Lecture - 21
Absorption

Welcome to the first lecture of module 4 of Mass Transfer Operation, in this module we will discuss Absorption. In our no previous lecture mostly all the modules which we have covered so far module 1 was on diffusion mass transfer, module 2 was on interface mass transfer when you have a more than one phases involved. And then we have considered different types of equipment which are used for the gas liquid operations.

And now we will discuss the application part of the mass transfer processes. So, one such processes is the absorption process and in this first lecture we will have introduction to absorption process. And in this process we will try to see how to calculate the minimum liquid flow rate required for a given separation.
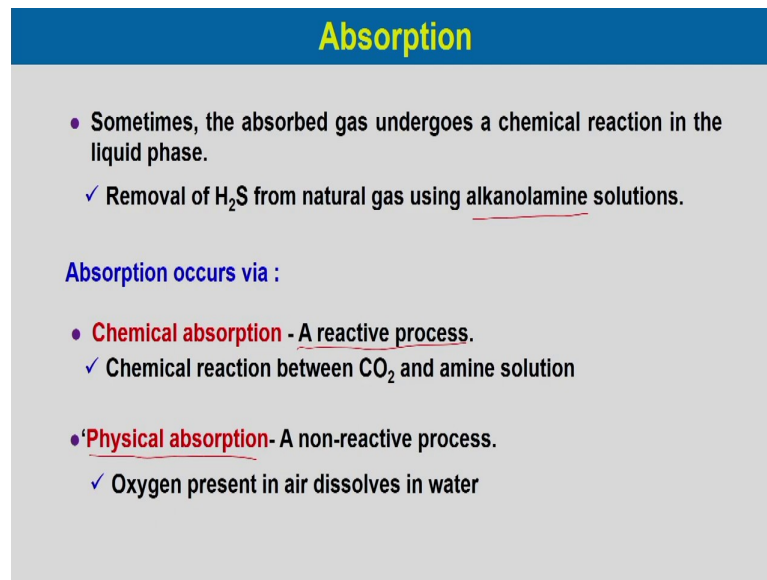
(Refer Slide Time: 01:47)

At the beginning we have introduced about the absorption process. Gas absorption is dissolving one or more components of the gas into a liquid system and to provide a solution.

So, basically if we have a mixture of gases or if it is a one component and we want to make a solution of it or we have a two component or more components systems where we would preferentially separate a certain components what we do we dissolve the components of the gas into the liquid systems and then we provide a solution of it. For example, gas from by-product coke ovens; in the by-product coke oven we generally have ammonia as a byproduct and benzene and toluene also mixed with that vapor.

So, gas from this by product coke oven is washed with water to remove ammonia and again with an oil to remove benzene and toluene vapor. You can see that depending on the suitability of the solvent for a particular component to absorb the solvent over here is decided accordingly, like you can see if you wanted to remove ammonia which is highly preferential in case of water. Water can have higher affinity for ammonia compared to benzene and toluene vapor.

So, the mixture initially what happens it passes through the solvent water and then which removes the ammonia and then again the exit gas is contacted with oil to remove the benzene and toluene vapor, like you know objectionable hydrogen sulphide gas so which are present in natural hydrocarbon gases sometimes it is present and that is separated with various alkaline solutions. So, hydrogen sulphide is very corrosive gas and it is generally not vapor with a natural gas for its use in different purposes. So, we need to remove the hydrogen sulphide gas. So, being it acidic gas we need to have alkaline solutions to remove it.
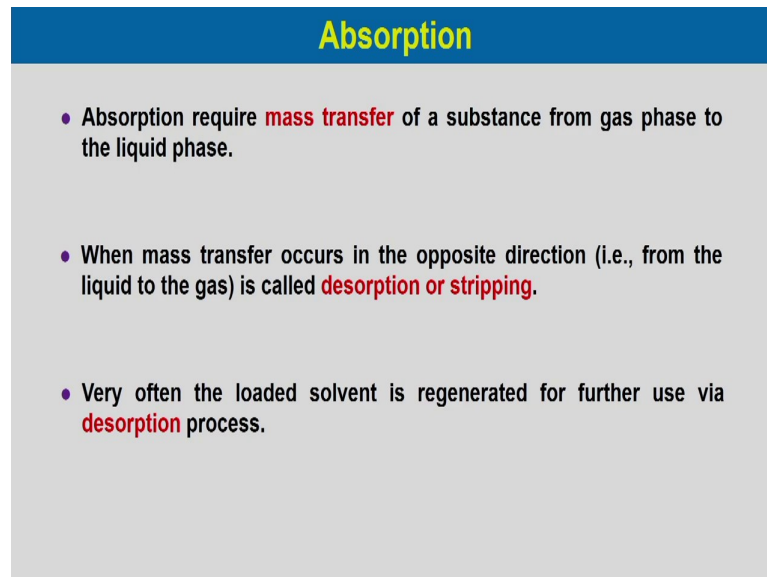
(Refer Slide Time: 04:36)

Sometimes the absorbed gas undergoes a chemical reactions in the liquid phase, as we discussed in the earlier examples like removal of hydrogen sulphide from natural gas using alkanolamines. So, what happens alkaline solution over here is alkanolamines. So, it has ammine functional group like monoethanolamine diethanolamine, different ethanol ammines. These reacts almost instantaneously with hydrogen sulphide because the reaction is proton transfer reactions and hence once we use the alkaline solution or alkanolamines the hydrogen sulphide reacts with it. So, very highly reactive solvent with the liquid phase.

So, absorption occurs via the two process, one is called chemical absorption a reactive process. So, like in hydrogen sulphide similar we can remove carbon dioxide using the alkaline or alkanolamine solutions as we discussed before. So, carbon dioxide is also as you all know it has a very significant effect on global warming and people are working a lot on the removal of carbon dioxide and absorption is one of the mature technology to separate carbon dioxide from different gas mixtures. One of them is natural gas, another one is flue gas; flue gas which comes from the you know power plant particularly coal based power plant. The other process is non reactive process, we call it physical absorption process.

So, in this case the solute which absorbs in the liquid phase it does not react with it, but it you know dissolves in the liquid phase based on its affinity and make a solution of its,

like oxygen present in the air it dissolves in water. So, water also contain dissolve oxygen because we have in the year about 20 percent oxygen. So, from the there it dissolve in the water as well. So, these are the two process via absorptions takes place

(Refer Slide Time: 07:13)

Absorption

- Absorption require **mass transfer** of a substance from gas phase to the liquid phase.

- When mass transfer occurs in the opposite direction (i.e., from the liquid to the gas) is called **desorption or stripping**.

- Very often the loaded solvent is regenerated for further use via **desorption** process.

Absorption required mass transfer of a substance from gas phase to the liquid phase. So, as we have said before there is a solute transfer from the gas phase to the liquid phase, like carbon dioxide present in the mixture of other inert gases. So, carbon dioxide preferentially transferred to the liquid phase depending on its ability of the solvent ok. So, when mass transfer occurs in the opposite direction that is from the liquid to the gas the process is called desorption or stripping.

So, basically once the particular gas is dissolved to the solvent and we wanted to recover that gas or we wanted to recover the solvent we need to dissolve it, we need to stripped it back. So, that the opposite process of absorption is called the desorption or stripping where, mass transfer takes place from the liquid phase to the vapor phase or the gas phase. Very often the loaded solvent is regenerated for further use via desorption process; if you see the absorption and stripping process for carbon dioxide capture you have typical observer column where you observe a particular gas preferentially from a mixture in an absorber and then it is the loaded solvent is fed to the top of the stripping tower and it is in the stripping section it is heated up or it operates at a lower pressure than the absorber.

And then you will get the dissolved gas at the top and at the bottom of the column you will get regenerated solvent which is usually at higher temperature and you can cool it down to use it for the in the observer where it will be feed at the top of the absorber.

(Refer Slide Time: 09:21)

Now, we will discuss about the equilibrium curve and equilibrium solubility; the rate at which a gaseous constituent of a mixture will dissolve in an absorbent liquid depends on the departure from the equilibrium which exist. So, the departure from the equilibrium states will define the rate of diffusion or rate of absorption process or the rate at which the gas will dissolve. Therefore, it is necessary to consider the equilibrium characteristics of the gas liquid systems, this is very important. Now if we consider two component systems, that is if a quantity of single gas and a relatively non volatile liquids are brought to equilibrium, then what happens?

So, single gas and a relatively nonvolatile liquid means the liquid solvent is not volatile it will has a very low vapor pressure at a particular temperature where the gas will be absorbed. So, the resulting dissolve gas in the liquid is said to be the solubility of the gas at the prevailing temperature and pressure. Once the system come in contact the solute gas and the nonvolatile liquid as solvent kept in an enclosure at a particular temperature and pressure and then they reached the equilibrium the amount of gas which will be dissolved in the liquid phase will be called as the solubility of that gas. Now at a fixed

temperature the solubility concentration will increase with pressure in the manner as shown in figure 1.

(Refer Slide Time: 11:25)
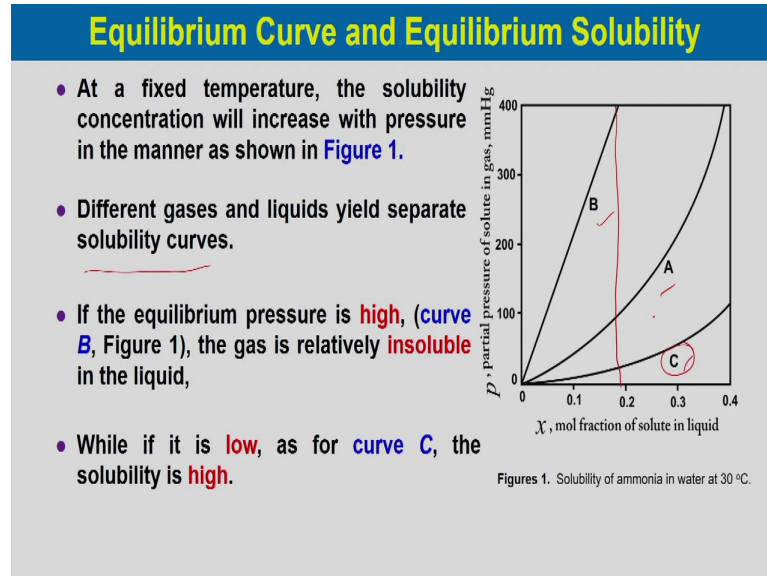
So, you can see that if you increase the pressure the solubility of the gas at a particular temperature, the solubility of the gas will gradually increase ok. So, the more gas you can see the solute concentration in the liquid phase will gradually increase as we increase the pressure, either if it is single gas it is no total pressure of the gas phase or if it is you know mixture of gases then you have a partial pressure of the gas.

So, different gases and liquids yields separate solubility curves, you can see A B and C they are three different gases and they under a particular temperature they show at different pressure, they show different solubility in a particular liquid.

Now if the equilibrium pressure is high that is curve B, figure 1. So, in this figure the solubility of ammonia in water at 30 degree centigrade is shown mostly and some other gas. So, if the equilibrium pressure is high the curve B, figure 1 the gas is relatively insoluble in the liquid even if increasing the pressure in the gas phase appreciably the solubility in the liquid phase is relatively low is closed to 0.2 mole fractions of the solute.

So, we call it is relatively insoluble if the equilibrium pressure is high, while if it is low as the curve C in this case the solubility is said to be high compared to B and A. So, in

this case you can see with a small change in pressure we have you know the mole fraction in the liquid phase is increased to 0.4. So, we say that the solubility is high.

(Refer Slide Time: 13:54)
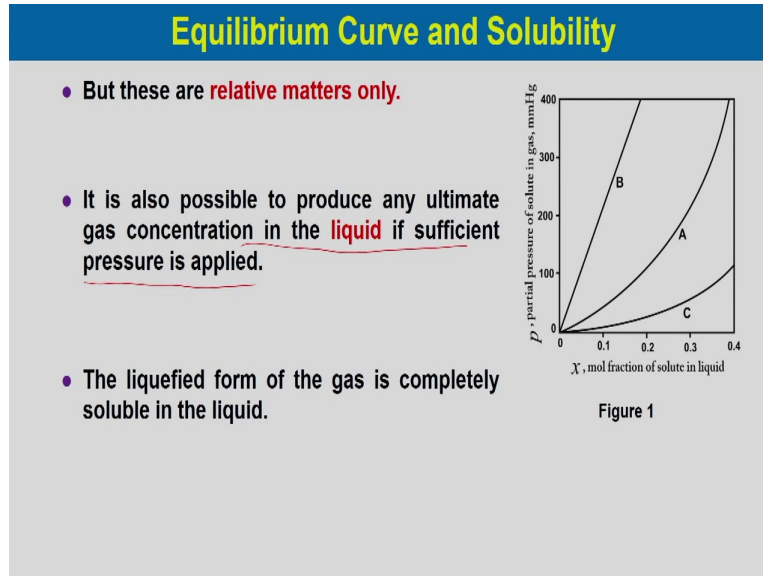
But all these are relative matters only so, if we can incorporate it is possible to produced any ultimate gas concentration in the liquid is sufficient pressure is applied. So, if we keep on increasing the, at a particular temperature if we keep on increasing the pressure the solubility we can make it any solubility we want in the liquid phase ok, ultimate gas concentration we can achieve.

The liquefied form of the gas is completely soluble in the liquid. So, if we increase the pressure in the gas phase and if we make it liquid and it is completely miscible with the liquid solvent. So, we can get mole fractions to 1.

The solubility of any gas is influenced by the temperature in a manner van't Hoffs law of mobile equilibrium. If the temperature of a system at equilibrium is raised that the changes will occur which will absorb heat, usually the solubility of the gas decreases with increasing temperature.

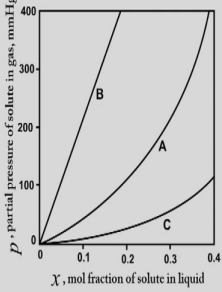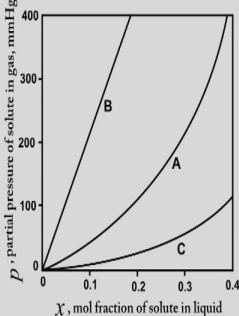Now if a mixture of gases is brought into contact with a liquid under certain conditions. So, so far we have considered the single gas and we have seen that how the solubility changes with you know change in pressure at a particular temperature and the solubility

changes with temperature at a particular pressure. Now, if we take more than one component in the mixture gas mixture that is mixture of gases and it brought into contact with the liquid under certain conditions the equilibrium solubility of each gas will be independent of the others that the equilibrium is described in terms of the partial pressure in the gas mixtures.

(Refer Slide Time: 16:16)

So, if one of the component of the gas are substantially insoluble then their concentration in the liquid will be so small that cannot influence the solubility of the relatively soluble other components. So, if we have a two component, like if we take air and ammonia mixture and ammonia is highly soluble in water whereas, the other component of air is very low solubility in water like carbon dioxide, oxygen, nitrogen this has very low solubility in water.

So, we now call them as inert with respect to ammonia and it is you know influence on the solubility of ammonia will be very less. For example, curve A will also describe the solubility of a in water when a is diluted with air, like as we said here ammonia mixture. Since air is so insoluble in water provided that the coordinate of the plot is considered as the partial pressure of A in the gas mixture. So, as you can see here already it is mentioned is the partial pressure of solute in the gas phase.

Now, if several component of the mixture are appreciably soluble, what happens the general rules which we have considered earlier it will not influence, the equilibrium solubility of a particular component will not be influenced by the presence of other components that is only hold when we have a one relatively highly soluble gases we and the other gas are considered as relatively insoluble. In that case that general principle can apply. But if have a components of the mixture that are appreciably soluble; the generalization will be applicable only if the solute gases are indifferent to the nature of the liquid.
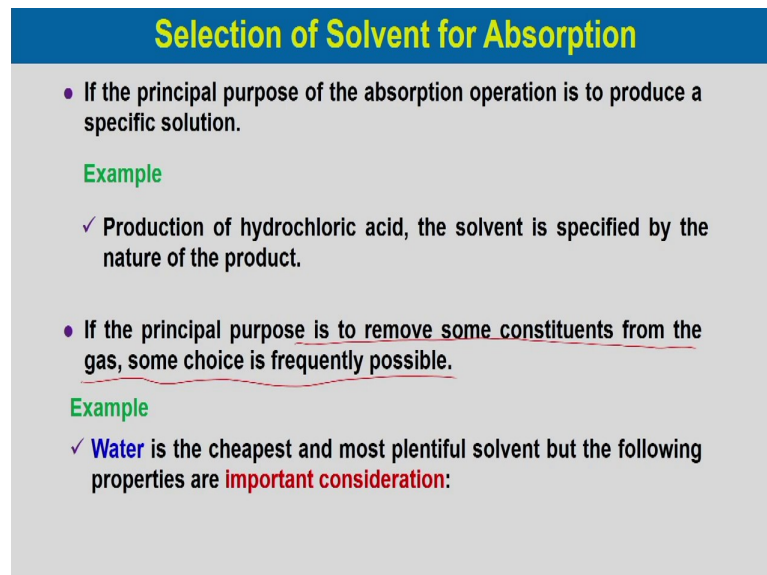
So, indifferent to the nature of the liquid means, if they soluble in the solvent and it forms the ideal solution then it will not influence. So, although you have a multiple component A B C and all of them are appreciably soluble in the liquid phase, but it forms the ideal solution, then the influence of the solubility of one component will not be influenced by the other component. For example, a mixture of propane and butane gases will dissolve in nonvolatile paraffin oil independently since, the solution that results are substantially ideal.

So, if we take the no homologous series of hydrocarbons propane and butane gas that can be dissolved in paraffin oil and then, independently since the solution that results are substantially ideal solution. So, if it is ideal solution then this will not influence of the one component of the other for their solubility. On the other hand the solubility of

ammonia in water can be expected to be influenced by the presence of methylamine since, the resulting solution of these gases are not ideal. So, ammonia will react with water it will form the reactive solutions and that is not ideal solution and methyl amine also will react with water and it forms the reactive solutions, the reaction takes place in the liquid phase and then the solution which it forms is non ideal.

So, in this case the generalization will not be applicable and that means, the solubility of the ammonia will be influenced by the solubility of the methylamine or vice versa. Now we need to select a particular solvent and what properties we need for its selection.

(Refer Slide Time: 21:06)

Selection of Solvent for Absorption

- If the principal purpose of the absorption operation is to produce a specific solution.

  Example

  ✓ Production of hydrochloric acid, the solvent is specified by the nature of the product.

- If the principal purpose is to remove some constituents from the gas, some choice is frequently possible.

  Example

  ✓ Water is the cheapest and most plentiful solvent but the following properties are important consideration:

The principal purpose of the absorption operation is to produce a specific solution. So, if our purpose is to produce a specific solution like for example, production of hydrochloric acid the solvent is specified by the nature of the product. So, if you wanted to produce hydrochloric acids it will absorb only the gaseous component produced the solution of the hydrochloric acid which will be usable product.

So, in this case the solution will be decided based on the use of hydrochloric acid, but if our principal purpose is not for the production of the specific solution, but to separate components then the principal purpose to remove or separate some constituent from the gas mixture so choice is frequently possible; like water is the cheapest and most plentiful solvent, but the following properties are important consideration. So, although water is
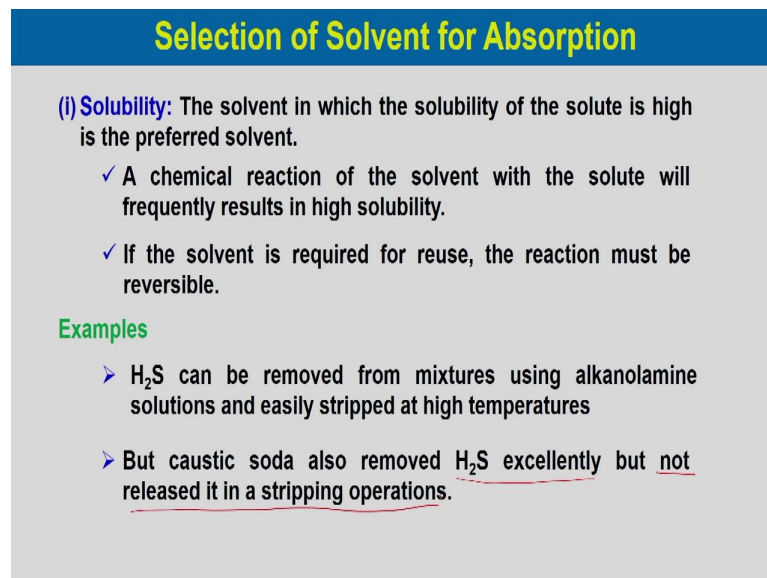
cheapest and available plenty of the solvent for use, but the properties of the water may not be suitable for all applications.

So, the important properties or the important characteristics which are required for the selection of solvent where we need to separate the mixture of constituents proper different properties need to be considered for selecting the solvent.

(Refer Slide Time: 22:53)

Selection of Solvent for Absorption

(i) **Solubility:** The solvent in which the solubility of the solute is high is the preferred solvent.

✓ A chemical reaction of the solvent with the solute will frequently results in high solubility.

✓ If the solvent is required for reuse, the reaction must be reversible.

Examples

➢ H_2S can be removed from mixtures using alkanolamine solutions and easily stripped at high temperatures

➢ But caustic soda also removed H_2S excellently but not released it in a stripping operations.

One is the solubility: the solvent in which the solubility of the solute is very high is the prefer solvent. So, if the solubility of that component is very high and then with a small solvent we can absorb appreciable amount of that gas or of that solute. A chemical reactions of the solvent with the solute will frequently result in high solubility. Now if there is a chemical reaction as we said earlier like carbon dioxide or hydrogen sulphide can react with base like sodium hydroxide, potassium hydroxide or alkanolamines like monoethanolamine diethanolamine these are highly reactive solvents with the particularly for this solutes.

So, that will enhance the total solubility or equilibrium solubility. So, a chemical reactions of the solvent with the solute will frequently result in high solubility, if the solvent is required to be reused the reaction must be reversible. For example, if we take hydro H 2 S hydrogen sulphide can be removed to from the mixture using alkanolamine solution and easily stripped at high temperature. Similarly hydrogen sulphide or carbon

dioxide if we react with alkanolamine the reaction happens through the formation of carbamate and finally, the bicarbonate ions and the reaction reversible in nature.

And if we take it to the reactive the solvent mixture after it reacts with this solute to the stripper or desorption sale and if we hit it off the reverse reactions will takes place and it will release carbon dioxide or absorbed H_2S. But if we do not want to shift it back we want it to make a solution of heat like caustic soda also removes hydrogen sulphide excellently, because it is very highly alkaline solution basic solution, but released it in on the stripping (Refer Time: 25:18), it does not release the you know H_2S in the stripping operation, if even if we increase the temperature because the reaction is irreversible in nature.

(Refer Slide Time: 25:32)

Selection of Solvent for Absorption

(ii) Volatility: A good solvent should have a low volatility or vapour pressure so that the solvent loss with the carrier gas due to vaporization remains small.

(iii) Cost: A solvent should not be very expensive so that the vaporization and other losses are not significant in terms of economy.

(iv) Corrosiveness: Use of a non-corrosive or less corrosive solvent reduces the material cost of the equipment as well as its maintenance cost.

(v) Viscosity: Low viscosity is preferred so that it flows easily; low pressure drops on pumping, improved flooding and good heat transfer characteristics.

(vi) Hazards and Toxicity: A solvent should not be hazardous or toxic. It should preferably be non-inflammable.

The second property is which we look for a good solvent should have a low volatility or vapor pressure So that the solvent loss with the carrier gas due to vaporization remain small. basically, if the vapor pressure is less of the no solvent particular it helps when we regenerate the solvent in the stripper, if its vapor pressure is very high there will be used solvent loss in the stripper or desorption sale. So, the solvent should have very low volatility or vapor pressure, the third point is the cost; a solvent should not be very expensive so that the vaporization and other losses are not significant in terms of economy ok.

The solvent cost should be less it should not be expensive, the fourth parameter which we look for is the corrosiveness; like use of a non-corrosive or less corrosive solvent reduces the material cost of the equipment as well as its maintenance cost. So, if the solvent is non-corrosive and then we can use the cheaper material and the overall cost of the equipment will be much less, but if it corrodes like hydrogen sulphide, if it presents in appreciable quantity in amine solvent then it corrodes the mild steel arrangements. So, carbon steel if we use.

So, material of construction in important in case of solvent of amine and no hydrogen sulphide gas. So, in that case we have to use expensive stainless-steel material which will increase the overall cost of the plant. So, corrosiveness is very important of the solvent, another property is the viscosity, the low viscosity is preferred so that it flows easily. Low pressure drop on pumping improve flooding and good heat transfer characteristics. So, basically if the viscosity of the solvent is very high it will increase the pumping cost, and it will increase the pressure drop as well in the column and the heat transfer of the viscous fluid will not be good.

So, the viscosity of the solvent should be as low as possible so that all this no important factors like pressure drop, pumping energy cost, flooding and no hit transfer this parameters improves. So, solvent viscosity should be less; other thing is the hazardous and toxicity a solvent should not be hazard as toxic and it should be preferably nonflammable and should not be hazard as or toxic. So, this properties are very important while selecting a particular solvent for a particular application.

(Refer Slide Time: 29:00)

Figure 2: Absorption column
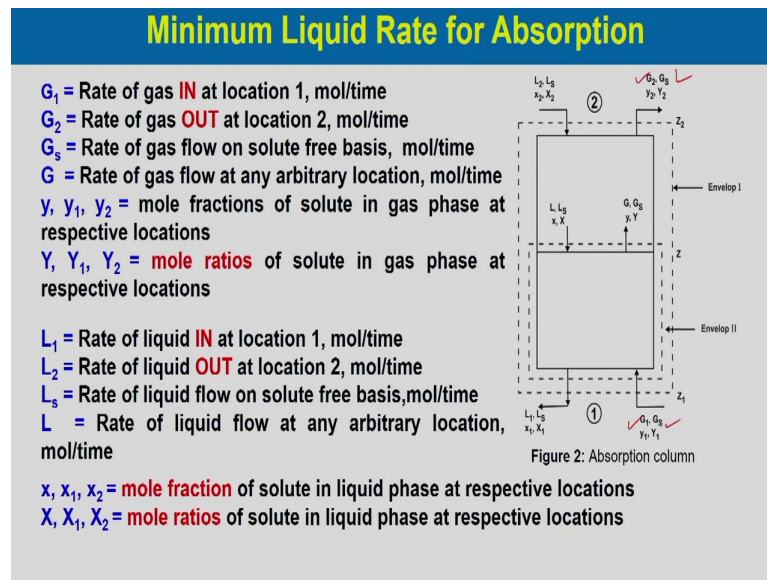
Now, let us consider an absorber column or absorption column. So, which is shown over here, you can see the gas which enters at the bottom as a flow rate of G 1, rate of gas IN at location 1 it is mole per time and G 2 is the rate of gas OUT at location 2, G 2 over here and G 1 over here is also mole per time. G s is the rate of gas flow on solute free basis, it is also a unit of mole per time then G is the rate of gas flow at any arbitrary location mole per time. So, inside the column and any arbitrary location small y 1 y and y 2 are the mole fraction of the solute in the gas phase at no respectively locations. Capital Y capital Y 1 and capital Y 2 are the mole ratios of the solute in gas phase at respective locations.

So, this nomenclature is already we have discussed in our previous modules, L 1, L 2, L s and L these are all liquid rates at inlet and outlet and also the L s is the rate of liquid on solute free basis, it is also mole per time. L is the rate of liquid flow at any arbitrary locations mole per time, small x, x 1 and x 2 are the mole fractions (Refer Time: 30:52) of the solute in the liquid phase at respective locations capital X, capital X 1 and capital X 2 are the mole ratio which of the solute in the liquid phase at respective locations. So, these are nomenclature of the typical absorption column.

Minimum Liquid Rate for Absorption

- A suitable solvent has to be selected and the equilibrium data at the chosen rating conditions (T & P) have to be obtained from the literature or from any other source.

- Now, how to determine the required solvent flow rate for a given absorption problem (Figure 2)?

- The overall material balance equation is given below.

$$G_s(Y_1 - Y_2) = L_s(X_1 - X_2) \qquad (1)$$

So, the equation of operating line is as follows:

$$(L_s/G_s) = (Y_1 - Y_2)/(X_1 - X_2) \qquad (2)$$

Figure 2

Now, a suitable solvent has to be selected for the absorption process, the equilibrium data at the chosen rating conditions that is temperature and pressure conditions have to be obtained from the literature or from any other source. So, once for a particular process depending on the properties of the solvent required for that application are selected at the particular separation process.

And then its equilibrium data of that particular gas mixtures should be obtained at a particular temperature and pressure condition or either particular temperature pressure or whatever the pressure condition and temperature conditions required, either that has to be obtained from the literature or from any other source

So, once these are in place now how to determine the required solvent flow rate for a given absorption problems. So, for this particular figure shown over here we have to find out how to calculate the minimum solvent range for a given absorption problem. Now if for this case if we do the overall material balance equation as we have done in our earlier section, this is G s into capital Y 1 minus capital Y 2 would be equal to L s capital X 1 minus capital X 2.

So, this is the overall material balance equation 1. The equation of operating line is L s by G s would be equal to Y 1 minus Y 2 divided by X 1 minus X 2 this is equation 2. So, this is the equation of the operating line.
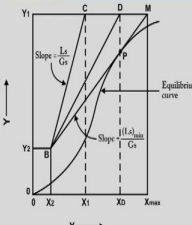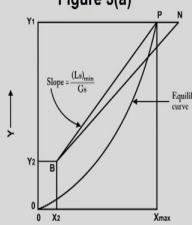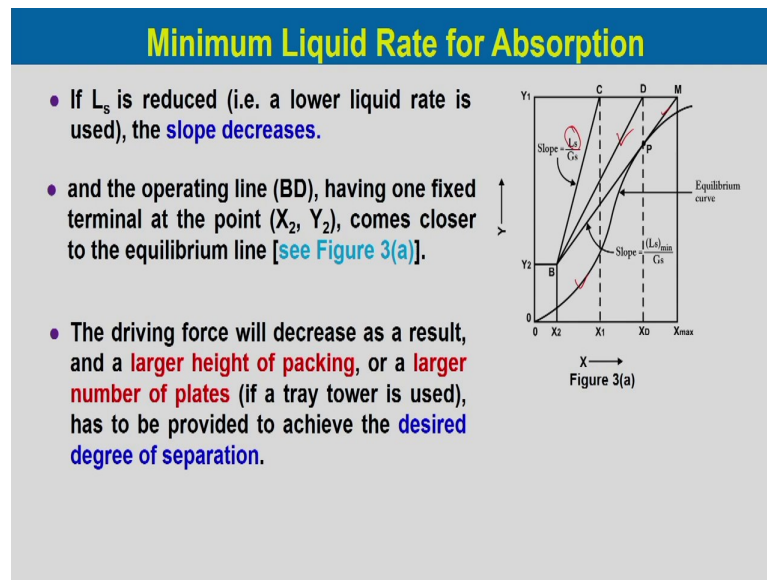
(Refer Slide Time: 33:13)

Figure 3(a)

Figure 3(b)

Now, there still remains two unknown quantity one is L s and X 1. So, L s and X 1 has to be determined, if one of these components say L s is fixed the other x one can be calculated from the material balance equation given earlier and vice versa. So, either L s is fixed we can calculate the X 1 from the material balance or X 1 is fixed then you can calculate the L s.

Now, the operating line can then be drawn by locating and joining the terminal points that is X 1 Y 1, X 1 X 2 on the X Y plane. The slope of the operating line that is L s by G s two types of equilibrium lines and set of operating lines of different slopes are shown in figures 3 a and 3 b. You can see over here, this is equilibrium curve and in this case in the bottom curve this is the equilibrium curve, you can see the operating line BC BD and BM, similarly BP and BN in this no bottom figure. So, these are operating line with different slopes these are ploted.

Minimum Liquid Rate for Absorption

- If L_s is reduced (i.e. a lower liquid rate is used), the slope decreases.

- and the operating line (BD), having one fixed terminal at the point (X_2, Y_2), comes closer to the equilibrium line [see Figure 3(a)].

- The driving force will decrease as a result, and a larger height of packing, or a larger number of plates (if a tray tower is used), has to be provided to achieve the desired degree of separation.

Figure 3(a)

If L s is reduced that is a lower liquid rate is used the slope decreases, you can see if we here not decrease less the slope of the operating line will decrease and from BC it will come to no BD and then BM and so on.

So, it will change, the slope of the operating line will reduce as we reduce the liquid rate and the operating line BD having one fixed terminal at point X 2 Y 2 comes closer to the equilibrium lines. So, it is coming this is the equilibrium line and then operating line BC is no comes to BD which is closer to the equilibrium line compared to BC line the driving force will decrease as a result. So, the as we said at the beginning the departure from the equilibrium line is the driving force for mass transfer. So, the distance between the operating line and the equilibrium line represents the driving force.

So, in this case as we decrease the liquid rate the distance between the operating line and the equilibrium line decreases and hence the driving force decrease. So, a larger height of packing or is a larger number of plates if a tray tower is used has to be provided to achieve the desired degree of separation. For the same separation, if we have a higher liquid read the number of plate required or the height of tower required for that given separation should increase if we decrease the liquid rate.
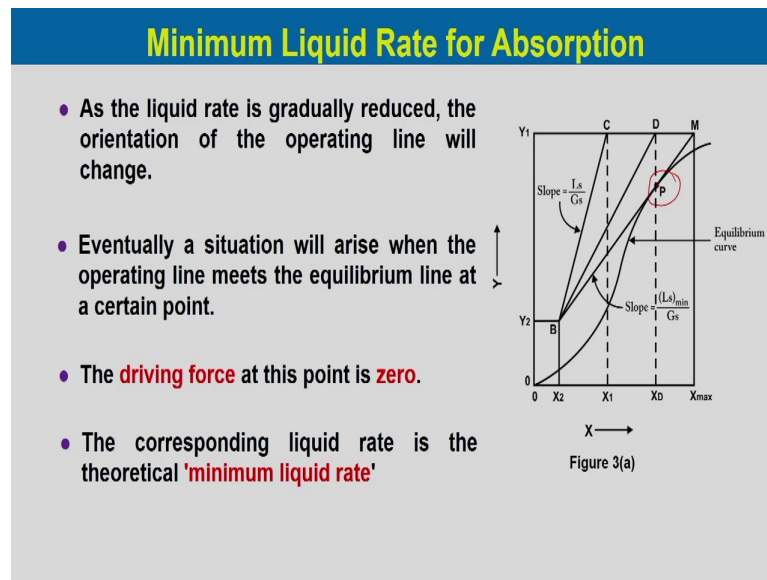
As the liquid rate is gradually reduced the orientation of the operating line will change eventually a situation will arise when the operating line meets the equilibrium line at a certain point. So, you can see the BM curve its meets at point P on the equilibrium curve. So, the driving force at this point that is the intersection point between a tangent point between equilibrium curve and the operating line curve which is at point P. So, the driving force over there is 0.

So, these means that the corresponding liquid rate is called the theoretical liquid rate. So, once these liquid rate is achieved and it touches the equilibrium curve at that point which is tangent to that point P this liquid rate is called the minimum liquid rate.

(Refer Slide Time: 38:00)
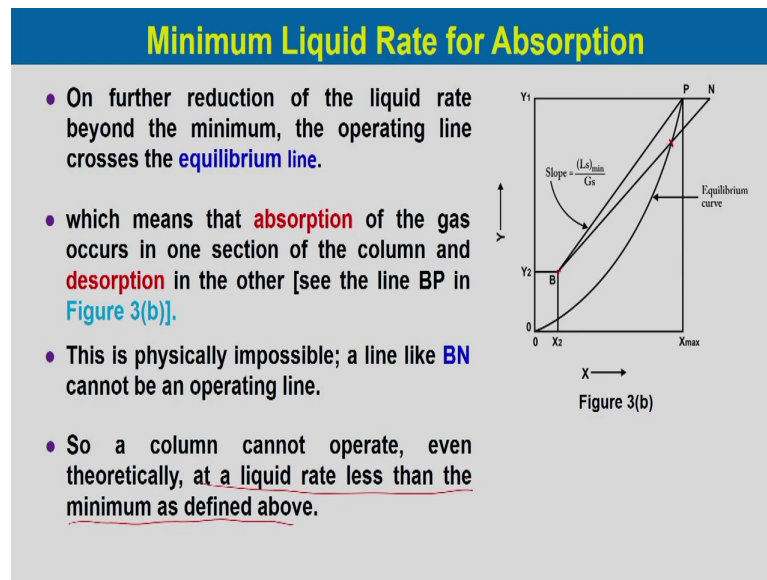
Now, if we further reduce the liquid rate beyond the minimum the operating line will cross the equilibrium line like over here, which means that the no absorption of gas occurs in one section from here to this because for absorption the operating line will lie above the equilibrium line and for stripping the operating line will lie below the equilibrium line.

So, from this point to this point the absorption would take place and then the other section of the column you will have desorption, from this point to point N. This is physically impossible a line like BN cannot be an operating line. So, because in a column a single column it cannot part of this can operate as observer and part of this can operate as stripper. So, which is physically it cannot cross the equilibrium curve same operating line cannot cross the equilibrium curve.

So, this is physically impossible and hence this cannot be an operating line. So, a column cannot operate even theoretically at a liquid rate less than the minimum defined above. So, minimum liquid rate which is required which touches the point at equilibrium. So, an absorber cannot operate below this liquid rate.

(Refer Slide Time: 39:49)

Figure 3(a)

So, the slope of the operating line at minimum liquid is L s mean by the G s since, G s the gas flow rate of the carrier gas is known L s mean can be calculated from the slope of the BM. So, career gas flow rate is already known and then L s by G s we can get the slope of this operating line at the minimum liquid rate and then we can calculate the L s minimum from the slope of this curve B and M.

The corresponding concentration of the exit liquid is X max, that is the maximum liquid concentration we can achieve is X max the driving force is 0 at point P. So, at this point the driving force is 0 that is the point of tangency for the particular shape of the equilibrium line which is called the pinch point, the point P over here is known as pinch point.

(Refer Slide Time: 41:02)
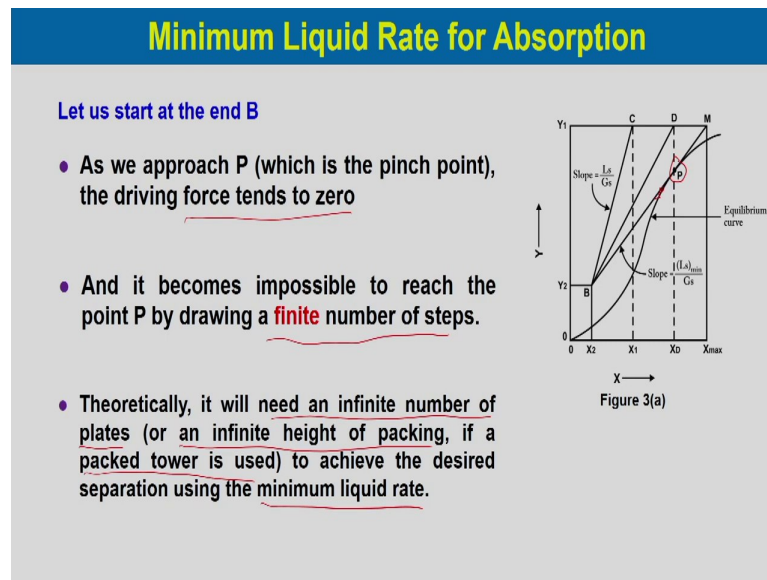

Minimum Liquid Rate for Absorption

- What result do we expect if we want to find out the number of ideal plates required for the desired separation using the minimum liquid rate?

- In order to address this question, we redraw the equilibrium line and the operating line BM for the minimum liquid in Figure 3(a).

- To find out the number of 'ideal stages', construct steps between the equilibrium line and the operating line starting from either end.

Figure 3(a)

What result do you expect if you want to find out the number of ideal plates required for the desired separation using the minimum liquid rate? So, how many ideal plates should be required if we wanted to calculate the number of stages required for a given separation, that is we need to answer. In order to address this question we redraw the equilibrium line and operating line BM for the minimum liquid in figure 3 a over here, to find out the number of ideal stages construct the steps between the equilibrium line and the operating line starting from the from either end.

So, either you can start from this position or you can start from any other position. So, if you do this staircase arrangement what you will notice?

(Refer Slide Time: 42:12)

Minimum Liquid Rate for Absorption

Let us start at the end B

- As we approach P (which is the pinch point), the driving force tends to zero

- And it becomes impossible to reach the point P by drawing a **finite** number of steps.

- Theoretically, it will need an infinite number of plates (or an infinite height of packing, if a packed tower is used) to achieve the desired separation using the minimum liquid rate.

Figure 3(a)

Let us starts at point b as we approach P which is the pinch point the driving force tends to 0 and it becomes impossible to reach the point P by drawing a finite number of steps or as you go on over here by drawing the steps towards the pinch point the driving force is so less you cannot achieve no to reach this point P by drawing finite number of plates

So, theoretically it will need an infinite number of plates or an infinite height of packing if you packed tower is used to achieve the desired separation using the minimum liquid rate ok. So, for practical applications we have to run the absorber, more than the minimum liquid flow rate.

Minimum Liquid Rate for Absorption

A few more points have to be noted in this connection.

- The minimum liquid rate can also be determined by a similar graphical construction on the x-y plane using the mole fraction unit of concentration.

- Recall that the operating line will no longer be a straight line in this case.

- The procedure described above can be followed in principle to determine the minimum liquid rate for absorption.

A few more points have to be noted in the minimum liquid rate can also be determined by a similar graphical construction on the x-y plane using the mole fraction unit of concentration. So, far we have shown you the graphical construction using the mole ratio unit which is capital X and capital Y, but same thing can be done with the mole fraction unit small x small y plane, recall that the operating line will no longer be straight line in this case. So, it in the if the operating line is not straight the procedure described above can be followed in principle to determine the minimum liquid rate for absorption.

Minimum Liquid Rate for Absorption

- But we will have to deal with two curves in order to determine the point of tangency or the pinch point.

- This poses a practically difficulty.

- So, as a matter of convenience and practice, the minimum liquid rate' is determined by graphical construction on the X-Y plane

However we will have to deal with two curves in order to determine the point of tangency or the pinch point, because both the lines are curved both equilibrium line as well as the operating line.

So, somehow, we have to deal with this which is sometimes difficult to find out the pinch point, this poses practical difficulty. So, as a matter of convenience and practice the minimum liquid rate is determined by graphical construction of the capital X Y plane.

(Refer Slide Time: 44:47)

Minimum Liquid Rate for Absorption

- If the equilibrium relation, expressed in terms of mole ratio unit, is linear ($Y = \alpha x$), the minimum liquid rate can be determined algebraically by calculating $X_{max} = Y_1/\alpha$ and substituting it in the material balance eq(1). In this case, the coordinate of the pinch point is $(Y_1/\alpha, Y_1)$, and

$$(L_s)_{min} = G_s (Y_1-Y_2)/[(Y_1/\alpha)-X_2] \qquad (3)$$

- Also, it has to be noted that in any practical problem, the pinch point does not occur at the top end of the column for absorption.

Now if the equilibrium relation which is expressed in terms of mole ratio unit is linear that is capital Y is equal to alpha capital X the minimum liquid rate can be determined algebraically by calculating X max would be equal to capital Y 1 by alpha and substituting it in the material balance equation 1 which we have done before.

In this case the coordinate of the pinch point would be capital Y 1 by alpha Y 1 and this L s mean would be G s into capital Y 1 minus Y 2 divided by Y 1 by alpha minus X 2 also it has to be noted that in any practical problem the pinch point does not occur at the top end of the column for absorption. So, the pinch points is observed either bottom of the absorption column or at some point of the absorption column, it does not occur at the top end of the absorption column.

(Refer Slide Time: 46:08)

And absorption tower has to be operated at a liquid rate larger than the minimum one; there is no general rule for determining the actual liquid rate to be used. So, the factors that govern the choice of the liquid rate will be discuss later; however, a liquid rate 1.2 to 2 times the minimum liquid rate is frequently used.

So, in this connection it will be interesting to have a closer look at the shape of an equilibrium line in connection with the determination of the minimum solvent rate for gas absorption.

(Refer Slide Time: 46:52)

If Henry's law is applicable; that means, y is equal to m x and if m is greater than 1. So, in this case what happens the equilibrium line on the capital X-Y plane that is the mole ratio unit is concave upward. So, equilibrium line would be concave upward. So, the pinch point corresponding to the minimum solvent rate for absorption occurs at the bottom of the tower. So, you have a pinch point which will be at the bottom of the tower, but on the other hand if m is less than 1 the X-Y curve is concave downward.

So, you will have the operating line touches the equilibrium line at some intermediate points when the minimum solvent rate is used. You can see that for the minimum liquid rate the pinch point occurs either at the bottom of the column or at some point of the column not at the top of the column.

(Refer Slide Time: 48:01)

Solution

A gas mixture containing 3% by volume pentane vapor and 97% inert. The mixture is treated with a non-volatile absorption oil in an absorber and 97% removal of pentane is required. The feed solvent is free from solute. The feed gas rate is 50 kmol/h. The equilibrium relation is given as
$Y = 0.25X/(1+0.75X)$
Calculate the minimum solvent rate required.

Solution

Given: Gas rate = 50 kmol/h and y_1 = 0.03 mol fraction

Input rate of pentane = 50*0.03 = 1.5 kmol/h

Carrier gas in = 50-1.5 = 48.5 kmol/h = G_S

97% solute has to be absorbed and 3% leaves with the carrier gas:

$Y_1 = y_1/(1-y_1) = 0.03/(1-0.03) = 0.03/0.97 = 0.0309$

$Y_2 = 0.03*Y_1 = 0.03*0.0309 = 0.009$

Also, $X_2 = 0$ (feed solvent is free from solute)

Now, let us take an small example, a gas mixture containing 3 percent by volume pentane vapor and 97 percent inert. The mixture is treated with a non-volatile absorption liquid oil in an absorber and 97 percent removal of the pentane is required. The feet solvent is free from solute the feed gas rate is given as 50 kilo mole per hour the equilibrium relation is given as y is equal to 0.25 X divided by 1 plus 0.75 X. Now we have to calculate the minimum solvent rate required.

So, let us do that. So, gas rate which is given 50 kilo mole per hour and 97 percent inert and three percent pentane which is small y 1 is 0.03 mole fractions of the pentane vapor, input range of the pentane would be 50 into 0.03. So, it is 1.5 kilo mole per hour which is

the input pentene rate. So, career gas would be total 50, so, minus 1.5, so, 48.5 kilo mole per hour.

So, that is the G s, so, this is G s and this is the pentane rate pentane flow rate. Now 97 percent solute has to be observed and 3 percent leaves with the carrier gas. So, Y 1 would be small y 1 divided by 1 minus y 1 which is equal to 0.03 divide by 1 minus 0.03 which is equal to 0.03 divide by 0.07. So, capital Y 1 would be 0.0307 and capital Y 2 would be equal to 0.03 into Y capital Y 1 which is equal to 0.03 into 0.0309 which is equal to 0.009.

So, we can calculate capital Y 1 and capital Y 2 and the solvent is given pure solvent which is free of solute. So, capital X 2 is 0.

(Refer Slide Time: 50:39)

Solution

A gas mixture containing 3% by volume pentane vapor and 97% inert. The mixture is treated with a non-volatile absorption oil in an absorber and 97% removal of pentane is required. The feed solvent is free from solute. The feed gas rate is 50 kmol/h. The equilibrium relation is given as

$Y = 0.25X/(1+0.75X)$

Calculate the minimum solvent rate required.

Solution

Steps:

(i) Plot the equilibrium data on X-Y plane

(ii) Locate the point (X_2, Y_2)

X	0	0.001	0.01	0.02	0.04	0.06	0.08	0.1	0.12	0.14
Y	0	0.0025	0.0025	0.005	0.0097	0.014	0.019	0.023	0.027	0.032

Now what we need to do with the equations given for the equilibrium relations. So, we can draw the X-Y plane the equilibrium curve and then look at the point capital X 2 Y 2. So, these are the data which we can calculate from this no equilibrium relation capital X and capital Y. So, this is equilibrium data and then if we can plot this is the equilibrium line.

Now, draw the operating line X 2 Y 2 that touches the equilibrium line. So, it will be touches somewhere here, not this point. So, it is touches somewhere here which is at this point, the point of tangency p is the pinch point and the operating line corresponding to the minimum liquid rate, at this point we need to calculate X value that is X 1 and Y 1.

So, we can calculate the slope of operating line. So, with respect to this point is 0.01 019. So, which is over here and this is no Y 2 you have calculated this is Y capital Y 2, this is

capital Y 1 and then this is X 1 and this is X 2 which is 0. So, we can calculate the no slope which is 0.125 and G s is given which is 48.5 kilo mole per hour.

So, L s minimum would be equal to 48.5 into 0.125. So, it is 6.06 kilo mole per hour so, this way we can calculate the minimum liquid flow rate. Now for practical application if it is given that the actual liquid rate you need to use for the particular operation, if it is not given then you can use some factor between 1.2 to 2 to calculate the no actual liquid flow rate required for that separation process.

Thank you for attending and hearing this lecture and we will continue our lecture on absorption in the next class.