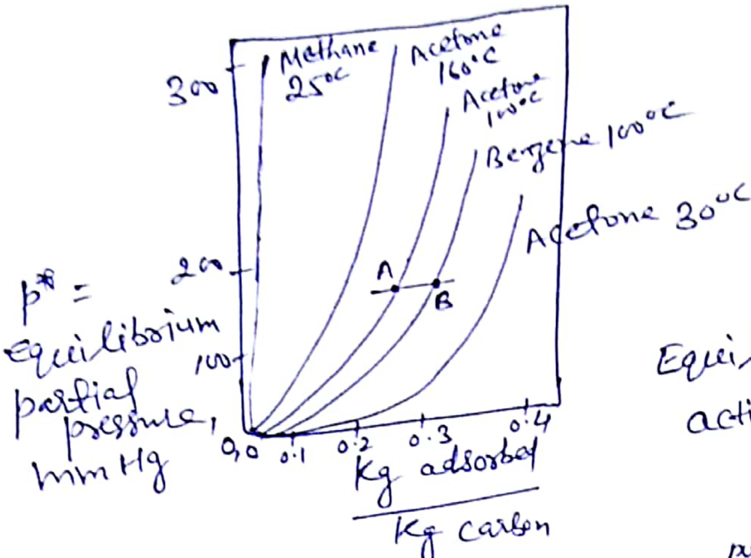
Applications of adsorption

Adsorption Equilibria :-

Solid $\Leftrightarrow$ adsorbate $\Leftrightarrow$ fluid,
Equilibrium at const.
T and P

Adsorption of single gases and vapors

Below figure shows the several equilibrium adsorption isotherms for a particular activated carbon as adsorbent, where the adsorbate concentration on the solid is plotted against the equilibrium partial pressure $\bar{p}^*$ of the vapor or gas at constant temperature



Effect of temp.

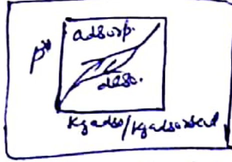
Equilibrium adsorption of vapors on activated carbon

① For example at point A → pure Acetone vapor at 100 °C and 190 mmHg is in equilibrium with an adsorbate conc. of 0.2 Kg adsorbed/Kg carbon.

② Increasing pressure cause more adsorption but approximately constant beyond certain equilibrium partial pressure.

(3) Benzene is more adsorbed than acetone at constant T and P, comparatively.

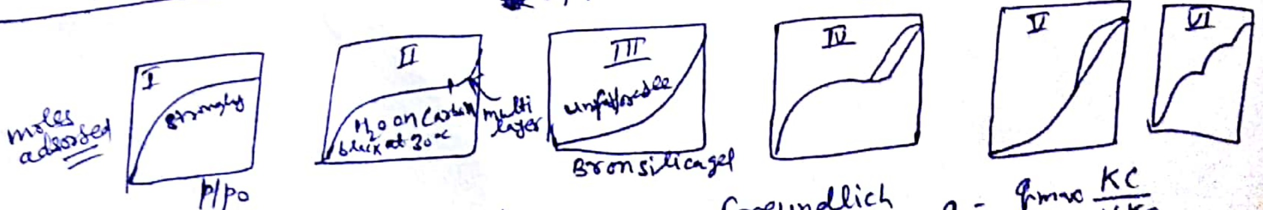
(4) If many components are available and only one component is appreciably adsorbed. In such instances, the adsorption of vapor will be substantially unaffected by the presence of the poorly adsorbed gas, and the adsorption isotherm for the pure vapor will be applicable provided the equilibrium pressure is taken as the partial pressure of the vapor in vapor-gas mixture. For example, acetone-methane mixture



Describe hysteresis using point A.
A can be achieved by adsorption over fresh carbon or desorption with initially higher conc. of adsorbate

Adsorption Isotherms

(IUPAC classification)



Models for adsorption isotherms (1) Freundlich $q = KC_A^n$ $q = q_{max}\frac{KC}{1+KC}$ (Langmuir)

$$\frac{1}{v(P_0/P-1)} = \frac{C-1}{v_m C}\left(\frac{P}{P_0}\right) + \frac{1}{v_m C}$$

(linear form of BET equation for multilayer physisorption)

ADSORPTION

Reference

Treybal, McCabe, Genkoplis

- **Module – 6:** ADSORPTION Introduction, nature of adsorbents, batch adsorption, Adsorption isotherms. Adsorption equipment, pressure swing, thermal-swing, breakthrough curves, design of fixed bed adsorption column. . (5)

Types of adsorption

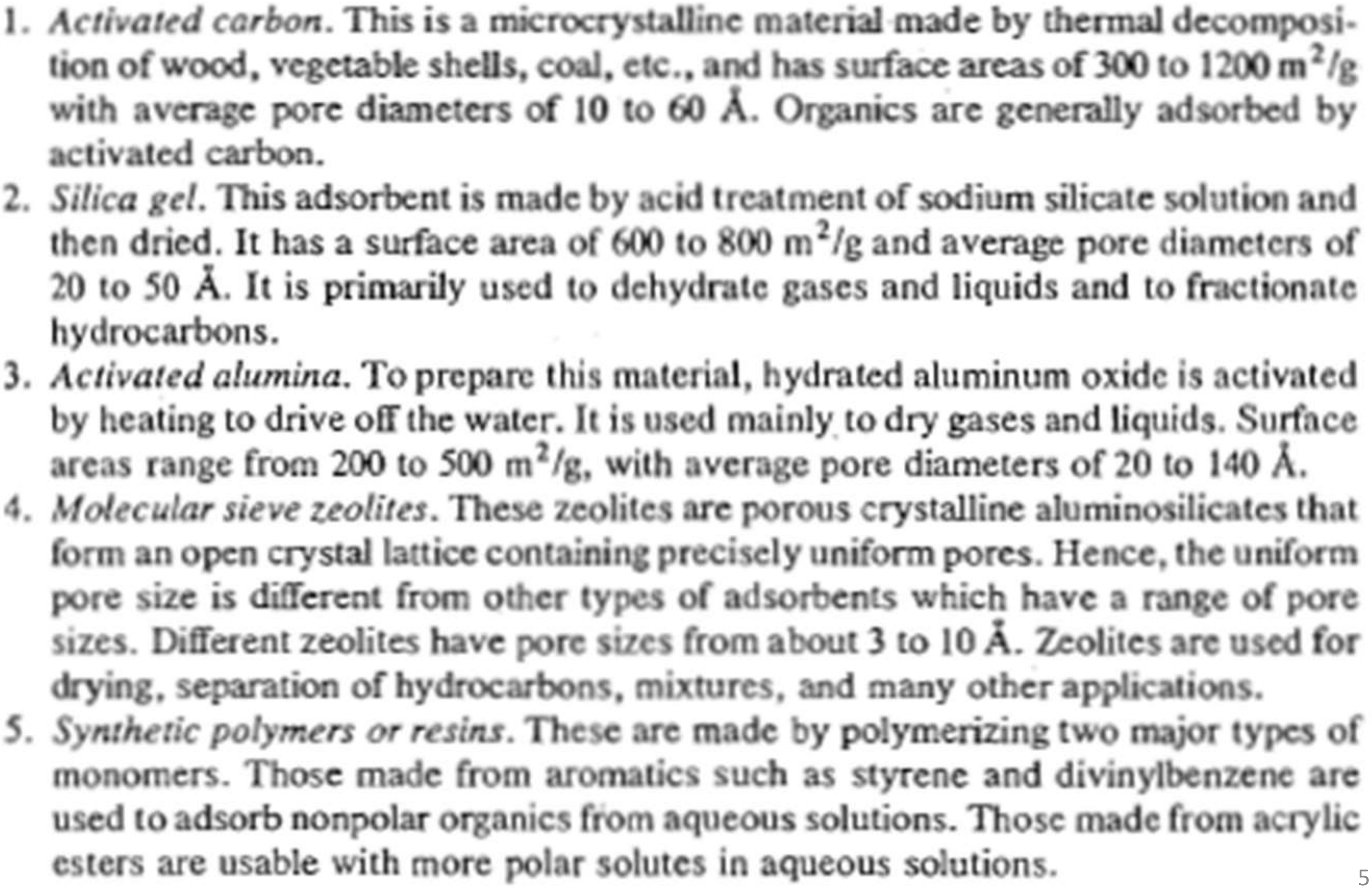
- Physical Adsorption or van der Waals adsorption or Physisorption
  - The heat of adsorption 1-4 times the heat for vaporization
  - Electrostatic forces may be present
  - Reversible
- Chemisorption
  - Interaction between the solute and adsorbent very strong due to chemical bond formation
  - Heat of adsorption much larger than than physisoprtion
  - May not be reversible

ADSORBENTS

- Fullers earth
- Activated clays
- Bauxite
- Alumina
- Activated carbon
    - Bone char
    - Decolorising carbon
    - Gas adsorbing carbon
    - Molecular screening activated carbon
- Synthetic polymeric resin
- Silica gel
- Molecular sieve

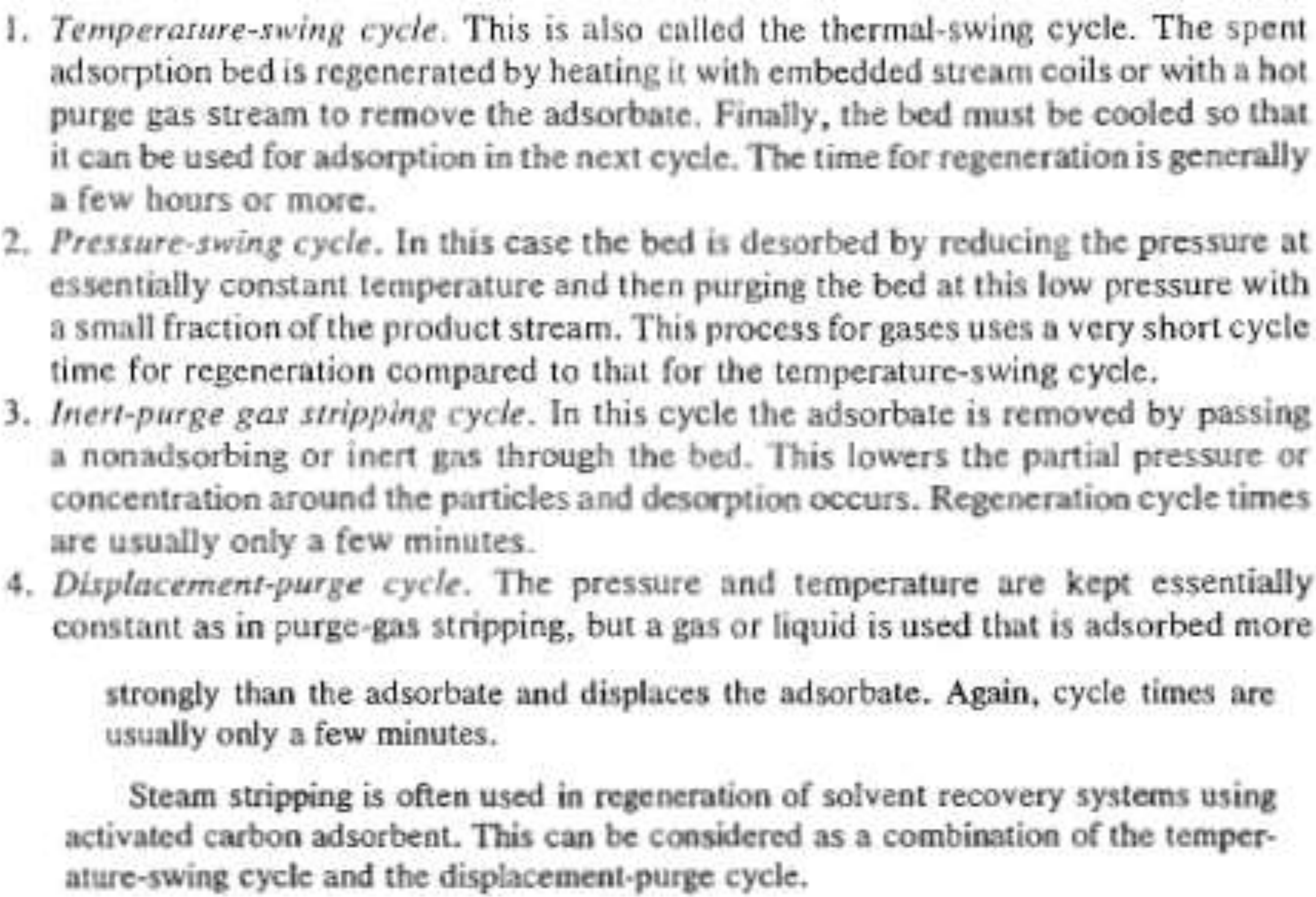
	Pore size ^{o}A	**Surface area** m^2/g
Activated carbon	10 to 60	300-1200
Silica gel	20 to 50	600 to 800
Activated alumina	20 to140	200 to 500
Molecular sieve	3 to 10	

ADSORBENTS



1. *Activated carbon*. This is a microcrystalline material made by thermal decomposition of wood, vegetable shells, coal, etc., and has surface areas of 300 to 1200 m^2/g with average pore diameters of 10 to 60 Å. Organics are generally adsorbed by activated carbon.
2. *Silica gel*. This adsorbent is made by acid treatment of sodium silicate solution and then dried. It has a surface area of 600 to 800 m^2/g and average pore diameters of 20 to 50 Å. It is primarily used to dehydrate gases and liquids and to fractionate hydrocarbons.
3. *Activated alumina*. To prepare this material, hydrated aluminum oxide is activated by heating to drive off the water. It is used mainly to dry gases and liquids. Surface areas range from 200 to 500 m^2/g, with average pore diameters of 20 to 140 Å.
4. *Molecular sieve zeolites*. These zeolites are porous crystalline aluminosilicates that form an open crystal lattice containing precisely uniform pores. Hence, the uniform pore size is different from other types of adsorbents which have a range of pore sizes. Different zeolites have pore sizes from about 3 to 10 Å. Zeolites are used for drying, separation of hydrocarbons, mixtures, and many other applications.
5. *Synthetic polymers or resins*. These are made by polymerizing two major types of monomers. Those made from aromatics such as styrene and divinylbenzene are used to adsorb nonpolar organics from aqueous solutions. Those made from acrylic esters are usable with more polar solutes in aqueous solutions.

METHODS OF REGENARATION OF SPENT ADSORBENTS



1. *Temperature-swing cycle.* This is also called the thermal-swing cycle. The spent adsorption bed is regenerated by heating it with embedded stream coils or with a hot purge gas stream to remove the adsorbate. Finally, the bed must be cooled so that it can be used for adsorption in the next cycle. The time for regeneration is generally a few hours or more.
2. *Pressure-swing cycle.* In this case the bed is desorbed by reducing the pressure at essentially constant temperature and then purging the bed at this low pressure with a small fraction of the product stream. This process for gases uses a very short cycle time for regeneration compared to that for the temperature-swing cycle.
3. *Inert-purge gas stripping cycle.* In this cycle the adsorbate is removed by passing a nonadsorbing or inert gas through the bed. This lowers the partial pressure or concentration around the particles and desorption occurs. Regeneration cycle times are usually only a few minutes.
4. *Displacement-purge cycle.* The pressure and temperature are kept essentially constant as in purge-gas stripping, but a gas or liquid is used that is adsorbed more strongly than the adsorbate and displaces the adsorbate. Again, cycle times are usually only a few minutes.

Steam stripping is often used in regeneration of solvent recovery systems using activated carbon adsorbent. This can be considered as a combination of the temperature-swing cycle and the displacement-purge cycle.

Application

Gaseous phase

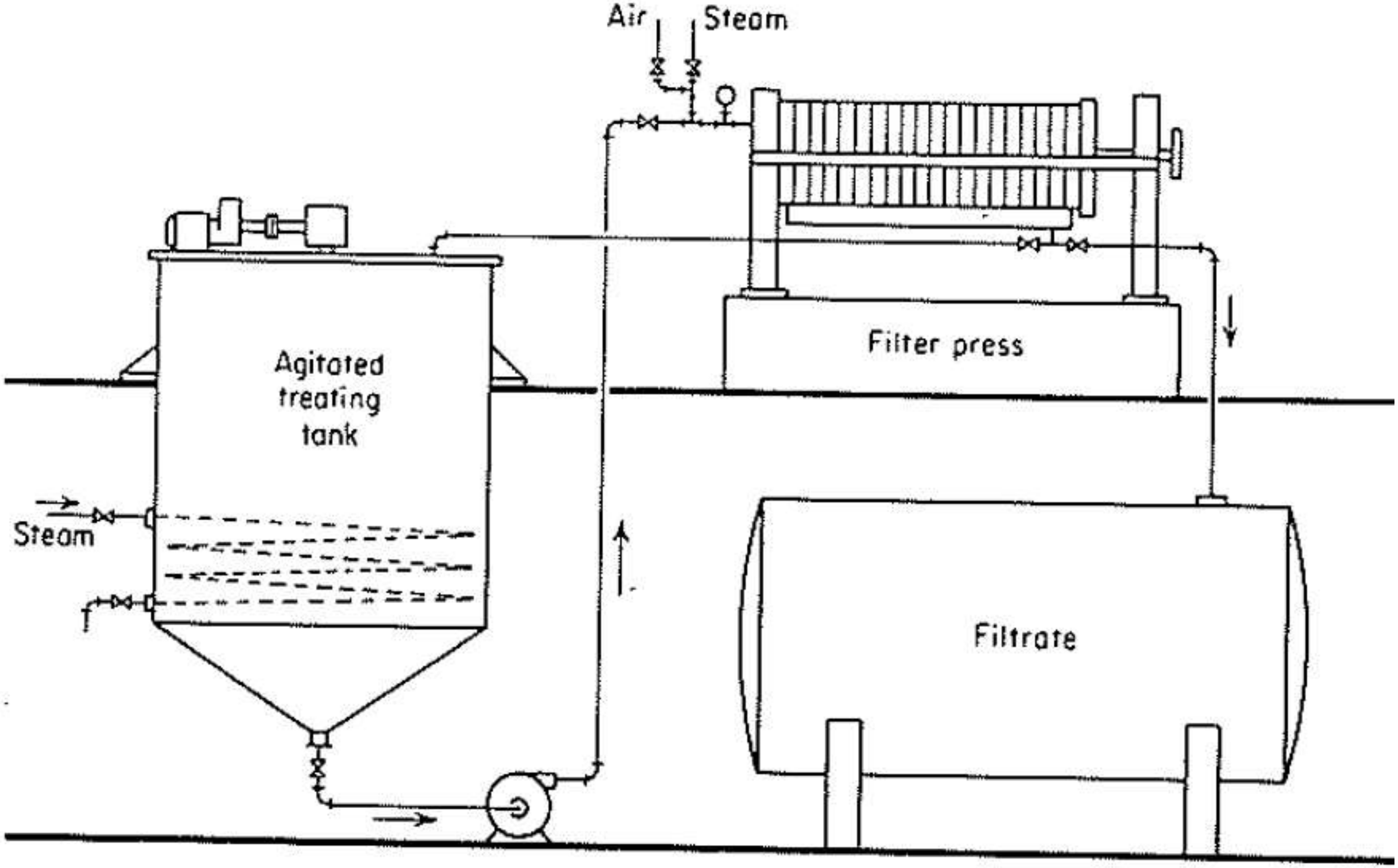
- Dehumidification of air and other gases
- Removal of odour and impurities from industrial gases.
- Recovery of solvent vapours from dilute mixture with air and other gases
- Fractionation of Hydrocarbon gases methane, ethylene, ethane, propylene and propane

Liquid phase

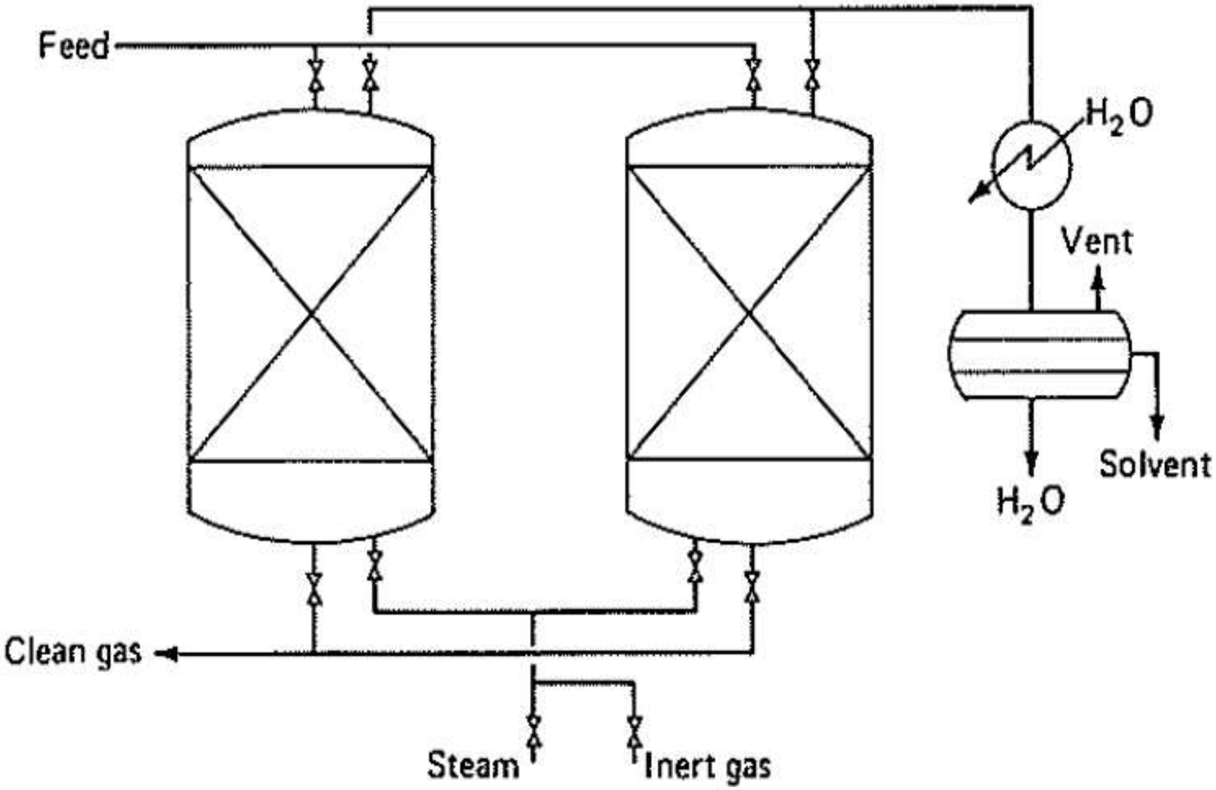
- Removal of moisture from gasoline
- Decolonization of petroleum products and aqueous sugar solution
- Removal of objectionable taste and odour from water
- Fractionation of mixtures of aromatic and paraffinic hydrocarbons.

ADSORPTION EQUIPMENT

CONTACT FILTRATION- Liquid System Batch/ stage wise contact

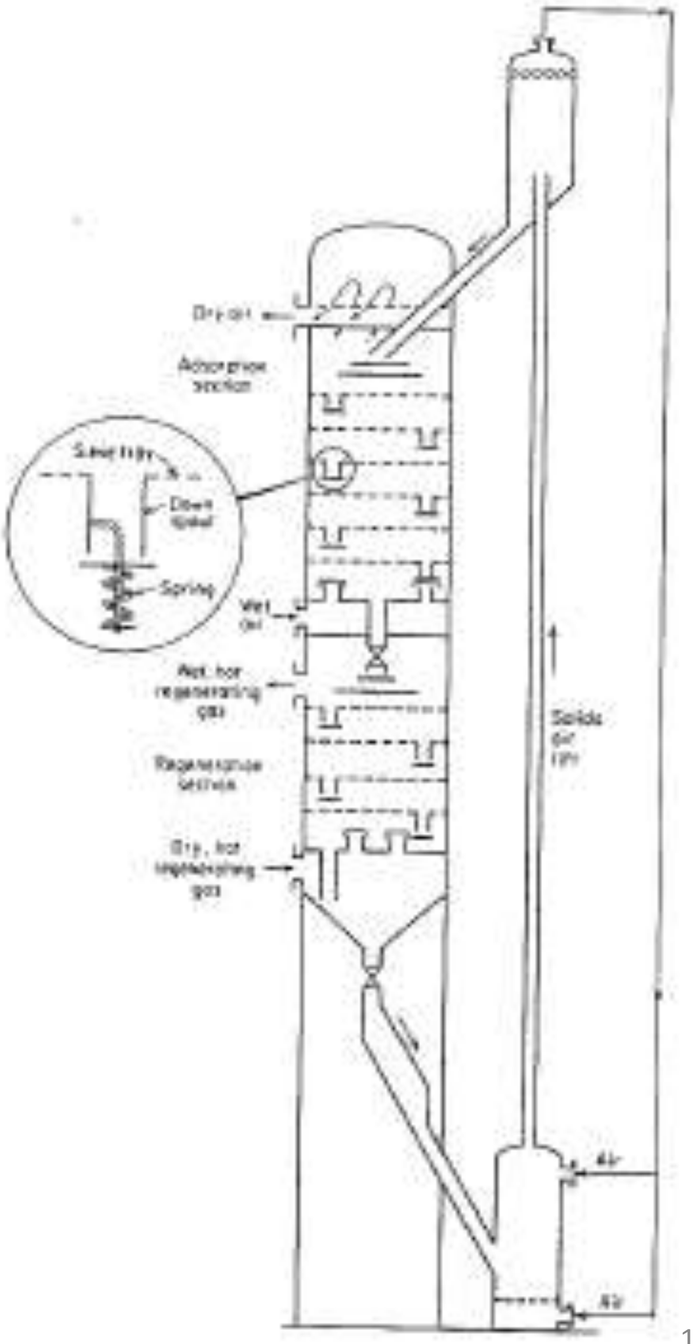


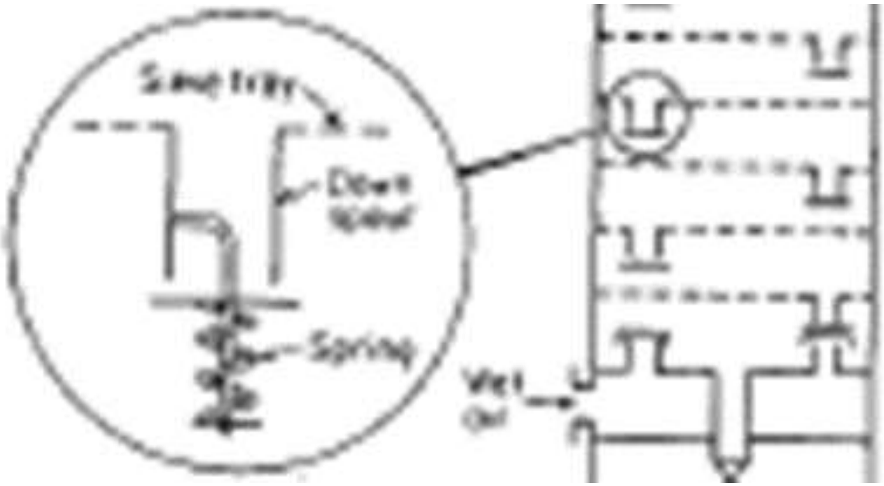
VAPOUR PHASE ADSOPTION [Dual fixed bed with Thermal Regeneration and solute recovery]



FLUIDIZED BED/
TEETER BEDADSORBER
for GASES

- Fluidized beds for adsorbent <20 mesh, upto 325 mesh superficial gas velocity of 0.6m/s
- Teeter Bed for coarse adsorbent upto 10 mesh and gas velocities from 1.5 to 3 m/s





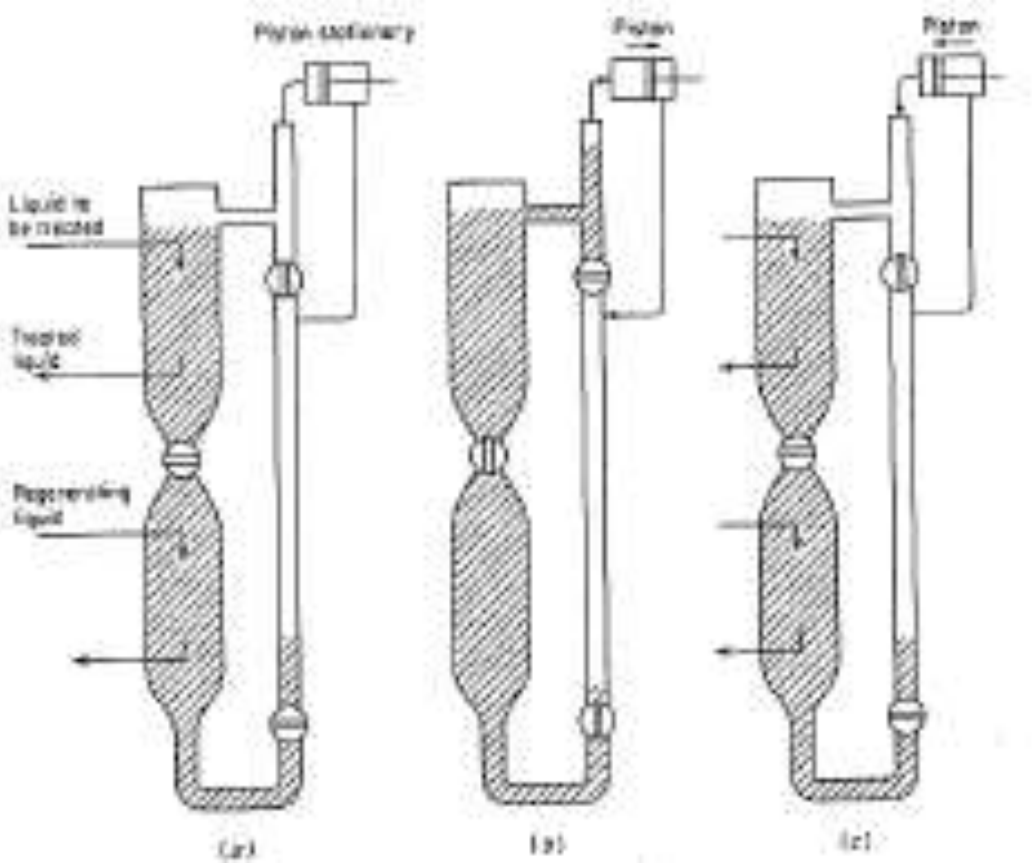
HIGGINS CONTACTOR

SOLID LIQUID CONTACT.

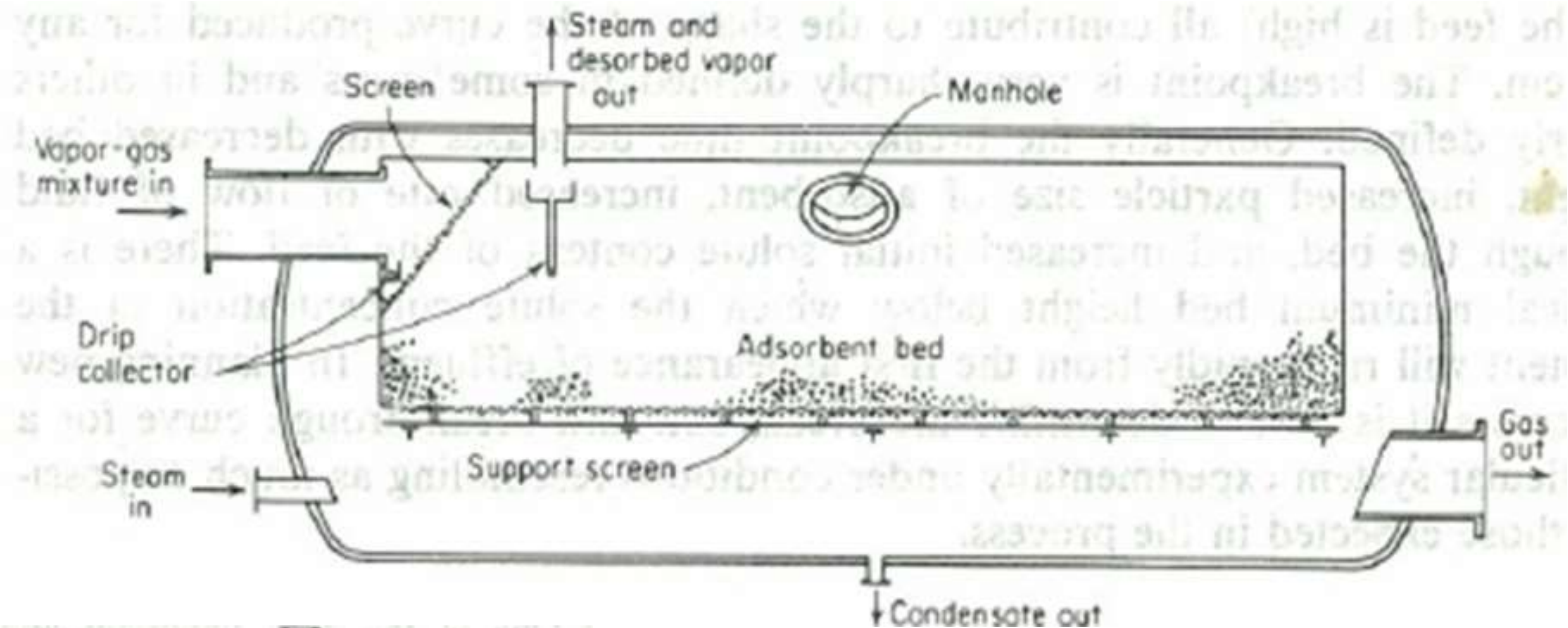
(a) Temporarily stationary upper bed of solid is contacted with liquid flowing downwards and lower bed being regenerated

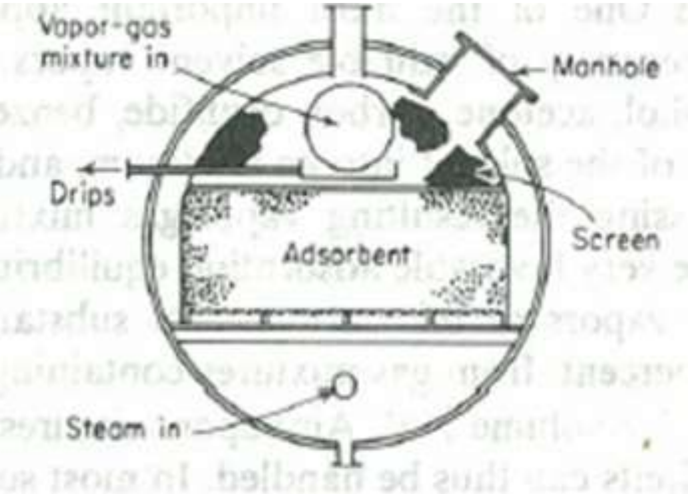
(b) Valves are turned such that liquid filled piston pump moved so that solid is moved clockwise hydraulically, regenerated solids goes to upper chamber and spent solid to the lower regeneration chamber

(c) Valves readjusted to the original position and operation restarted



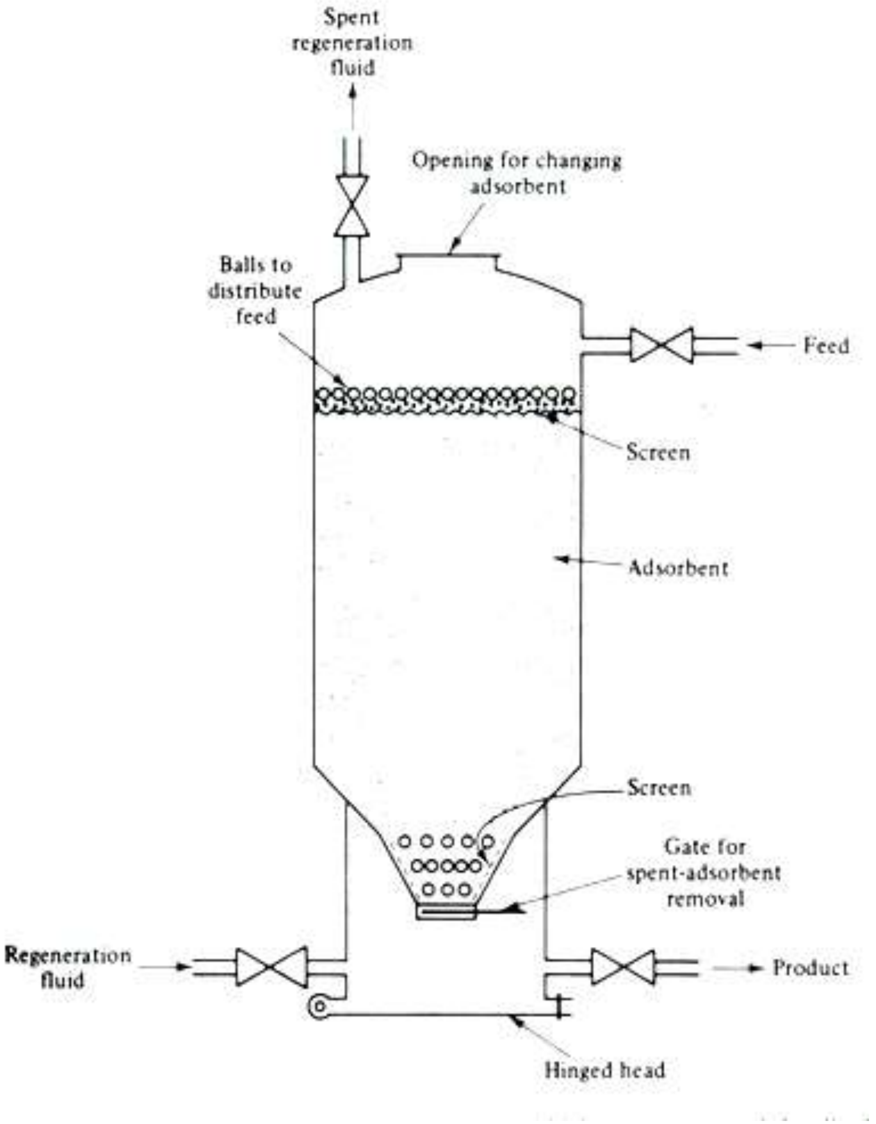
FIXED BED ADSORBER FOR VAPOUR AT LOW PRESSURE

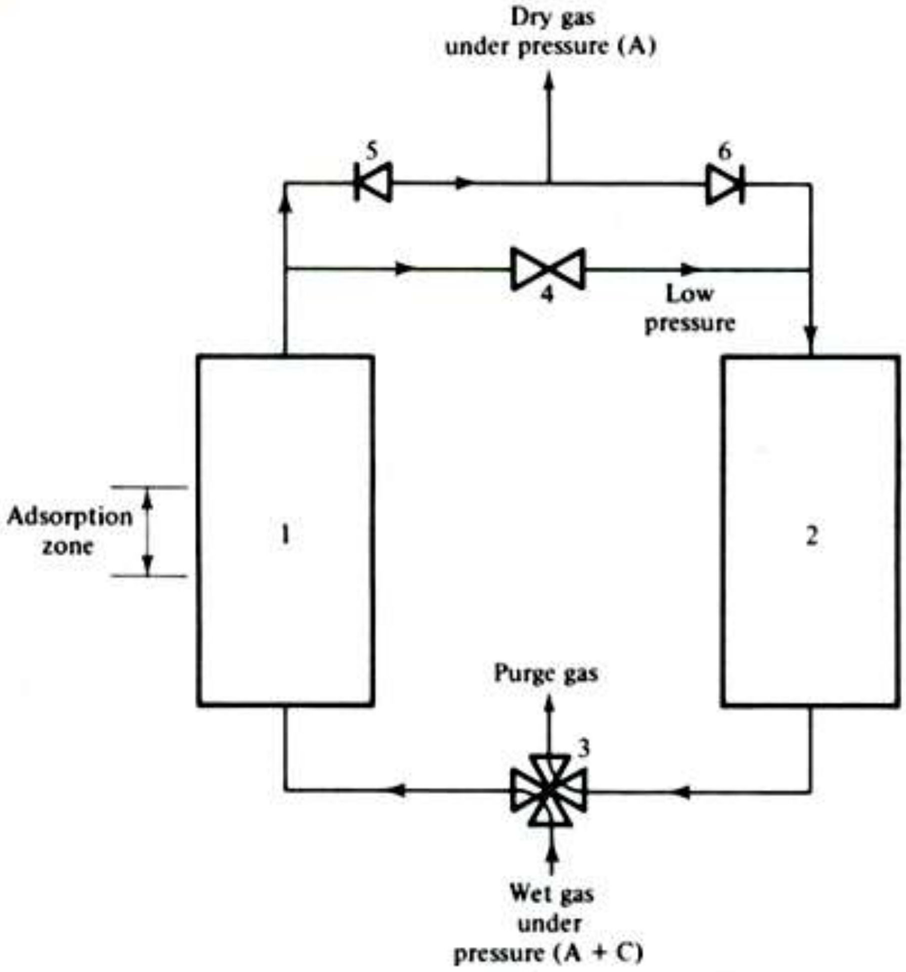




- Shallow granular bed, (0.3 to 1 m) large cross section with super ficial gas velocity 0.25 to 0.6m/s.

FIXED BED ADSOBER ATI HIGH PRESSURE AND PRESSURE SWING ADSOPTION

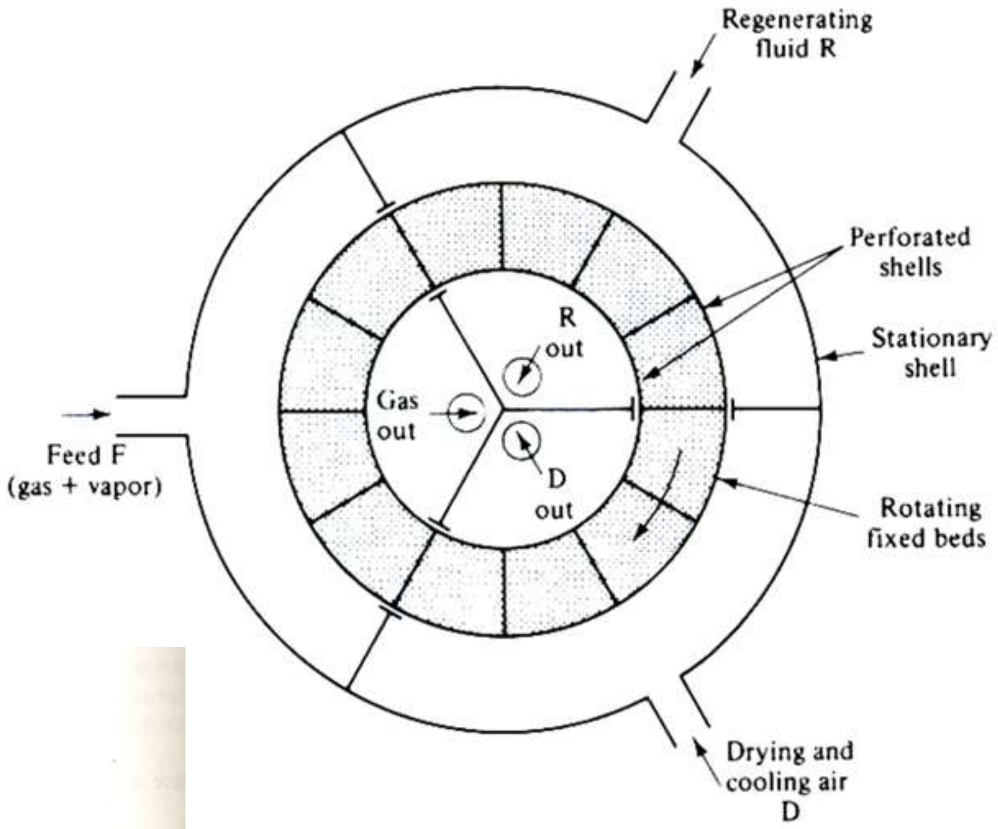


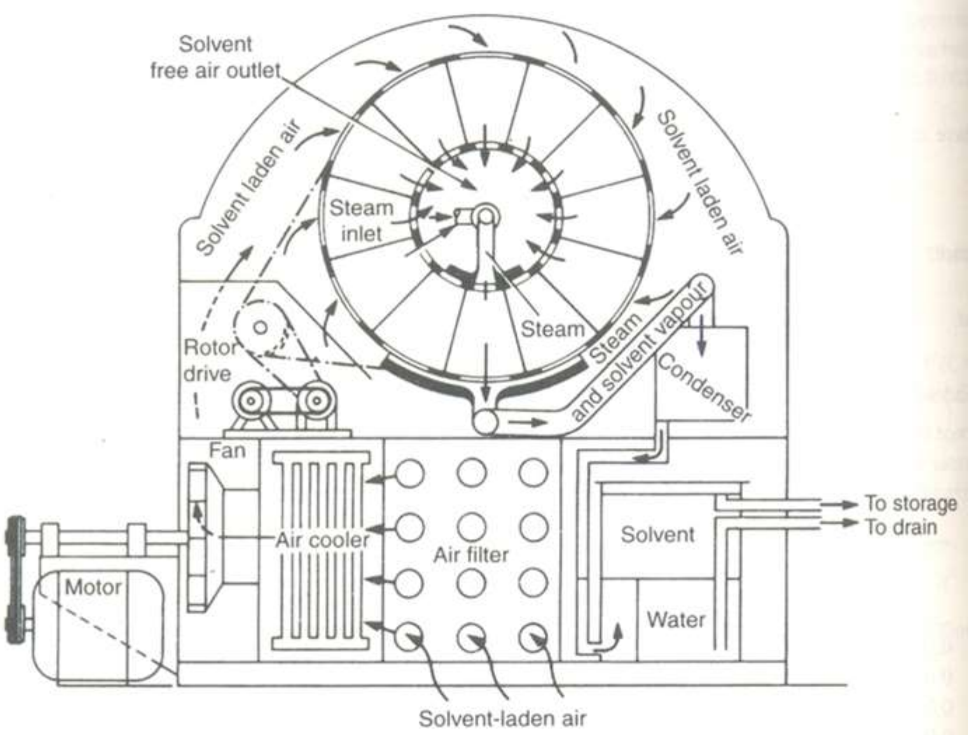


The heatless adsorber.

ROTARY [FIXED]BED ADSORBER

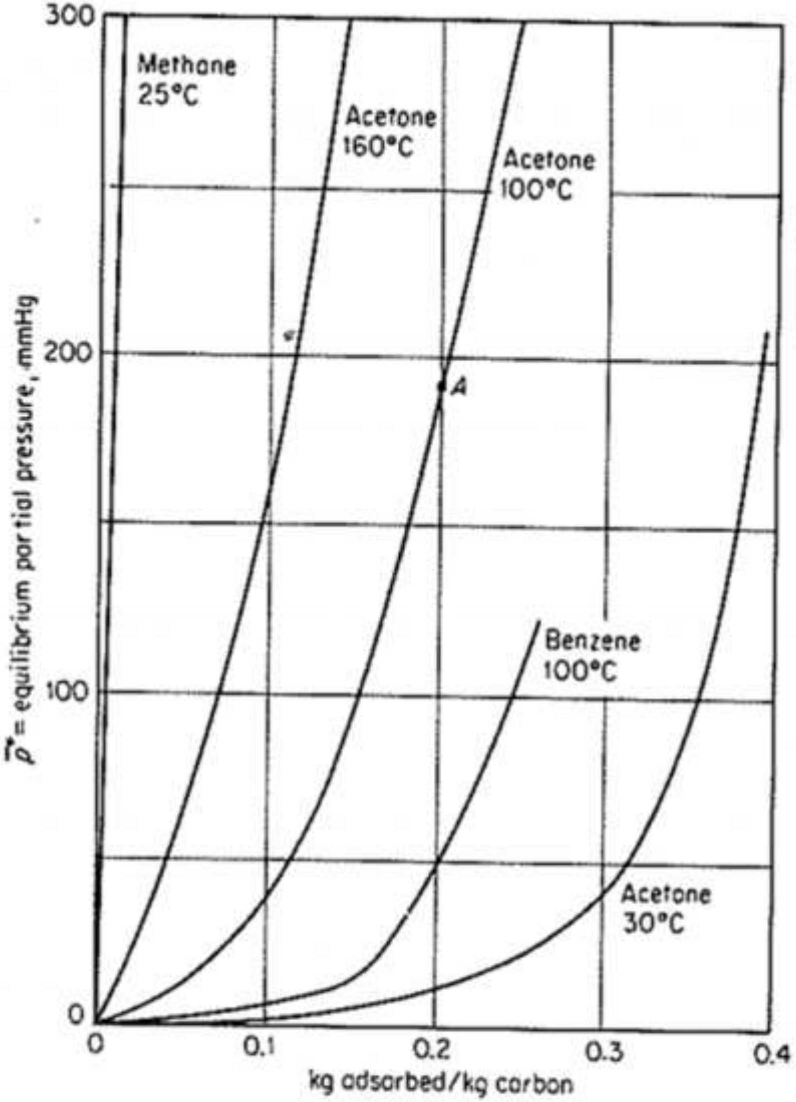
The inner drum rotates, the adsorbent is successively subject to adsorption, regeneration and drying and cooling.



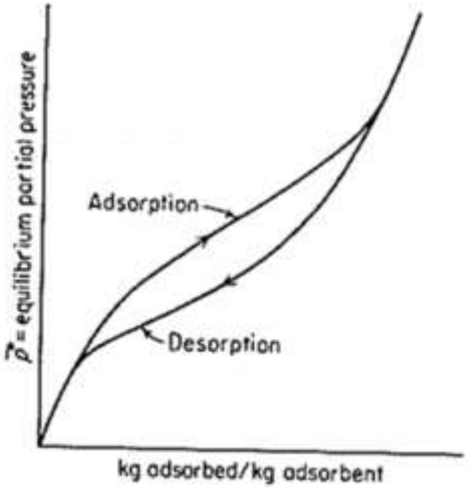


ADSORPTION QUILIBRIUM :

- Relationship between the amount adsorbed and the concentration of the adsorbate or solute a ta constant temperature T is called an adsorption isotherm.
- A plot of equilibrium adsorbent loading q, vs temperature at a constant pressure is called isobar

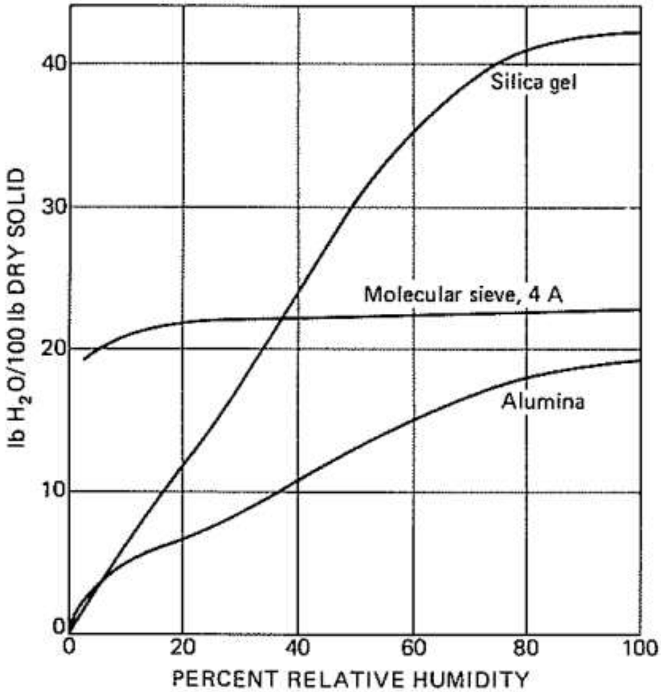


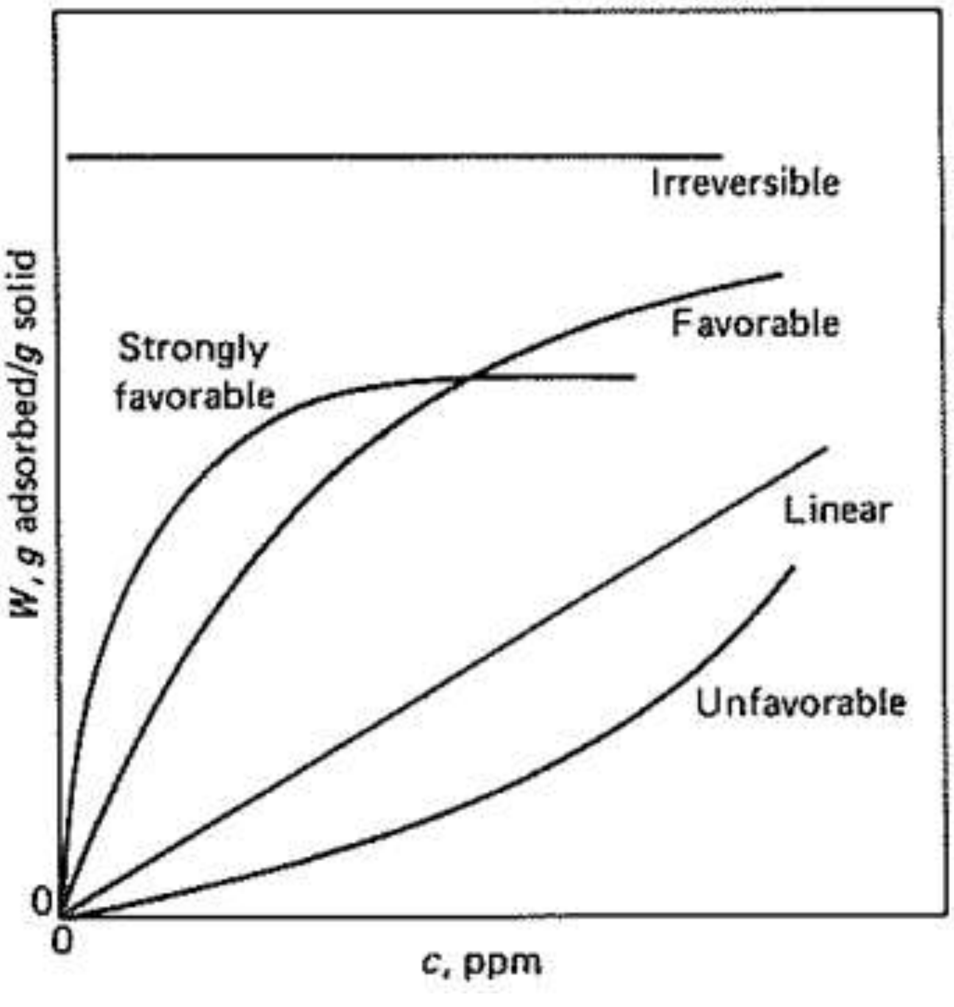
  - ADSORPTION ISOTHERM SHOWING HYSTERISIS

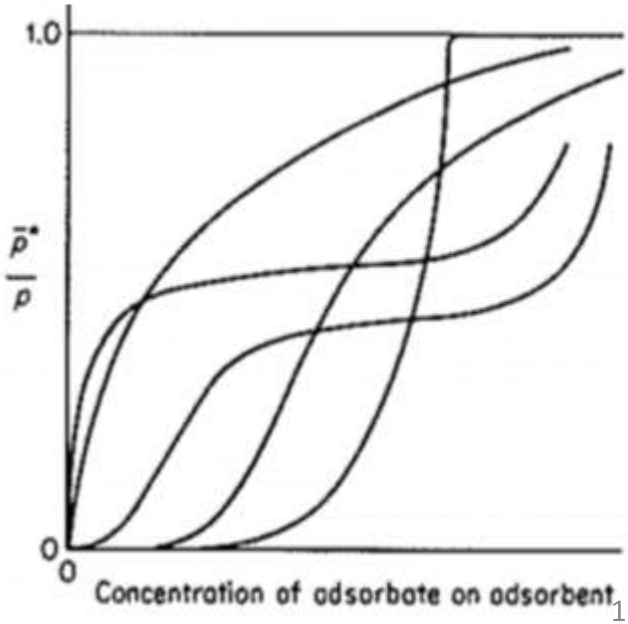


ADSORPTION ISOTHERM

[Note the solute conc in adsorbent may be in x or y axis]







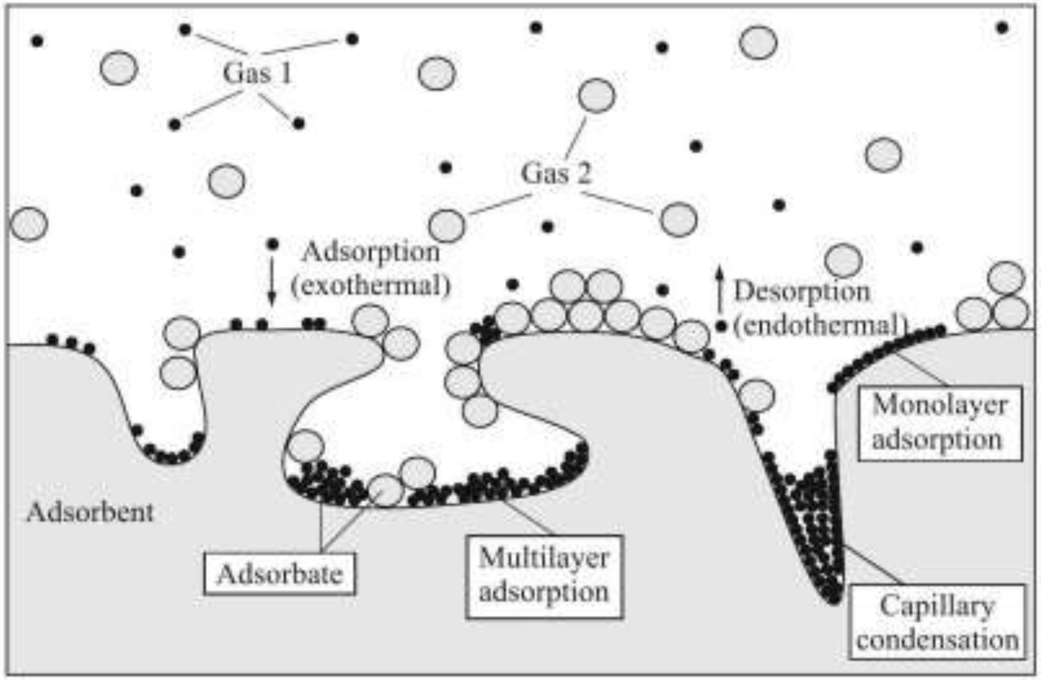
Types of Isotherm

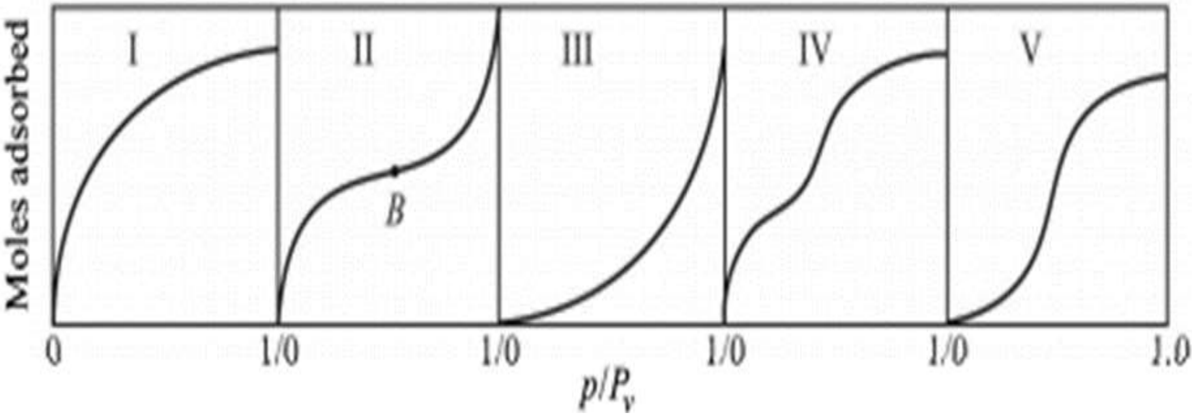
Type I – Adsorption proceeds upto mono layer. Favourable as high solute loading. Langmuir isotherm

Type II – Multilayer adsorption BET isotherm, generally for physisorption

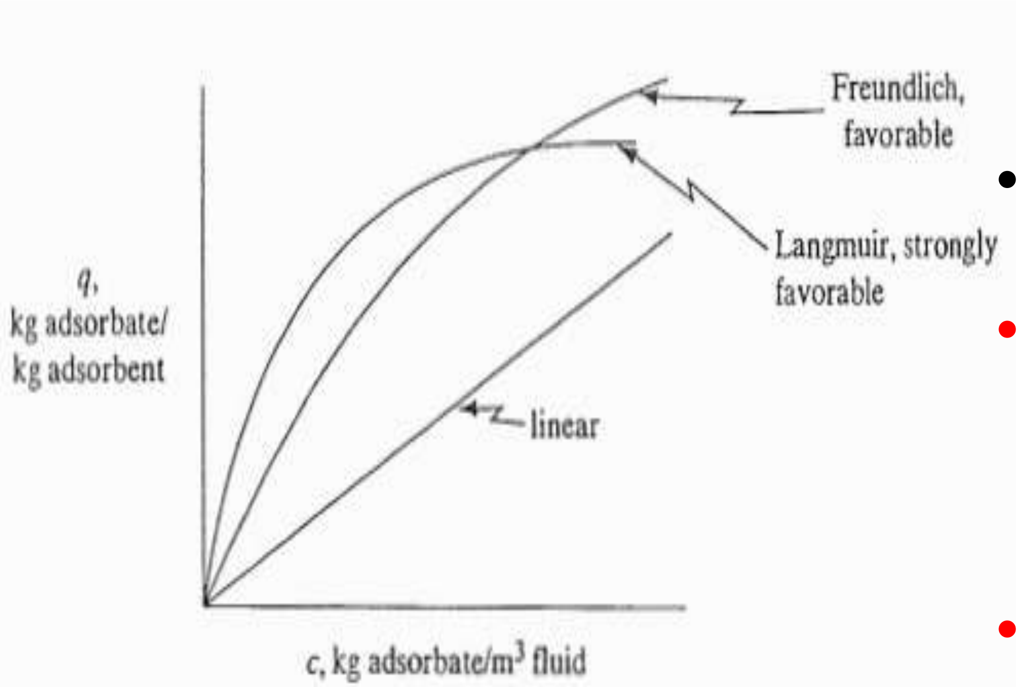
Type III- Unfavourable as solute loading is low, Rare

Type IV and V: alternating convex concave curve represents condensation within pores





Mathematical forms of Adsorption Isotherm



- If, $q = \frac{kg\ of\ adsorbate\ (solute)}{kg\ of\ adsorbent}$
- And c=$\frac{kg\ of\ adsorbate\ (solute)}{m^3\ fluid}$
- Henrys Equation for linear isotherm:

$$q = Kc$$

- K, m^3/s is a empirical constant
- **Freundlich isotherm** Equation, particularly for liquid:

$$q = Kc^n$$

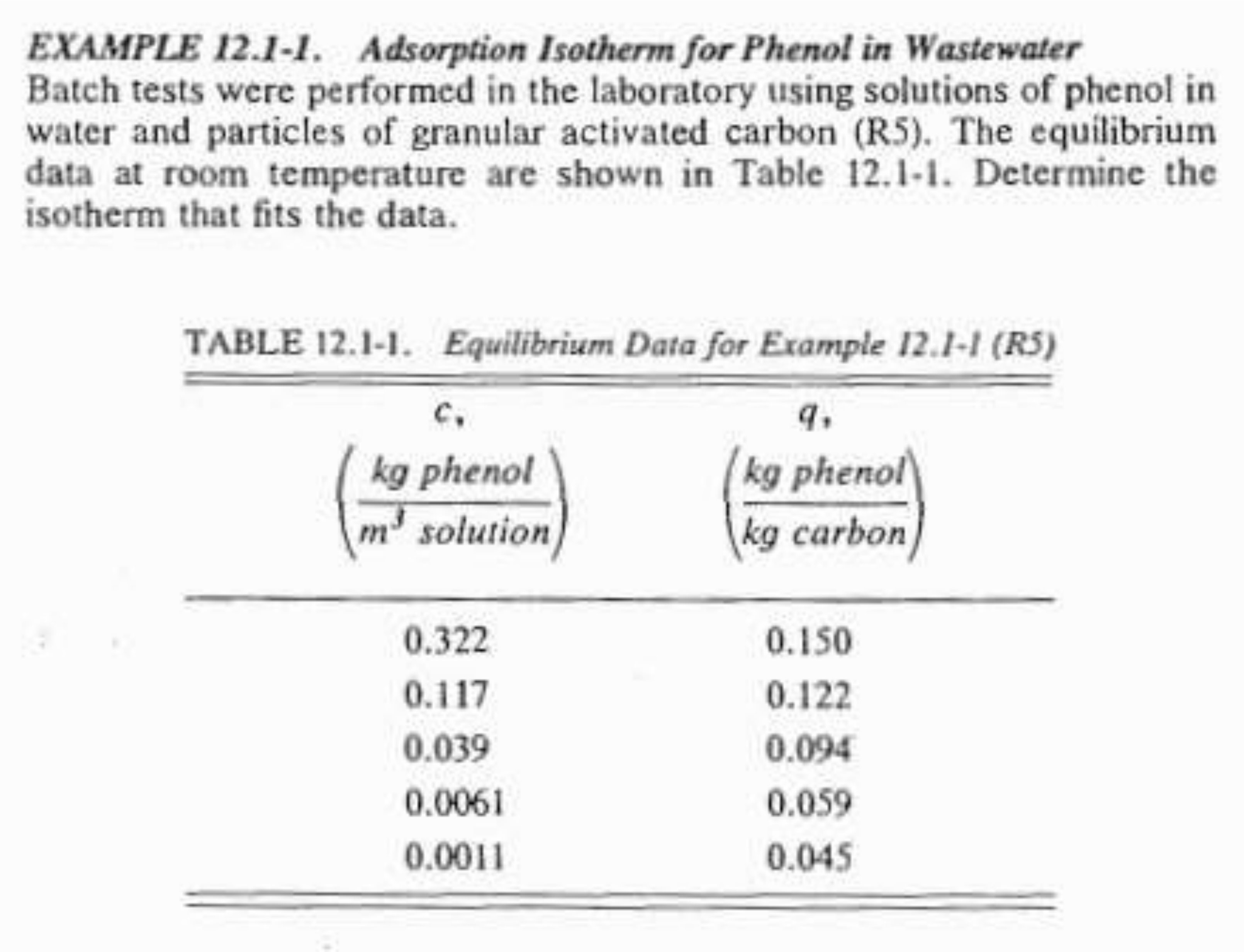
- **Langmuir isotherm** has a theoretical basis:

$$q = \frac{q_o c}{K + c}$$

LANGMUIR’S and FREUNDLICH ISOTHERM

Langmuir’s model of adsorption assumes that the solid surface is uniform, i.e. the availability of every site of adsorption to the adsorbate is equal. The adsorbate is bound to the solid as a monomolecular layer. No molecules are adsorbed after the monomolecular layer is filled. The rate of adsorption at any moment is proportional to the concentration of the adsorbate molecules in the solution or in the gas and to the fraction of free sites on the solid surface. Simultaneously, molecules are desorbed from the solid and the rate of desorption is proportional to the fraction of occupied sites. At equilibrium, the rate of adsorption is equal to the rate of desorption.

Freundlich Isotherm was proposed originally as an empirical equation. The Freundlich isotherm was shown later to have some thermodynamic justification. It has also been modified for binary mixtures It is mainly applicable to liquid system.



EXAMPLE 12.1-1. Adsorption Isotherm for Phenol in Wastewater

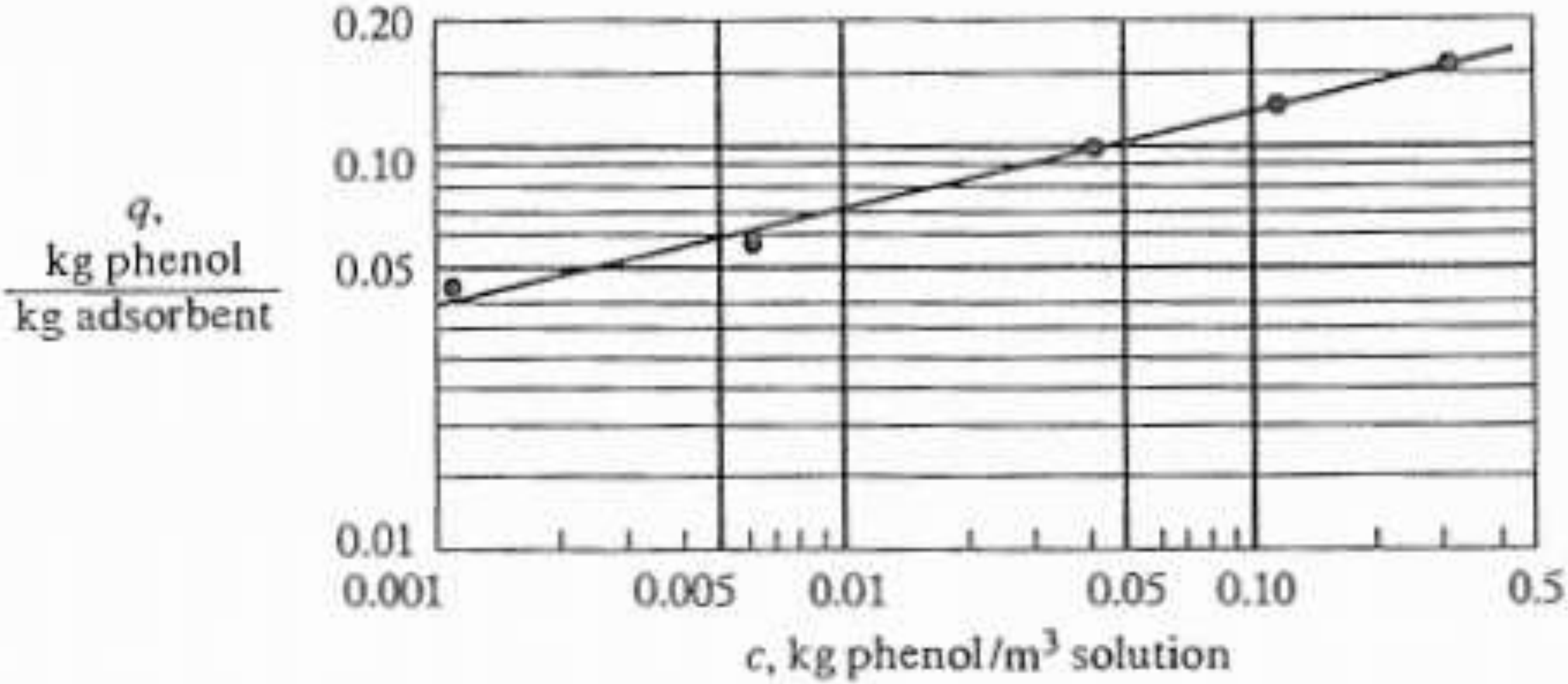
Batch tests were performed in the laboratory using solutions of phenol in water and particles of granular activated carbon (R5). The equilibrium data at room temperature are shown in Table 12.1-1. Determine the isotherm that fits the data.

TABLE 12.1-1. *Equilibrium Data for Example 12.1-1 (R5)*

c, $\left(\frac{\text{kg phenol}}{\text{m}^3\text{ solution}}\right)$	q, $\left(\frac{\text{kg phenol}}{\text{kg carbon}}\right)$
0.322	0.150
0.117	0.122
0.039	0.094
0.0061	0.059
0.0011	0.045

Solution: Plotting the data as $1/q$ versus $1/c$, the results are not a straight line and do not follow the Langmuir equation (12.1-3). A plot of log q versus log c in Fig. 12.1-2 gives a straight line and, hence, follow the Freundlich isotherm Eq. (12.1-2). The slope n is 0.229 and the constant K is 0.199, to give

$$q = 0.199c^{0.229}$$



BET EQUATION[***by Brunauer, Emmett and Teller]***

One of the shortcomings of Langmuir's theory is the assumption that no further net adsorption occurs once the monomolecular layer is full. In reality, additional molecules do adsorb on the monolayer, although with a considerably weaker bond. To address this difficulty, models of multilayer adsorption have been proposed. One of these models is the *BET isotherm*, developed ***by Brunauer, Emmett and Teller***.

The BET theory admits multilayer adsorption with increasingly weaker bonds (smaller energy of adsorption) for each subsequent layer. The equilibrium expression corresponding to the BET theory is given in terms of partial pressures.

$$x = \frac{x_m K(P/P_0)}{[1 + (K-1)(P/P_0)]\,[1-(P/P_0)]}$$

P = partial pressure of the adsorbate in the gas;

P_0 =vapor pressure of the pure adsorbate
x_m= monolayer value of x; K =a constant.
Note that the ratio P/ $P_0 = \pi$ the activity of the adsorbate.

$$[1 + (K-1)(P/P_0)]\,[1-(P/P_0)] = \frac{x_m K(P/P_0)}{x}$$

$$[1 + (K-1)\pi]\,[1-\pi] = \frac{x_m K\pi}{x}$$

$$\left(\frac{1}{x}\right)\frac{\pi}{1-\pi} = f = \frac{K-1}{x_m K}\pi + \frac{1}{x_m K}$$

- A sample of the powder is brought to contact with nitrogen vapors at the temperature of liquid nitrogen. The quantity of nitrogen adsorbed by the powder as a function of the partial pressure of nitrogen is determined. The BET monolayer value is calculated from the data. From that, the specific surface of the powder is calculated, assuming that one gram of nitrogen covers, as a monomolecular layer, a solid surface of 3485m2.

  An absorbent powder was subjected to the nitrogen adsorption experiment described above. The quantities of nitrogen adsorbed per one gram of powder at different pressures of nitrogen are given in Table . Calculate the specific surface area of the powder.

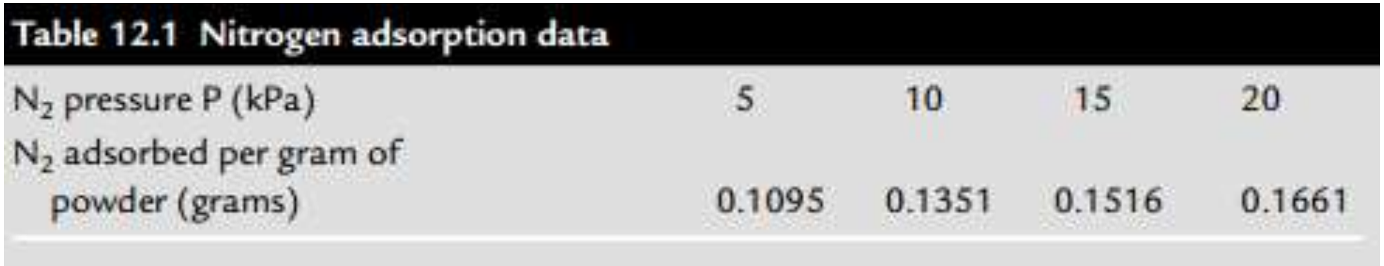
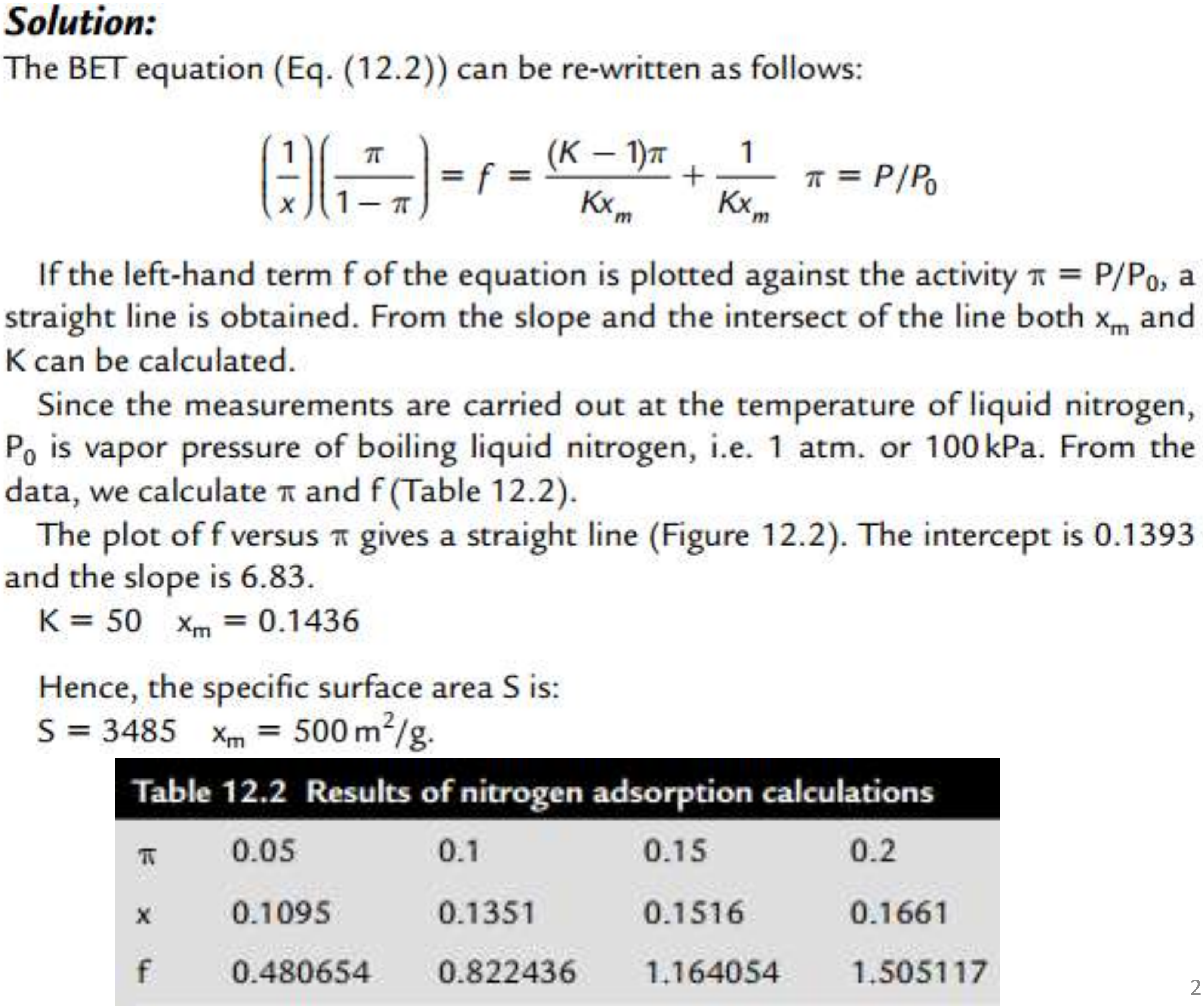


Table 12.1 Nitrogen adsorption data

N_2 pressure P (kPa)	5	10	15	20
N_2 adsorbed per gram of powder (grams)	0.1095	0.1351	0.1516	0.1661



Solution:

The BET equation (Eq. (12.2)) can be re-written as follows:

$$\left(\frac{1}{x}\right)\left(\frac{\pi}{1-\pi}\right) = f = \frac{(K-1)\pi}{Kx_m} + \frac{1}{Kx_m} \quad \pi = P/P_0$$

If the left-hand term f of the equation is plotted against the activity $\pi = P/P_0$, a straight line is obtained. From the slope and the intersect of the line both x_m and K can be calculated.

Since the measurements are carried out at the temperature of liquid nitrogen, P_0 is vapor pressure of boiling liquid nitrogen, i.e. 1 atm. or 100 kPa. From the data, we calculate π and f (Table 12.2).

The plot of f versus π gives a straight line (Figure 12.2). The intercept is 0.1393 and the slope is 6.83.

$K = 50 \quad x_m = 0.1436$

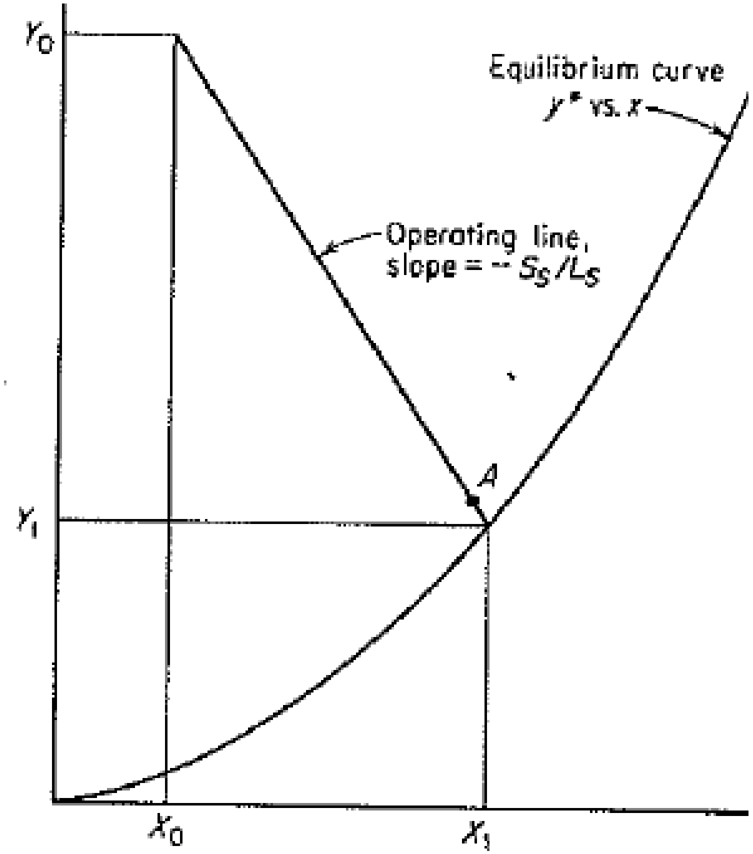
Hence, the specific surface area S is:

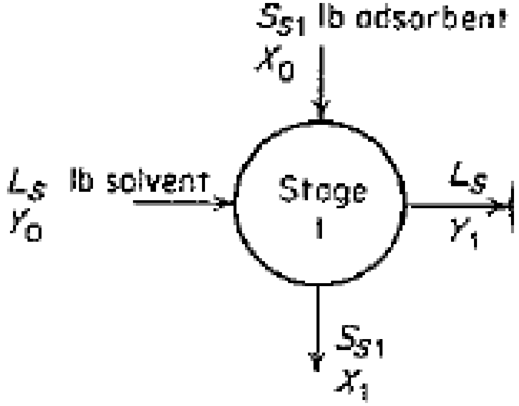
$S = 3485 \quad x_m = 500\,\text{m}^2/\text{g}$.

Table 12.2 Results of nitrogen adsorption calculations

π	0.05	0.1	0.15	0.2
x	0.1095	0.1351	0.1516	0.1661
f	0.480654	0.822436	1.164054	1.505117

SINGLE STAGE EXTRACTION



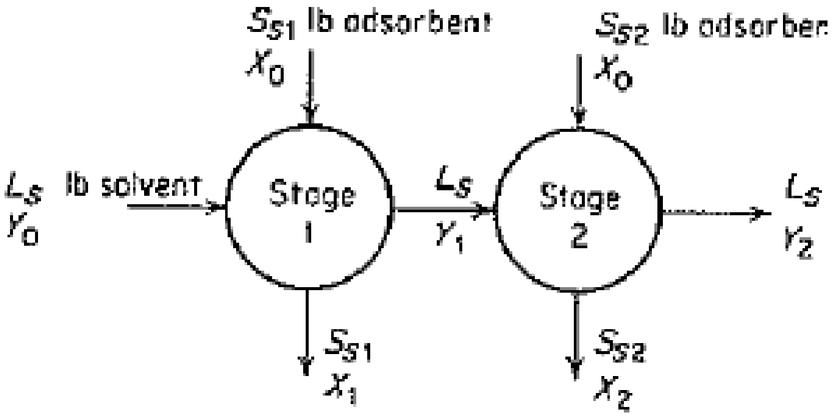


- Y= kg solute/kg of fluid; X-kg of solute /kg of adsorbent
- L_S= kg of fluid $S_s =$ kg of adsorbent
- $L_S(Y_o - Y_1) = S_S(X_1 - X_o)$

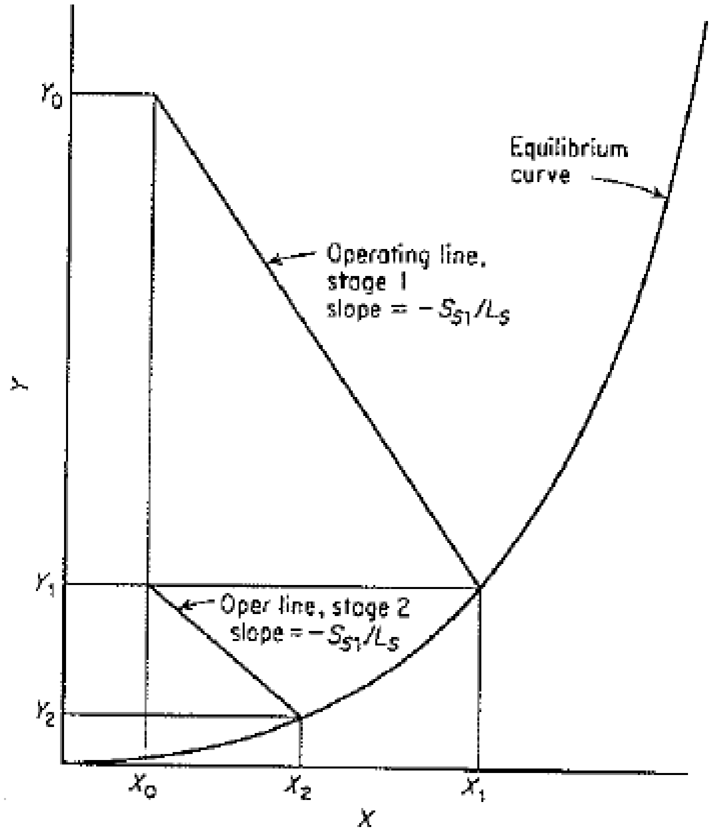
SINGLE STAGE ADSORPTION FOR SYSTEMS OBEYING FREUNDLICH EQUATION

- $Y^* = mX^n$
- $X_1 = \left(\frac{Y_1}{m}\right)^{1/n}$
- $L_S(Y_o - Y_1) = S_S(X_1 - X_o)$
- For fresh adsorbent Xo = 0
- $\frac{S_S}{L_S} = \frac{(Y_o - Y_1)}{X_1} = \frac{(Y_o - Y_1)}{\left(\frac{Y_1}{m}\right)^{1/n}}$

MULTISTAGE ADSORPTION



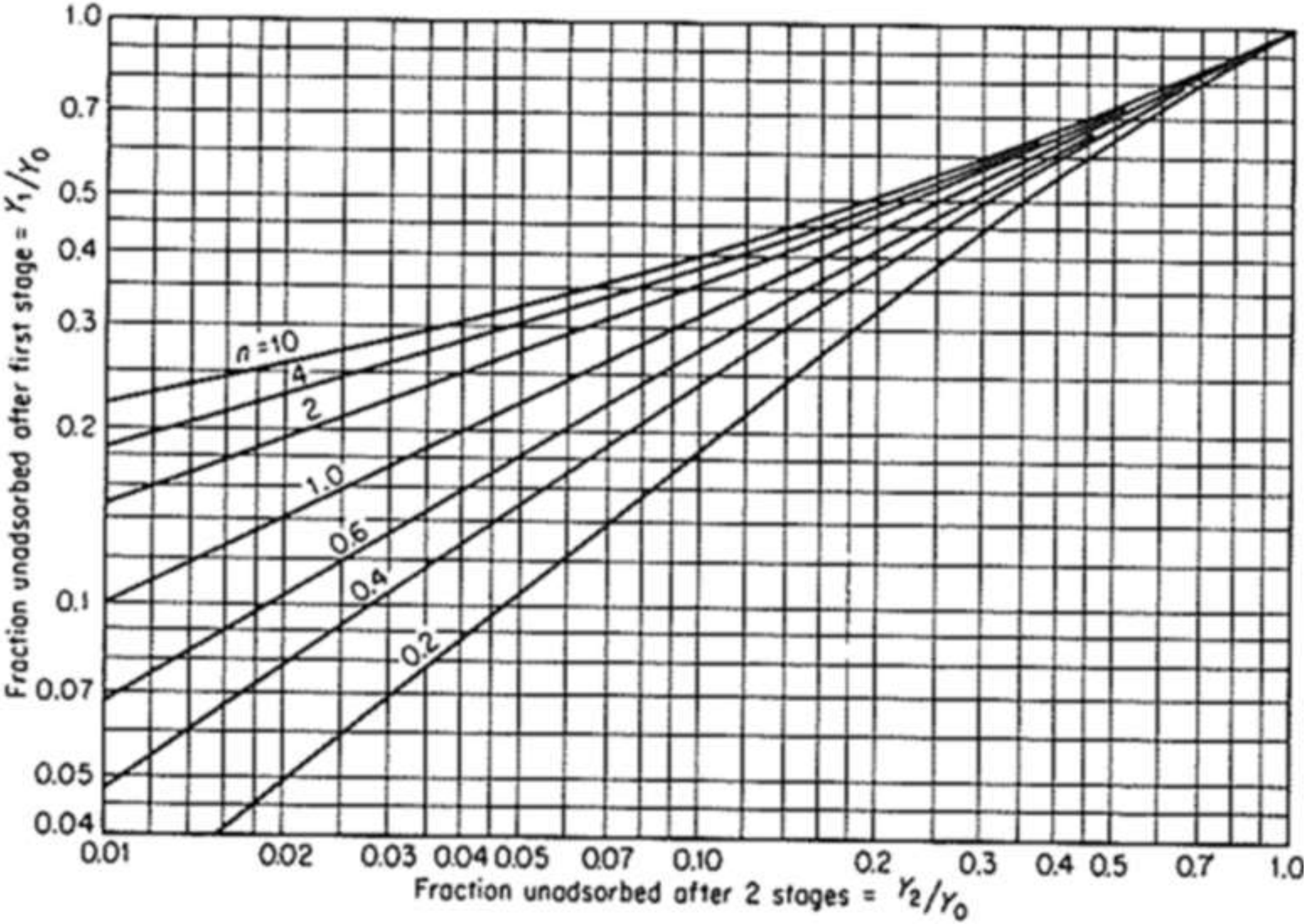
- $L_S(Y_o - Y_1) = S_{S1}(X_1 - X_o)$
- $L_S(Y_1 - Y_2) = S_{S2}(X_2 - X_o)$



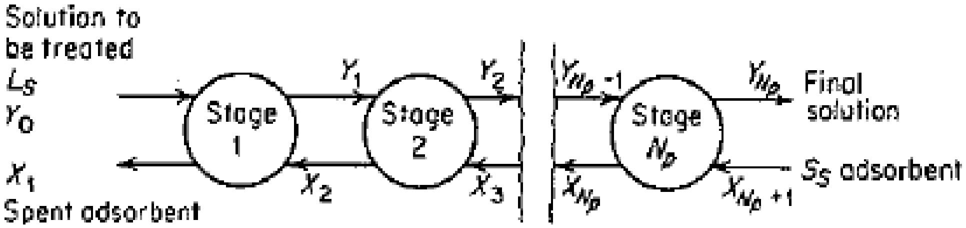
MULTIPLE STAGE CROSS CURRENT ADSORPTION FOR SYSTEMS OBEYING FREUNDLICH EQUATION

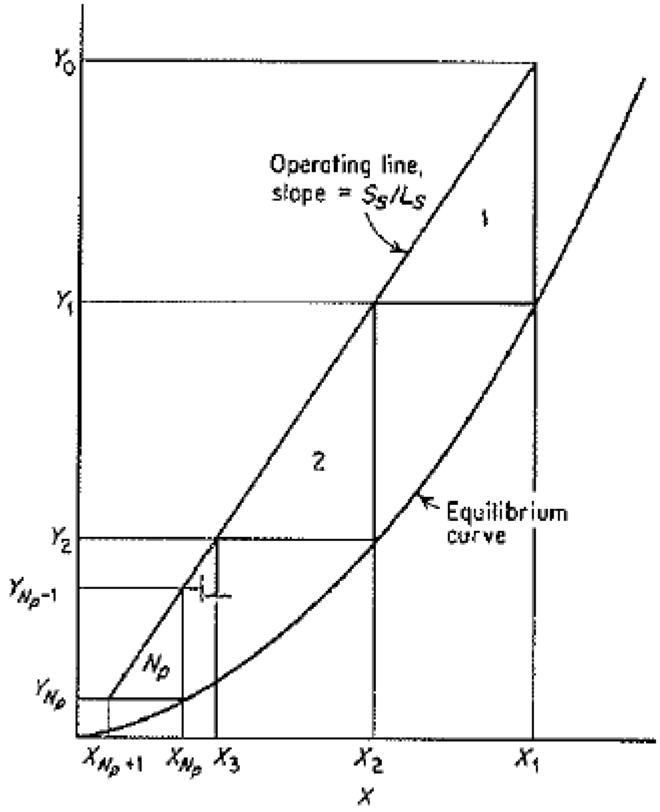
- $\frac{S_{S1}}{L_S} = \frac{(Y_o - Y_1)}{\left(\frac{Y_1}{m}\right)^{1/n}}$
- $\frac{S_{S2}}{L_S} = \frac{(Y_1 - Y_2)}{\left(\frac{Y_2}{m}\right)^{1/n}}$
- Total amount of adsorbent used:
- $\frac{S_{S1} + S_{S2}}{L_S} = m^{1/n}\left(\frac{Y_o - Y_1}{{Y_1}^{1/n}} + \frac{Y_1 - Y_2}{{Y_2}^{1/n}}\right)$
- $\frac{d\left[\frac{S_{S1} + S_{S2}}{L_S}\right]}{dY_1} = 0$
- $\frac{d}{dY_1}\left[\frac{Y_o}{{Y_1}^{1/n}} - \frac{Y_1}{{Y_1}^{1/n}} -\right.$

Minimum total adsorbent two stage cross current

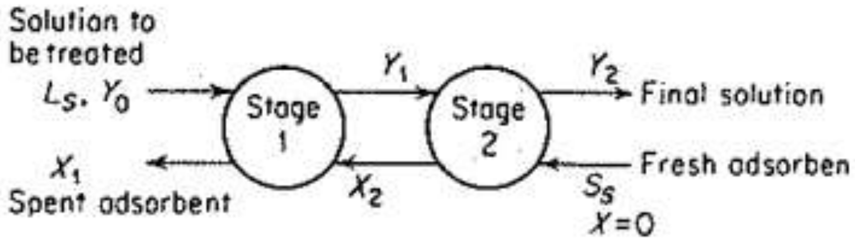


MULTISTAGE COUNTERCURRENT OPERATION

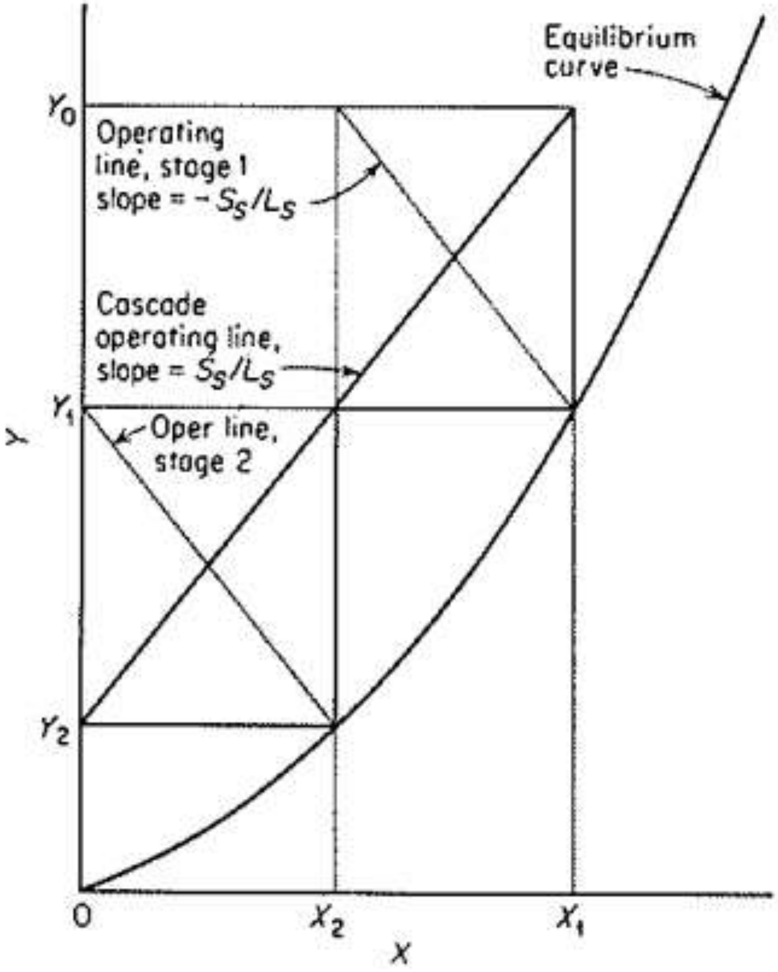




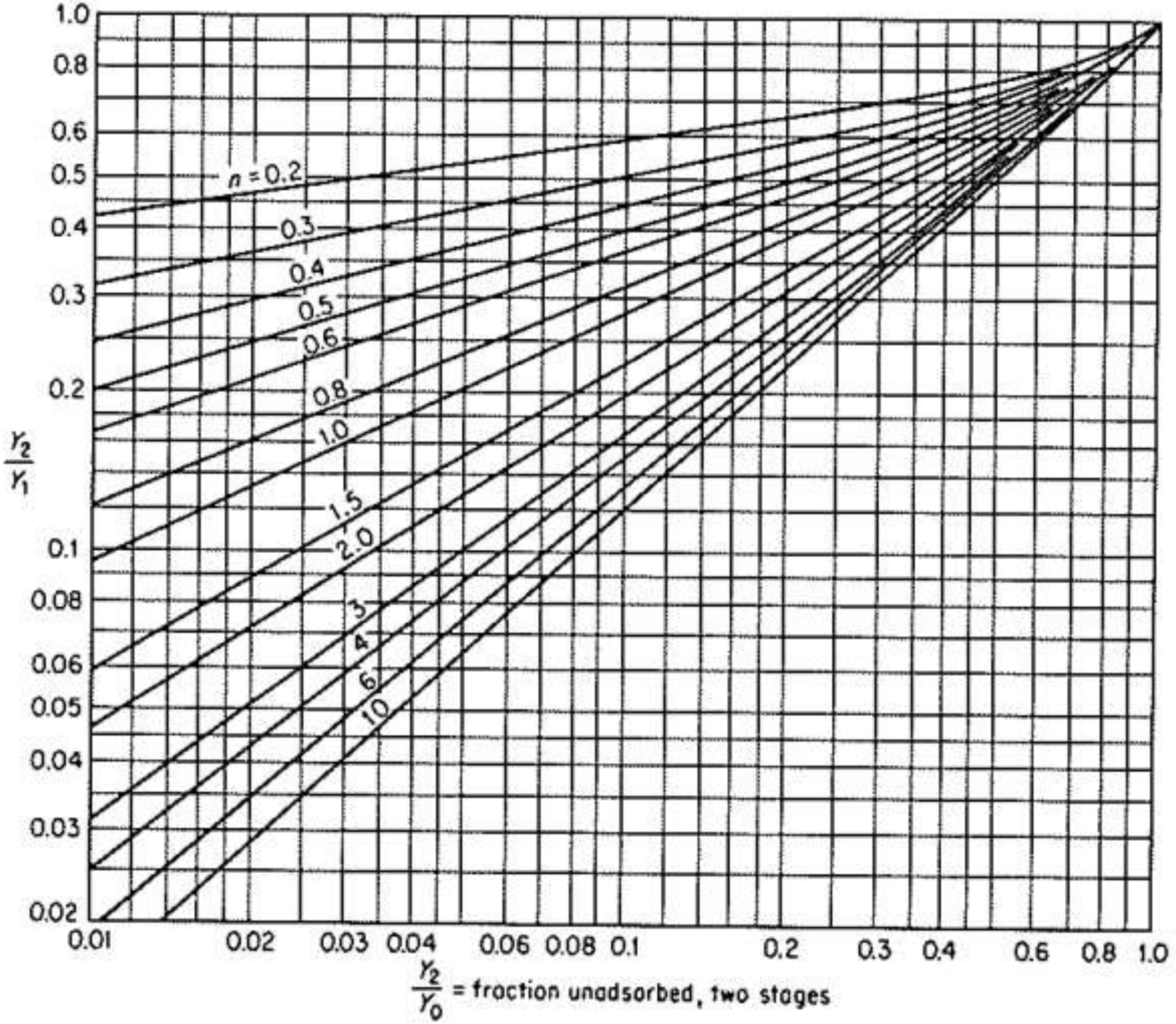
- $L_S(Y_o - Y_{N_P}) = S_S(X_1 - X_{N_P+1})$



- $L_S(Y_o - Y_2) = S_S(X_1 - X_0)$
- $L_S(Y_1 - Y_2) = S_S(X_2 - X_0)$
- $X_1 = \left(\frac{Y_1}{m}\right)^{1/n}$ $and X_2 = \left(\frac{Y_2}{m}\right)^{1/n}$
- $\frac{S_S}{L_S} = \frac{(Y_o - Y_2)}{\left(\frac{Y_1}{m}\right)^{1/n}} = \frac{(Y_1 - Y_2)}{\left(\frac{Y_2}{m}\right)^{1/n}}$

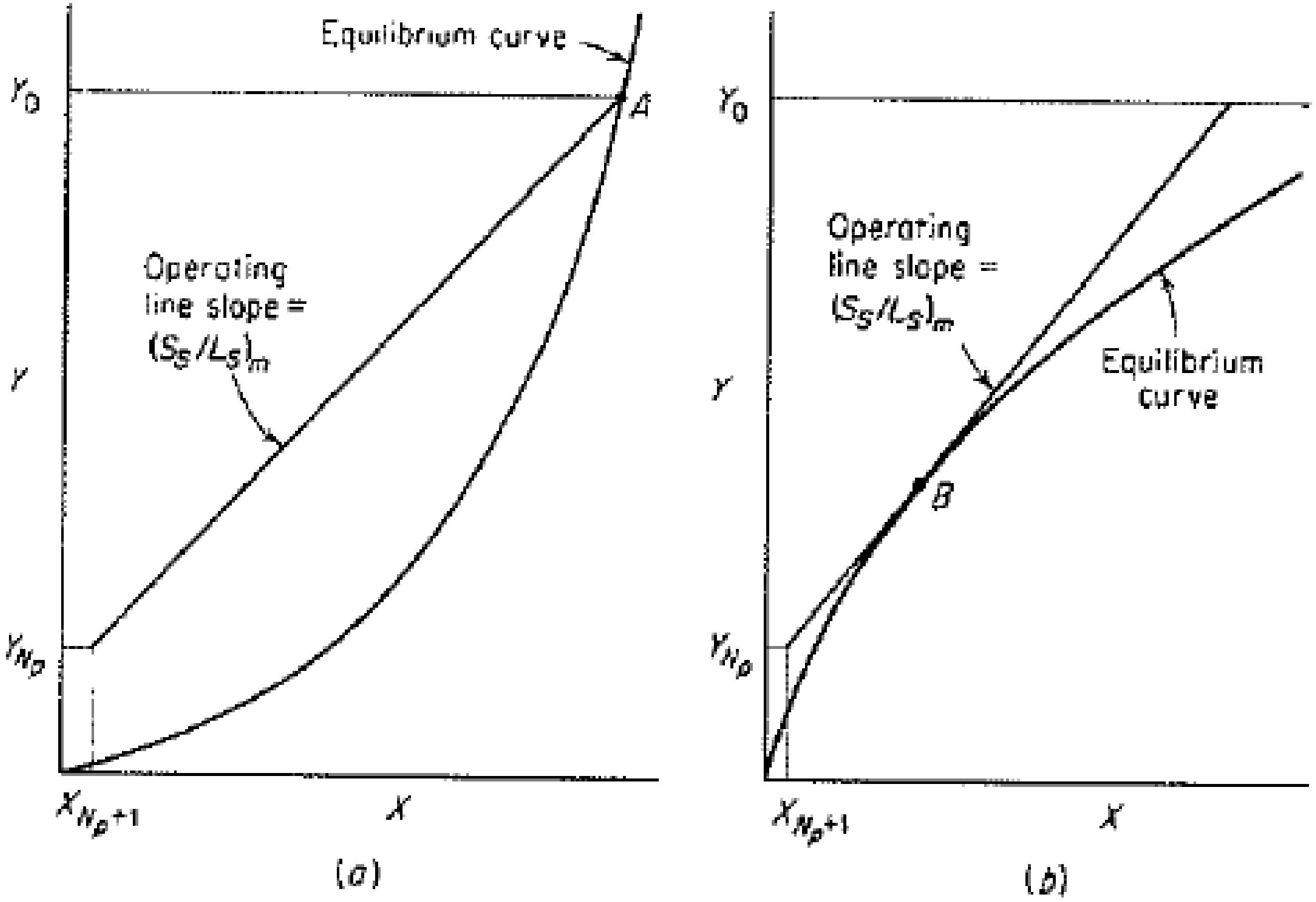


Two stage counter current



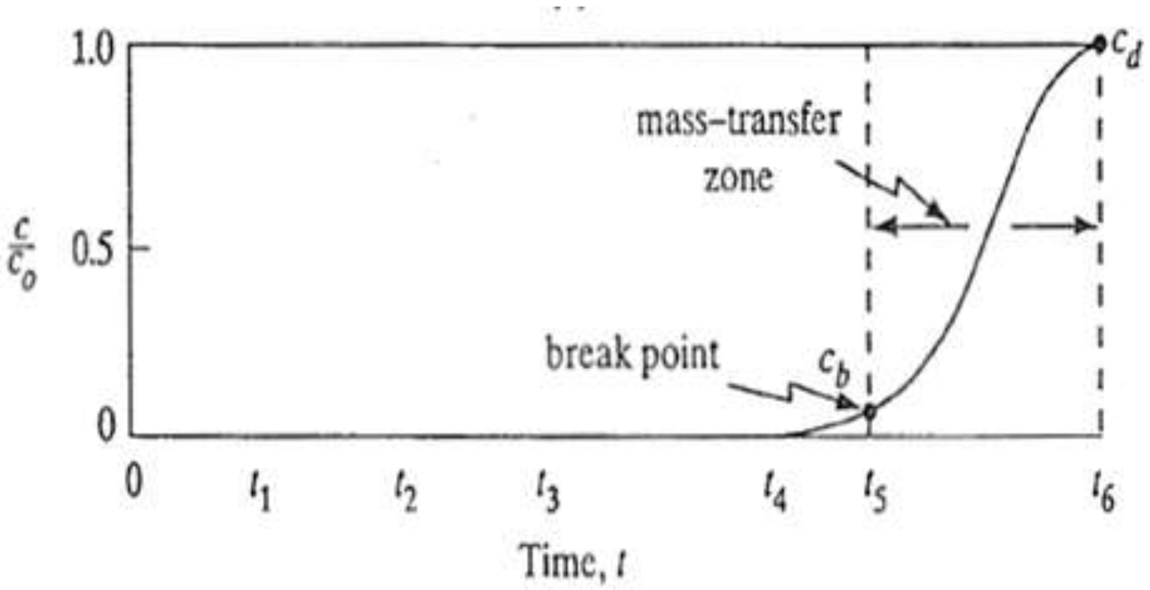
- An aqueous solution containing coloured impurity to be removed by adsorption on a carbon. The Freundlich equation is:
- $Y^* = 8.91\ x\ 10^{-5} X^{1.66}$
- Y=Equilibrium Unit of colour/kg of solution
- X= Adsorbate concentration, $\frac{units\ of\ colour}{kg\ of\ carbon}$
- It is desired to reduce the colour to 10% of its original value of 9.6unit. Determine the quantity of fresh carbon required per 1000kg of solution for a (i) single stage (ii) two stage cross current using minimum total amount on carbon. and (iii) two stage counter current process

OPERATING LINE AND MINIMUM ADSORBENT/SOLVENT RATIO FOR INFINITE STAGES



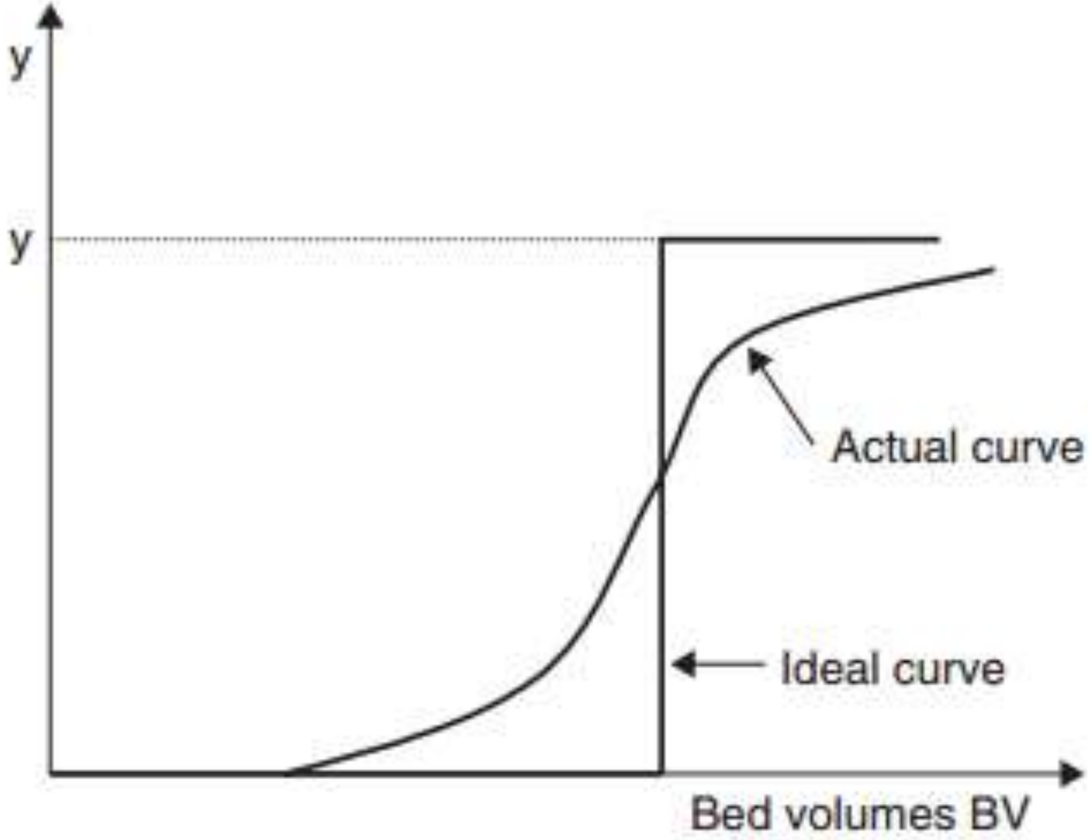
BREAKTHROUGH CONCENTRATION PROFILE in fluid at outlet of bed

Time	Conc at outlet,c	c/c_o



- Mass Transfer Zone: the narrow part of the adsorption column where adsorption takes place at any point of time. It is a S shaped.
- Break Point: The point at which traces of solute is detected at the outlet. Generally when cb/co = 0.01 to 0.05
- End point of breakthrough curve: cd when c/co = 1. Bed is totally effective.
- For narrow mass transfer zone the breakthrough curve is very steep and most of the bed capacity is used at break point
- For very fast mass transfer rate it is vertical

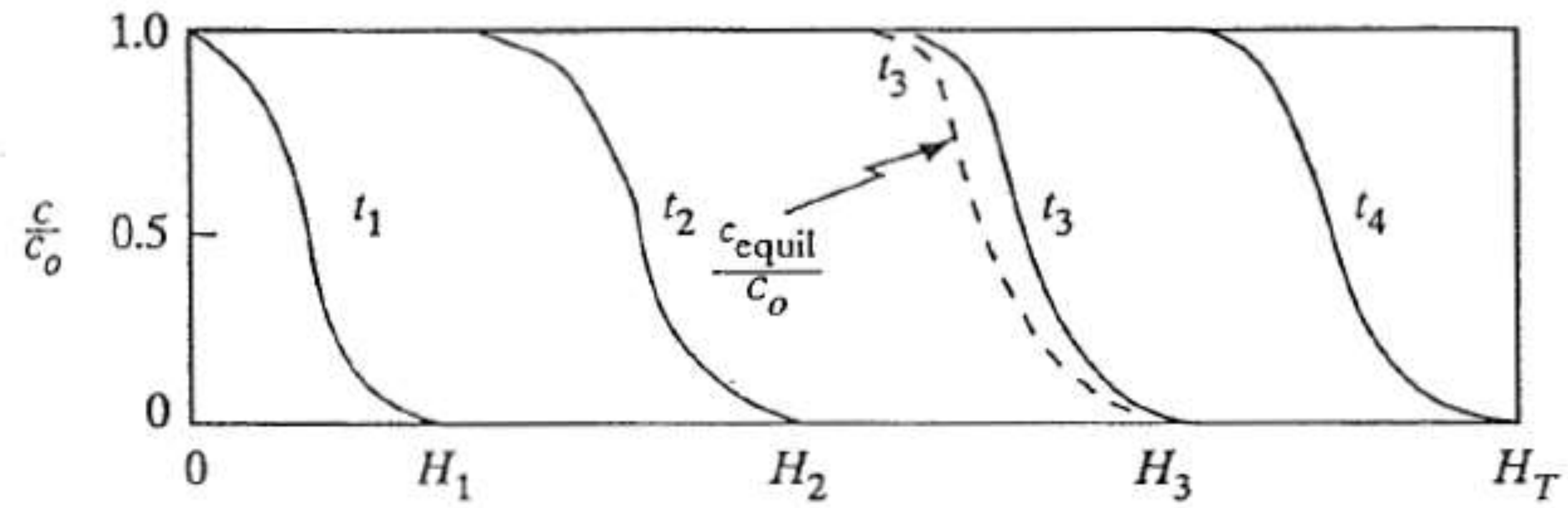
BREAK THROUGH CURVE



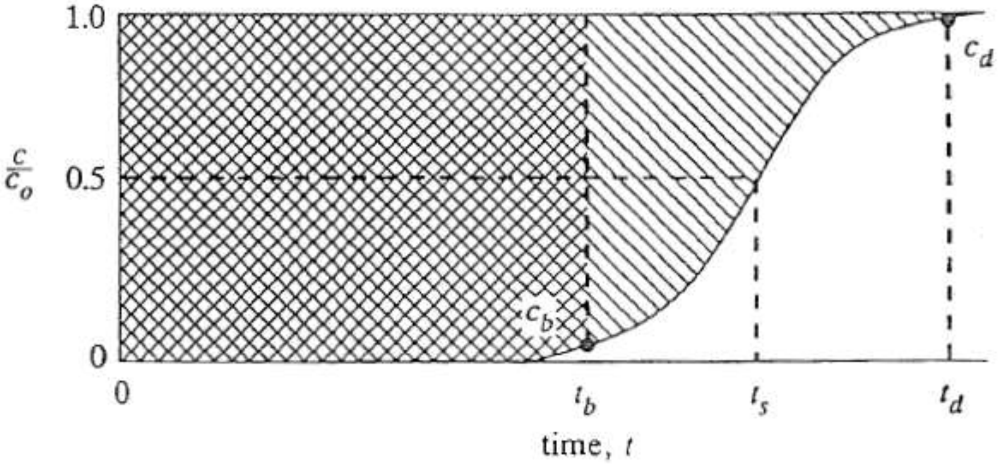
Mass Transfer zone

Mass Transfer Zone: the narrow part of the adsorption column where adsorption takes place at any point of time. It is a S shaped curve.

H	c/c_o at t_1	c/c_o at t_2	c/c_o at 3	c/c_o at t_4



Capacity of column



- The stoichiometric capacity of the packed bed tower is proportional to shaded area[area between the curve and c/c0 =1.
- Time equivalent to total capacity[hatched area]:
- $t_t = \int_0^\infty \left(1 - \frac{c}{c_o}\right) dt$
- Time equivalent to the usable capacity,[cross hatched area:
- $t_u = \int_0^{t_b} \left(1 - \frac{c}{c_o}\right) dt$

- Fraction of the bed height utilized till break point=t_b/t_u
- If Ht= total bed height, Hb= usable bed height
- $H_B = \frac{t_u}{t_t} H_T$
- Unused Bed height
- $H_{UNB} = \left(1 - \frac{t_u}{t_t}\right) H_T$
- $H_T = H_B + H_{UNB}$

EXAMPLE 12.3-1. Scale-Up of Laboratory Adsorption Column

A waste stream of alcohol vapor in air from a process was adsorbed by activated carbon particles in a packed bed having a diameter of 4 cm and length of 14 cm containing 79.2 g of carbon. The inlet gas stream having a concentration c_o of 600 ppm and a density of 0.00115 g/cm^3 entered the bed at a flow rate of 754 cm^3/s. Data in Table 12.3-1 give the concentrations of the breakthrough curve. The break-point concentration is set at $c/c_o = 0.01$. Do as follows.

(a) Determine the break-point time, the fraction of total capacity used up to the break point, and the length of the unused bed. Also determine the saturation loading capacity of the carbon.

TABLE 12.3-1. *Breakthrough Concentration for Example 12.3-1*

Time, h	c/c_o	*Time, h*	c/c_o
0	0	5.5	0.658
3	0	6.0	0.903
3.5	0.002	6.2	0.933
4	0.030	6.5	0.975
4.5	0.155	6.8	0.993
5	0.396		

(b) If the break-point time required for a new column is 6.0 h, what is the new total length of the column required?

Solution: The data from Table 12.3-1 are plotted in Fig. 12.3-3. For part (a), for $c/c_o = 0.01$, the break-point time is $t_b = 3.65$ h from the graph. The value of t_d is approximately 6.95 h. Graphically integrating, the areas are $A_1 = 3.65$ h and $A_2 = 1.51$ h. Then from Eq. (12.3-1), the time equivalent to the total or stoichiometric capacity of the bed is

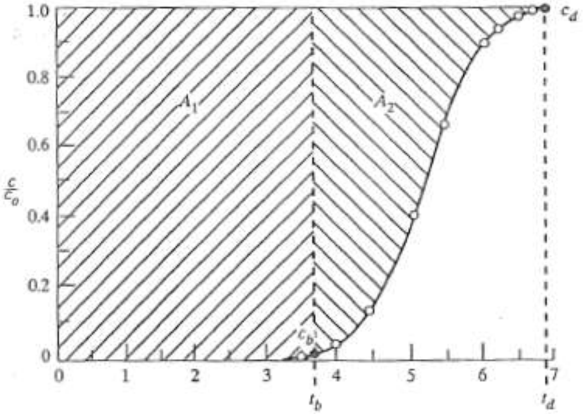
$$t_t = \int_0^\infty \left(1 - \frac{c}{c_o}\right) dt = A_1 + A_2 = 3.65 + 1.51 = 5.16 \text{ h}$$

The time equivalent to the usable capacity of the bed up to the break-point time is, using Eq. (12.3-2),

$$t_u = \int_0^{t_b = 3.65} \left(1 - \frac{c}{c_o}\right) dt = A_1 = 3.65 \text{ h}$$

Hence, the fraction of total capacity used up to the break point is $t_u/t_t = 3.65/5.16 = 0.707$. From Eq. (12.3-3) the length of the used bed is $H_B = 0.707(14) = 9.9$ cm. To calculate the length of the unused bed from Eq. (12.3-4),

$$H_{UNB} = \left(1 - \frac{t_u}{t_t}\right) H_T = (1 - 0.707)14 = 4.1 \text{ cm}$$



For part (b) for a new t_b of 6.0 h, the new H_B is obtained simply from the ratio of the break-point times multiplied by the old H_B.

$$H_B = \frac{6.0}{3.65}(9.9) = 16.3 \text{ cm}$$

$$H_T = H_B + H_{UNB} = 16.3 + 4.1 = 20.4 \text{ cm}$$

We determine the saturation capacity of the carbon.

$$\text{Air flow rate} = (754 \text{ cm}^3/\text{s})(3600 \text{ s})(0.00115 \text{ g/cm}^3) = 3122 \text{ g air/h}$$

$$\text{Total alcohol adsorbed} = \left(\frac{600 \text{ g alcohol}}{10^6 \text{ g air}}\right)(3122 \text{ g air/h})(5.16 \text{ h})$$

$$= 9.67 \text{ g alcohol}$$

$$\text{Saturation capacity} = 9.67 \text{ g alcohol/79.2 g carbon}$$

$$= 0.1220 \text{ g alcohol/g carbon}$$

The fraction of the new bed used up to the break point is now 16.3/20.4, or 0.799.

1.Batch tests were performed in the laboratory using solutions of phenol in water and particles of granular activated carbon. The equilibrium data at room temperature are given below Determine the isotherm that fits the data:

Kg of phenol per m3 of solution	0.322	0.117	0.039	0.0061	0.0011
Kg of phenol per kg of carbon	0.150	0.122	0.094	0.059	0.045

2. Equilibrium isotherm for adsorption of glucose from an aqueous solution to activated alumina are as follows Determine the isotherm that fits the data and give the constants of the equation.

[Ans :Langmuir, q= 0.145c/(0.0174+c)]

g of glucose/cm3 of sol.	0.004	0.0087	0.019	0.027	0.094	0.195
g of glucose/g alumina	0.026	0.053	0.075	0.082	0.123	0.129

- 3. A waste water solution having a volume of 1.0m3 contains 0.21 kg phenol/m3 of solution(0.21g/L) A total of 1.40kg of fresh granular activated carbon is added to the solution, which is then mixed thoroughly to reach equilibrium. Using the isotherm data, what are the final equilibrium values and what percent of phenol is extracted?
- 4. A waste water solution having a volume of 2.5m3 contains 2.5 kg of phenol /m3 of solution. This solution is mixed thoroughly in a batch process with 3.0 kg of granular activated carbon. Calculate final equilibrium values and the percent phenol extracted.

5.A waste stream of alcohol vapour in air from a process was adsorbed by activated carbon particles in a packed bed having a diameter of 4 cm and length of 14 cm containing 79.2 g of carbon. The inlet gas stream having a concentration co of 600 ppm and a density of 0.00115 g/cm3 entered the bed ata flow rate of 754cm3/s. The break point concentration is set at c/co = 0.01

Time,h	0	3	3.	4	4.5	5	5.5	6.0	6.2	6.5	6.8
c/co	0	0	0.002	0.030	0.115	0.396	0.658	0.903	0.933	0.975	0.993

a) Determine the break point time, the fraction of the total capacity used up to the break point, and the length of the unused bed. Also determine the saturation loading capacity of the carbon.

b) If the break point time required for a new column is 6.0 h what is the new total length of the column required?

c) The break point time for a new column is to be 8.5 hour. Calculate the new total length of the column required, column diameter, and the fraction of the total capacity used upto break point. The fow rate is to remain constant at 754cm3/s.

d) Repeat part c, but the flow rate is to be increased to 2000cm3/s