Mass Transfer II

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Lecture No. # 9

In today's lecture, we take up this absorption unit operation, and we address mass transfer rate and hydrodynamics. And if you recall, we said earlier that we can have continuous process or we have stage wise process. Typically absorption is done in a continuous packed bed, we have a packing, and two streams, gas phase, and the water phase or the liquid phase, they are brought in contact through some packing. And similarly, we can have a co-current process or we can have a counter-current process, and if you recall, we said that in counter-current continuous contact process, the driving force is more, large, so in which case, we have a shorter column.

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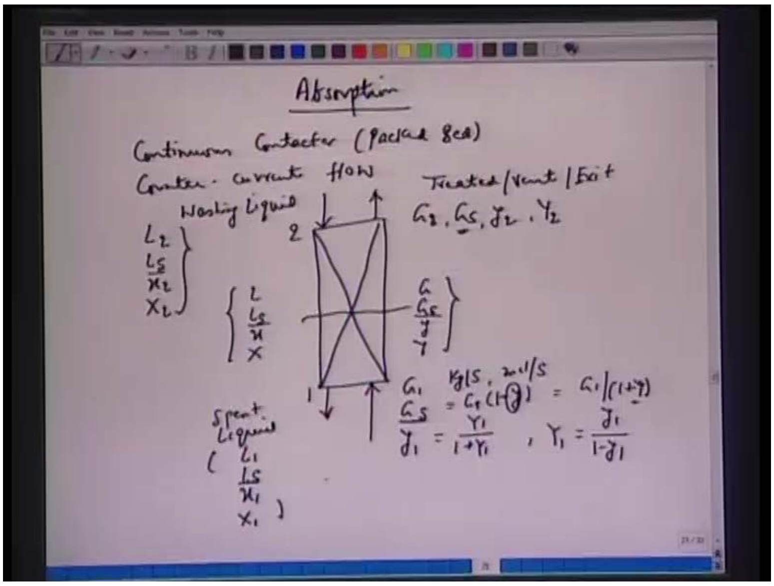

So, now we take this absorption column, continuous counter-current packed at bed column. So, what we have here is absorption, we look at continuous contactor, essentially we have a packed bed, and we have counter-current flow. Schematically, we have an absorption column like this, sand packing we denote with this cross, we have a stream of gas effluent, with mass flow rate G 1 kg per second or mole per second, we have G s which is solvent or solute-free basis flow rate, which is G 1 into 1 minus Y. We have mole fraction, which we can write in terms of solute-free basis mole fraction, and which means we can also write this as G 1 over 1 plus Y. So you must check yourself, how we are writing G s in terms of mole fractions Y, and how we are writing in terms of mole fractions solute-free basis.

All it means we can also write Y 1 as y 1 over 1 minus y. This gas phase is brought counter-currently, in contact with washing liquid solvent, it has a flow rate L 2, we denote here two, we denote here this one, we can have L s, we can have X 2 and we can have X 2, the gas effluent which leaves from here treated or went or exit this has flow rate G 2 or G s, G s same as this G s, because it is the solvent flow rate y 2, and capital Y 2.

One, we have this spent liquor or spent liquid, this has a L 1 L s x 1 X 1, at any cross section you can write L L s x X. And here in the second phase, we can write G G s y and capital Y. Make a notice here that G s G s G s is constant here remain the same L s L s and L s, they remain the same because, these are all solute-free basis.

Now, if you look at the equipment, with the two types of equipments, one is a stage wise, and one is a packed bed; packed bed is the most common for absorptions, stage wise or tray wise mostly common for absorptions, but there are some industrially distillation column, where we have stage wise treysers, treys also. In which case we have trace, they are perforated liquid trickles from one stage to another stage, and we have the gas which flows through this through this trace.

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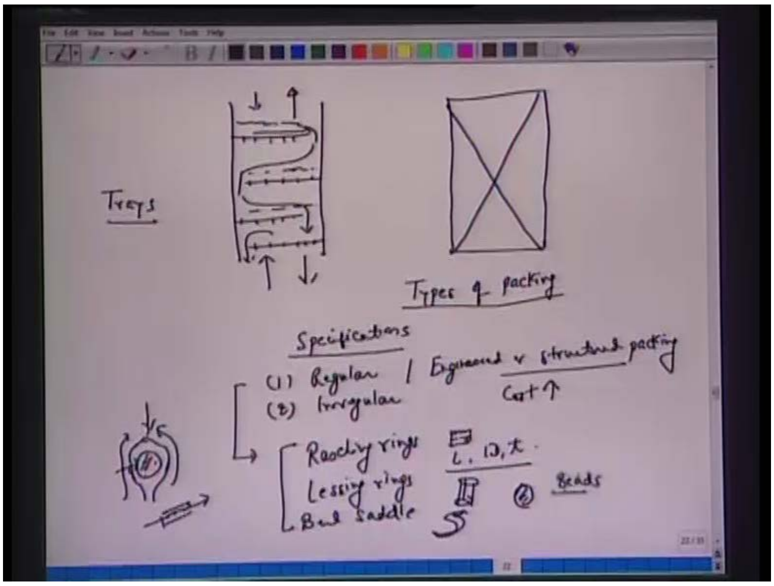

So, schematically this equipment, if you discuss here, then we can have the trace like this, all this is not very common for absorption; distillation it is widely used, and these are perforated. Now, this gas to be treated flows through this, and the liquid which comes from here, in a way, it flows like this, through this, so there is a pool of liquid or on every trace; and it makes an exit here, and the liquid makes an exit.

These are, this is like, trays wise operation or a stage wise operation, on the other hand, which is the most common here is a packed bed, when you have the packed bed column, and you look at the packing that several types of packing. It is recommended that you go through the text book or go through some handbook, and become familiar with the several types of packing, which are used. Packing are also you know, they have the specifications; so any packing material you choose or which is given, they have certain specifications; for example, first thing is, these are regular packing, there are regular packing or we can have you know irregular, regular packing also sometimes we have very engineered, or structured packing.

So of course, the cost is also involved here these packing are very expensive, cost is generally very high, but when we say regular packing, one common packing would be what we call ranching rings. If we look at some of the regular packing, we have ranching rings which is nothing but a cylinder shell. It has length, it has inside ID and the thickness; we can also have Lessing rings; there are several types of packing Lessing rings, they are also cylindrical, except that there is a partitioning inside, we also have berl saddle, certain geometrical configuration like this, one can also have spherical, you know spheres, the beads; these are all regular packing. And if you look at just one packing for example, the simplest this, the spherical beads like this, there will be a film of liquid liquid, if you flows like this, it will trickle like this, it will make a film around this, and the gas will flow go pass this, and the gas will diffuse inside the liquid.

Similarly, if you have packing like this, you know made of ranching rings, then there will be inside, there will be thin layers of liquid, and the gas will flow through this these packing or this ranching rings. And structured packing or engineered packing you know, they are also very specific, but they are very cost effective, the idea here is that all of these packing, they have certain meters square per cubic meter, specific surface area and that the parameter which plays a major role, if you know should be able to realize is mass transfer. So when we say there is a flux of certain species, which we diffuse from one phase to another, there is a moles per second per meter square; so there is a interfacial area between the two phases. And idea is that choose that type of packing which gives the largest area, largest interfacial area or contact area in a small given volumes. One cubic meter generally, everybody prefer a very larger meter squares, so that total amount of solute transferred from one phase to another phase is very large.

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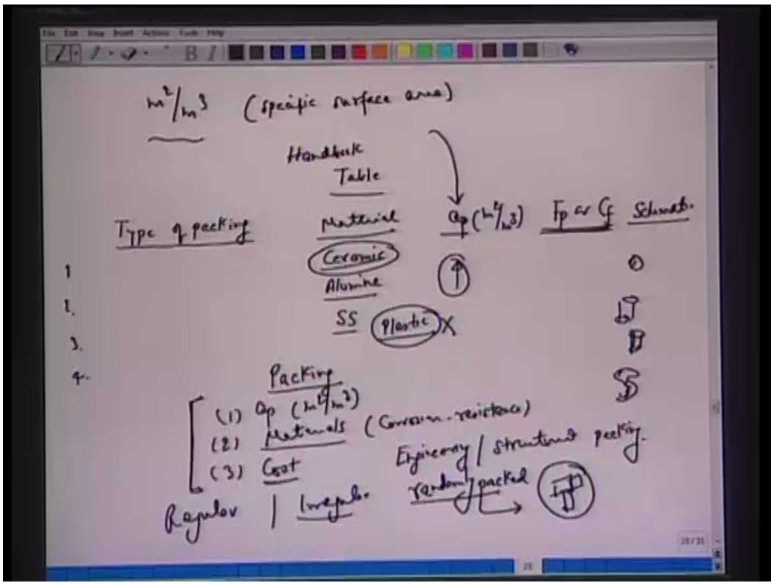

All of these specifications going back to this, you know they are characterized mostly by meter square per cubic meter, what is a specific, surface area of these packing you know, which we said like sphere berl saddles or Lessing rings or the ranching rings. If you look at any handbook or if you look at some table or you will see type of packing, it is encouraged that you go through some of the handbooks say, Perry's handbook or go through treble in the mass transfer or Macbeth Smith you know, some of the books which we are calling in this course for reference course, and they have given, they have a very nice table, and they have tried to include most of the regular packing which we use.

If you look at type of packing, and there will be serial number 1, 2 for example, type of packing, then there will be material here, maybe it is a ceramic. Most of the packing may be, they are made of ceramics, it is also possible that they are made of alumina, stainless steel etcetera, so the material of construction of the packing. Then there will be a column for a p, this is the a p which we are talking meter square per cubic meter; now this meter square per cubic meter is of course our engineering parameters, but very often manufacturers also supplies under a very common name packing factor F p or C f.

We will talk about these parameters, and they are used in some design calculation etcetera, and then you will see a schematic of this packing, whether they are a spherical or they are or it is a ranching rings or it is a Lessing rings with partitions or you have this berl saddle etcetera, it is recommended that you go through these tables are given in most of the text books. Typically, whenever you choose these packing of course, one favors very large meter square per cubic meter, but these are also important things to note here that these are also design consideration.

For example, when you choose a packing, then what the things you know generally one looks for one would be of course, a p meter square per cubic meter, it should give us reasonably a very large contact area, but more important also is here is material of constructions, because depending upon the type of fluid, we must ensure that this is corrosion resistance; for example, if you use sulphur dioxide, then you must use or you will like to use ceramic, which is corrosion resistance. You can also have packing made of plastics, if we are using sulphur dioxide, itself there is a strong likelihood that, this plastic packing will not work.

Packing specs should be a p materials of construction of course, the cost play a major role, if you have you know structure packing or engineering packing or a structured packing, and these are very expensive. So the cost also plays a major role. These are the things, and these are the aspects, one generally looks for while choosing a certain type of packing here, packing could also be, as you said regular or we said irregular essentially it means, when we packed they are randomly they are packed.

If we have you know, one packing sitting like this, another packing sitting like this, another packing sitting like this, it is a randomly packing we have in case of absorption columns, and if you look at this absorption column typical schematics, you will have a shower, when the liquid flows from the top it has to go through a regular shower, so that water or the liquid will distribute itself over the packing. And when similarly, when the as is you know sent from the bottom, there may be some distributor.

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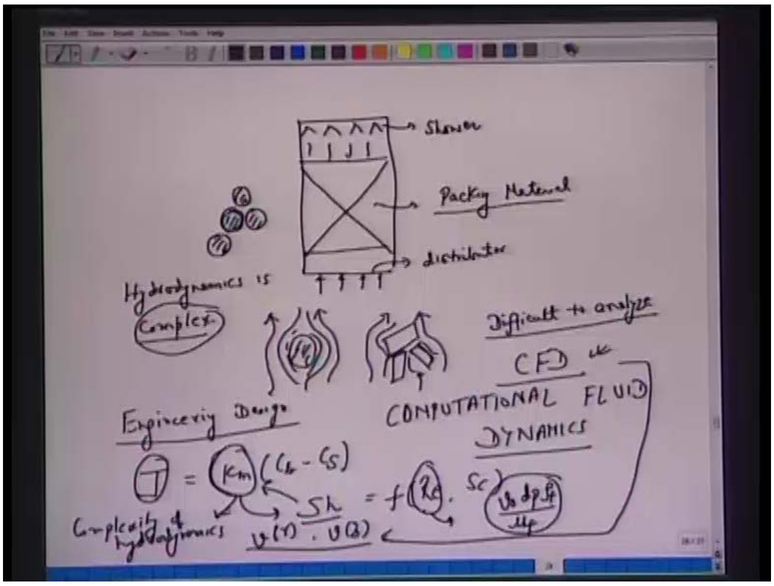

Typically, if will draw here you have a column, then you have a distributor. So, there will be a shower like this, liquid it will trickle form here, it will go through this packed bed, and here you have gas going through this, so there will be a some distributor here. So you have a distributor, you have a shower, and here you have this packing material, which is randomly packed, all it means if you look at very carefully, suppose you have a very simplest you know spherical beads, another bead sitting next to it, another bead sitting on top of it, another bead sitting here, the hydrodynamics is quite complex, you must appreciate that in this case hydrodynamics is complex.

You do not have a situation like this, where you just have one sphere, and it forms a regular film, water forms a film here, and the gas goes pass this you know the film on the packing. Generally the all this is very complex dynamics, if you have one packing like this, another packing like this, another packing like this of ranching rings, and you can imagine that the flow here is quite complex; around this either the water flow rate or the gas flow rate.

It is very difficult to analyze; these days if you heard of CFD - computational fluid dynamics. One makes use of this C F D to resolve this complexity of hydrodynamics in two phases systems like this, we have in case of absorption columns. Generally, what happens when it comes to engineering design engineering design, then hydrodynamics is not solved to that extent you know, the way we do it in case of C F D. Now, what we do here in case of absorption column design or similar unit operations, one has a macroscopic analysis; or it means water flows from the top and gas flows from the bottom.

If we have two counter-current flows from engineering point of view or from the operation point of view, it should be loading and flooding, and you know, which should be the main concern. You can imagine that if the water flows is very large, gas flow is very small, entire column will be flooded with water, it will prevent gas to go from the from the top bottom. Similarly, if the gas flow rate is very large, and water flow rate is very small, gas may prevent the water to flow from the top; and the entire packing will be flooded or loaded with the gas.

These are like more of a macroscopic analysis instead of getting into complex fluid dynamics, velocity profile inside the packed bed column, you know by making use of this CFD one looks at macroscopic, what is the superficial velocity. If you recall, we talked about mass transfer coefficients as in engineering parameters, here you can think of why do we need this mass transfer coefficients; if the hydrodynamics is very complex, we do not dissolve the fluid profile around the packing, there could be boundary layer, there could be film layer all we are concerned with what is the rate of mass transfer. In that case, if you recall we said that J mass transfer is k m mass transfer coefficient, you can write that c b in one phase, and may be c s on the other phase, and this case may be it is a liquid phase.

This is a mass transfer coefficient which we said that it is related to Sherwood number, and this is related to Reynolds number and Smith. So, all we do in as far as engineering concern, design concern, we look at the Reynolds number to which is superficial velocity V 0 packing certain characteristics let v d rho over mu mu of the fluid, and rho density of this fluid. We look at Reynolds number, we calculate Sherwood number, and then we have this mass transfer coefficient, calculated to obtain our flux here.

In other words entire complexity of hydrodynamics is embedded in this mass transfer coefficient; we do not solve velocity profile locally V as a function of R or V as a function of Z, which we can do by using this computational fluid dynamics. We try to understand, we must appreciate here that hydrodynamics in a typical absorption column or for that matter in most of the unit operation is very complex; it is not like we have a simple open tube, and Reynolds number is say 2100 or less than 2100 and 100 we have a very nice velocity parabolic profile.

If you have a packed bed columns, which is packed with different type of packing simplest would to be spherical beads, even in the case of spherical beads if the Reynolds number is very small, and these packing have been they packed are randomly the velocity profile around any sphere, any beads will be very complex. It is not possible to resolve unless until we make use of CFD, and you know we try to solve local velocity profiles. So, most of the times we have very macroscopic analysis, all we need a Reynolds number; if a Reynolds number it is known, we can calculate Sherwood number we can calculate mass transfer coefficient, the second or the only most important hydrodynamics, which we consider is loading and flooding. We ensure that the column is running under a very safe and smooth condition, so that is the only hydrodynamics which we have for this course mass transfer. So, we look at this hydrodynamics of loading and flooding before we start you know, mass transfer aspect.

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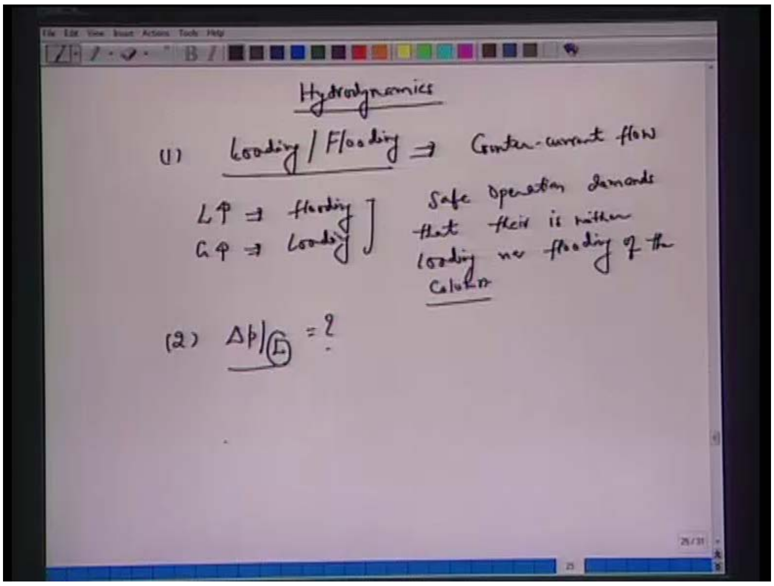

In this lecture, we look at very small aspects of this hydrodynamics, but it is a very important we said, we have loading and flooding. And we must realize that this will happen, if we have situation like this counter-current flow. If liquid velocity is very large, it is possible that we will have flooding; if gas velocity is very large or flow rate is very large what do we call we have this loading. And a safe operation demands safe operation demands, that there is neither loading nor flooding of the column, that is one thing. And the second is of course, pressure drop one would be interested in finding pressure drop per unit length or per unit height of this column.

Now pressure drop in a packed bed column is very similar or at least you can make an analogy pressure drop, if we recall we did or we must have done in some you know at the second year level, if at the first year level, flow through the packed bed, where you have argon equations. So, argon equation can be applied to find the pressure drop, but there if you recall it is a stationary phase, we have a very nice packing arrangements, we have some certain packing porosity sphericity, we have certain Reynolds number, and then we have analytical expression obtained based on the viscous term, and the inertial term, we write the pressure drop as a function of v and v square. So, this is the analytic equation of course we obtained or one has obtained, one can obtain, starting from the first principle.

But generally in case of this packed bed column when we have counter-current flow, very often we have to rely on certain correlations or we rely on certain graphs which have been prepared by the manufacturers or by certain experiment under certain experimental conditions; of course argon equation can be applied to get an estimate, for the pressure drop, one can work on this relative velocity assuming that one phase is stationary etcetera to obtain this pressure drop, but generally it is not it is a seldom done one has several or several, such graphs for pressure drop for different types of packing in given in most of the textbooks.

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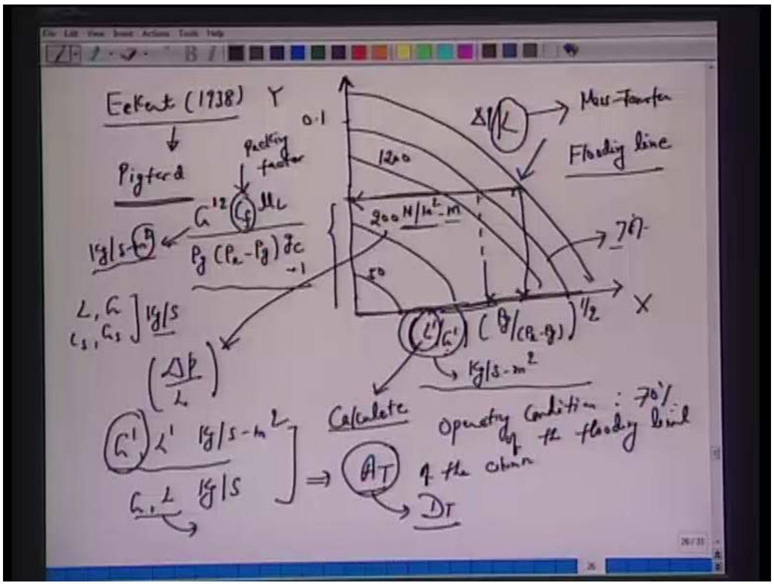

One very common plot, very classical plot for this counter-current flow in a packed bed column, which we are applying here the absorption is given by Eekert, very classical plot here. So, we look at this plot, and try to become be familiar with this; this is a very old plot, in of 1938, and there has been several modifications or update may be by Pigferd, later to determine or do some analysis for this loading, flooding and the pressure drop. It is a very classical plot here it is a recommended that you become familiar with this, and solve at least one few problems or you know, address certain examples here.

This plot will look like this on the x axis, you have L prime over G prime, and will talk about this; and you have rho g over rho l minus rho g the above half. This L prime and G prime of course, L denotes for the liquid phase, and G denotes for the gas phase, the unit of this is kg per second per meter square. It is very specific unit specific one has to go by this units here, kg per second per meter square, and here on the y axis, we have g prime again, square C f mu L over rho g rho l minus rho g, and you have this g c here, which is of course, one if you use SI units; this G is kg per second kg per second per meter square.

We understand that this is G prime, so for we have used the nomenclature L G or L S and G S which is Kg per second, this also a mass flux kg per second per meter square, and we will make use of this to determine the diameter or the size of the column. Let as come back to this one has to calculate the Y, and one has to calculate this X here, C f if we recall we talked about this packing factor. So, the manufacturer or the handout of that packing which you have chosen, should have given this C f here. We have several lines here like this, like this, like this, you will see the last line this will be marked as flooding line, and here you have some numbers like 0.1 etcetera; and each curve will have a certain numbers, which is say 1200, 200, 50 this is Newton per meter square per meter.

If you recall this is nothing but your pressure drop per unit length. So this is what we have right, so this is a plot graph very classical plot given by prepared by Eekert, some improvement here or some changes you know as given by Pigferd, it is a very important that you become familiar with this and how to use this. More important here is to calculate x, if you calculate any L prime by G prime it is a very easy to see that if we increase this number here keeping G prime constant. It is possible that we hit this flooding line. Whenever we do this analysis suppose we fix G prime, which means we have fixed the gas flow rate, and we increase this we have flooding line here.

For a given this Y axis, we have fixed here X axis from which we can calculate L prime, this will give us a limit for the flooding line, and here the pressure drop goes exceeds very high. Generally, operates operating curve or operates operating condition is seventy percent of the flooding conditions of the flooding limit. So we are talking about this limit here.

Now, if we work on say seventy percent of this say, this is the seventy percent of the line, then you know one can calculate L prime, G prime, one can calculate this y axis here to work on this; or so that is one thing more important here to note that, we are working on the quantity like G prime and L prime, which we said is kg per second per meter square, which means, if we know this quantity either L prime or G prime, and if we know or we should know G and L actual kg per second, then from this we can get cross sectional area of column. So, it is hydrodynamics which gives us cross sectional area of this column.

If G and L are fixed, because generally, these are given to us or given to the designer that we have certain kg per second of gas, and certain kg per second of liquid, you know which is a which is like solve, which is solvent to treat this effluent. Then it is hydrodynamics which will dictate us, what should be the size of it of the column and when we say the size the diameter not the height. Height comes from mass transfer, diameter comes from hydrodynamics. If we have a very large diameter or relatively larger diameters, and if the flow rate is fixed that means superficial velocity will be smaller, pressure drop will be smaller.

This is how we get into this pressure drop that if increased for a given G prime kg per second per meter square, if we increase L prime we hit the flooding line here, so if everything is fixed here one can obtain from the flooding line what is your maximum L prime, which is required as per as hydrodynamics is concerned. Again I am going back to this design aspect of an absorption column; you must not forget that we have hydrodynamics, and we have mass transfer, and very often it is an iterative process. Mass transfer may demand given certain type of problem that I require 1000 kg per second, but, it is possible that when we get back to this curve 1000 kg per second of the liquid flow rate might give you operating curve, which is very close to this flooding line or it is on this flooding line. That means one has to come back, reduce the size of the or in change the size of this column, redo the calculation for mass transfer; the two they go parallely, they are not in like series one has to do this kind of interest, I will take an example, where we have a mass transfer requirement, and then we have a different hydrodynamics requirement.

Hydrodynamics comes from loading and flooding, and one of these curves will also give us how much is the pressure drop pressure drop per unit length, look at this unit Newton per meter square per meter, which means the length should also come from some where else that is a mass transfer, now let us say mass transfer will tell us, how tall is the column. Hydrodynamics in general tells us how what is the size of this column, cross sectional area or the diameter of the column, this we denote by D T. This packing factor is also important here what type of packing we choose, so that this quantity is also is also you know, it varies here, then we calculate L prime, if we know L, we can take the ratios to obtain the diameter.

If we know G prime, if you know G actual G we can take the ratios to obtain the cross sectional area, this is a plot again I repeat it is very important, and you do at least one example to address this loading and flooding or the pressure drop per unit length basis how much is a pressure drop, because the pressure drop will decide, what is the pumping requirement say for liquid, trickles from the top one of course, makes use of this gravity, but generally you will you have to transfer this liquid from the ground from the storage tank to the top of the column.

Similarly, the gas flow rate it will require a blower, there also energy is required we need to know what is a size, not the kg per second, it is a more important a kg per second per meter square that decides your superficial velocity. And in fact superficial velocity will decide your Reynolds number, mass transfer coefficients etcetera, it is a bit complex design, this is not a design course, here we look at the tools slightly different, I am sure you have a design course or design lectures for in a very comprehensive, and design of distillation column or absorption columns, where you look at these quantities more rigorously, let us get back to this mass transfer here.

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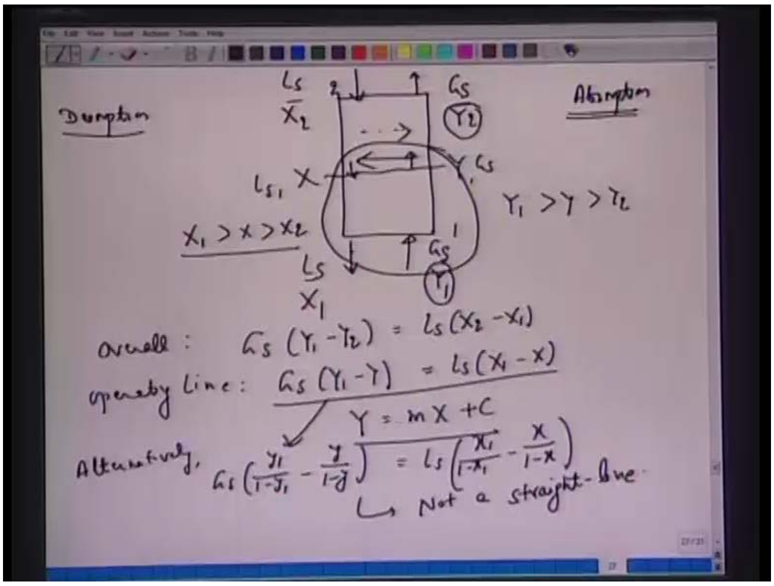

If we look at now mass transfer lets draw very quickly again, we have now, we worked just on G s, we have already realized, this is one, it is advantageous to work on G s or liquid free basis this is L s and we have X 1 here. Liquid comes from here at L s and we have X 2, this is level 2 and the effluent gas after treatment is remains a G s, and we have this Y 2. At any cross section, we have X and we have Y G s G s G s L s L s L s will remain the same it is a solvent-free basis, you can also make a note Y 1 is greater than Y greater than Y 2.

This concentration was high, which has been brought back to this, Y has been brought down to this Y 2, it is essentially an absorption column just reverse of this would be desorption column or stripping. There we have a gas which is or liquid, which is very high concentration, so here if you go by absorptions, we have this concentration is X 1 greater than X greater than X 2.

Pure solvent, nearly pure solvent becomes rich, in the transferring component desorption, the condition is reverse already we have a liquid, which is a very high concentration of X t it is X, and we want to strip in the opposite direction to this G s etcetera. o, qualitatively the treatment for absorption and desorption they are the same, here so this is what we have schematics, we are again interested in making say, you make it overall species balance you will have very simple similar to previous recall G s Y 1 minus Y 2. We have L s, X 2 minus X 1. And then all it means we can have operating line, which will relate bulk phase concentration of one phase to another, so we can write G s Y 1 minus Y.

All it means we have taken this envelope, this is again L s, X 1 minus X. So, one gets an operating line in terms Y equals m x, plus c this becomes your operating line, one can of course, just for your remembrance alternatively we can also work on a small mole fractions, actual solute mole fractions. In that case the curve will not be linear. We can write like Y over 1 minus Y, all we have done we have substituted for Y 1 in terms of Y 1, L s X 1, 1 minus X 1, minus X, minus 1 over X here, but, we make a note it is not a straight line here.

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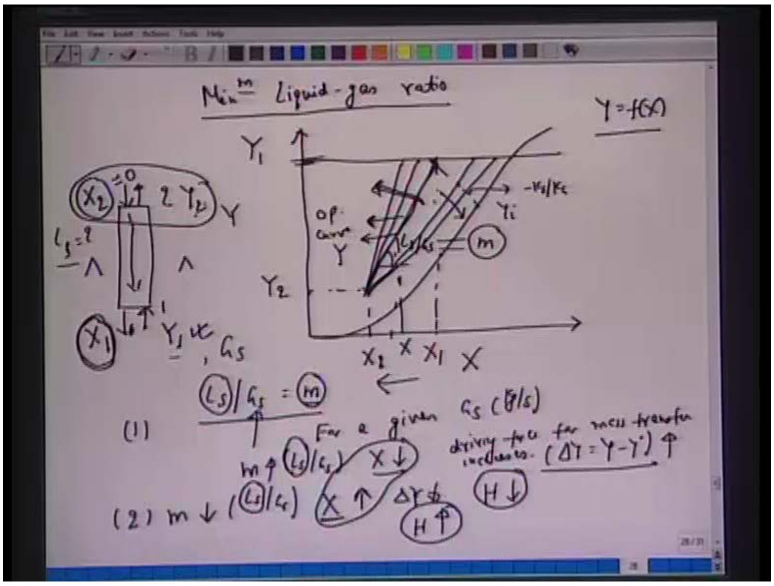

There is another interesting thing here, when we make this mass balance, we also address one parameter or one design variable it is called minimum liquid gas ratio, we will address this first before getting into details of this mass transfer. Let us try to understand this with this graph. So we have X, we have Y, thermodynamics is given as Y, as a function of X solubility curve given X, how much is Y if there is an equilibrium, we have this column at the bottom we had one, two we mark this as a gas or liquid entering and the gas leaving from the top.

In general, what you will have situations you know, very similar to the example which we took in earlier class, where we had this stage wise. Generally, this would be given to us of course, the problem can be formulate in different ways, but what is generally given to us are more simpler be that we know the gas flow rate.

Practical problem gas flow rate composition is given, we have been asked to reduce the composition of this gas from one level to another level, before we went to do that, we have been given a pure solvent or solvent in which there is some very small amount of the transferring species concentrations. We have been asked to determine the diameter, height of the column, how much is a requirement of this solvent and may be, what is a concentration of the liquid spent liquor, which comes out of this? Let us mark out those points.

All we are trying to say here that this Y 1, and this is your X 1 here, and this is Y 2 and X 2, we must note here is that the most common example would be or scenarios would be that Y 2 and X 2 are known, we have been Y 1 is given to us we want to reduce this concentration from Y 1 to Y 2, to do that we have been given a solvent, which is very small concentration approximately 0 here. So, Y 2 X 2 are known to us; lets mark these points X 2 and Y 2; you should also notice that X 2 is a smaller here, and Y 2 is very small here, because Y 1 is larger than Y 2, and X 1 is also larger than X 2, fresh solvent or nearly fresh solvent very small concentrations, and the affluent has been treated and it level has been brought so this point is fixed here.

Now, Y 1 is also given to us, we mark Y 1, here all we know in general we know the G s, we have been given this liquid, but we do not know what is this amount of this liquid that would be the most common scenarios. Now, if Y 1 is given to us, we know this we can mark the level here, but if X 1 now all we know that to go back to the operating curve we have the slope of the curve given as L s by G s; and this curve of course, we know it is a linear here.

If L s by G s is known to us, and we want to draw this line, then typically we will have a curve like this; so this would be L s by G s, if we know L s we can draw this line here, which is the operating curve, which will hit this concentration this level or at Y 1 to give us X 1. So, you understand what we are trying to say here is that, if we know L s liquid flow rate or if we know the slope of this line G s is given to us. If we know the slope we can find L s, if you can find L s you can draw this line here; once we draw this line here, we have Y 1 we can find out X 1, which is the how much is the concentration of X 1. So, we know X 1 Y 1, we will know X 2 Y 2 and at any locations given X, we can find out what is Y.

Alternatively, if we know X 1 what is the concentration here, we can mark this point, we can draw this line and we can calculate L s by G s, which is a slope of the curve and then we can given X we can find out Y. We can address you know, how much is the driving force may be for Y 1, we have to draw another line of k l by k l g, that will give us interfacial concentration etcetera, one can find that driving force.

The second thing, which we want to address here now, if we change the slope of this line lets increase L s by G s. If we increase the L s by G s, the line will move in this direction.

What does it mean? if the for a given G s, if we increase the slope all it means, the amount of liquid has increased the liquid flow rate has increased; and if the liquid flow rate increased you can see here that the concentrations X goes in this directions.

Let us note down this for a given G s. So G s kg per second is known to us. If we increase this slope L s by G s, if we increase this ratios of liquid with G s flow rate, then the X decreases, which is consistent with our understanding, if you have take a very large liquid flow rate, then this concentration will be smaller the liquid concentration at the exit will liquid will be dilute here. So, m increases X decreases. And also we note that driving force look at the driving force for mass transfer that also increases look at the difference between the operating curve, and the equilibrium curve, as the line moves in this direction, essentially driving force del Y, if you call it Y minus Y star, bulk phase call from our previous discussion that will increase here; and if this increases driving force increases the height of the column, we will expect to decrease.

So, taking the large amount of the liquid, we have reduction in the height of this, and the concentration of the liquid exit in this column is also small. We will see what is the significance here in a minute Let us take the second case, if we increase now let us decrease the slope, that means given for a fixed G s, now our curve goes like this. Now if it moves in this directions, we just have the reverse of reverse effect if m decreases or L s by G s decreases amount of it solvent is decreasing; if the amount of solvent decreases mole fractions or the concentration of the spent liquor that will increase, that is also expected, because now we have small amount of liquid. So the liquid will be more concentrated here, X will increase, but what happens to the driving force now the driving force decreases, and the height of the column will increase.

We have two contradictions here; if we take a larger amount of the liquid, height of the column is smaller, if we take a small amount of the liquid, then the height of the column is very large and at the same time the concentration here is also very large. We will see the significance of the spent liquor concentration, how does it affect our design. But right now let us just sum up very briefly that we have we are trying for a given gas flow rates, we are trying to determine what is the liquid flow rate, how does it change the height of this column. So, if the liquid flow rate is increasing, pump cost will also increase, amount of the liquid or the cost of the solvent itself will also increase, so we have to pay more there if the amount of liquid or the liquid flow rate is large, but the height of the column will decrease. So, that way we save the cost there.

On the other hand, we take a very small amount of the liquid, we save on the solvent flow rate pumping requirement, but height of the column will increase, so there is always an optimum, the scope of optimization this what we will do, when you do a very rigorously design course on the same design of an absorption column or a design of a distillation column, that is a economy you are going to address it separately.

Here in the mass transfer, we have seen the effect of the slope of the curve or does the slope of the curve L s by G s, effects the height of the column or effects the parameters like the liquid solvent flow rate or there heat spent liquor concentrations. Now very often, it happens that when you have this spent liquors, you are not going to dispose just like this, because there will be environmental regulations, that is spent liquor one has to recover, and one can make use, one should make use of certain useful products, for example, if we get some certain concentrated sulphuric acids, one or calcium sulphate you know, one can make certain crystal sort of it.

It is a desirable that we have liquid effluent concentration which is large, that is also for a mass transfer process, one will like to strip it, so for a stripping or for desorption that concentration should also be a large, that we have larger driving force and we have a smaller desorption column, just opposite of this. So, the economy plays a major role here, it is a not one requires that some kind of programming to address these issues one by one.

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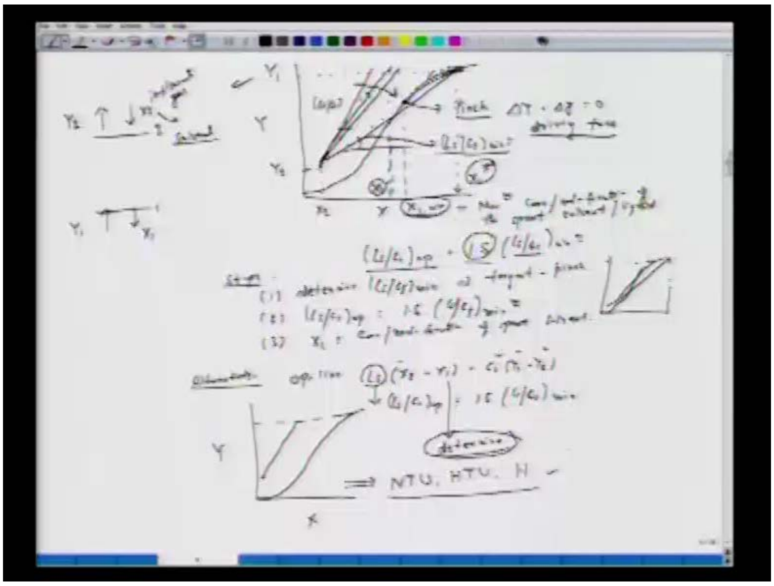

There is one more thing here, which must address before we end this lecture here. We redraw equilibrium curve, so let us say that we have Y versus X, and the shape of the curve is s shape. So it is let us say, it is like this; now let us mark the coordinates here, so, we have Y 1, this is the concentration of or the mole fraction of influent gas, we are looking at one and two levels here, gas gets in. So, let us make it this is two here this is one, let us make it one here, and two here, so we have Y 1 - concentration of incoming gas, Y 2 is a concentration or mole fraction of the treated gas, we have the liquid getting in here solvent, so the mole fraction or the concentration is X 2, and this spent solvent leaves from here, with the concentration or mole fraction X 1 here.

We have Y 1 here, and this is the Y 2 let us mark it here Y 2, and corresponding to this coordinate we have this X 2. So, the mole fraction or the concentration of that solvent; this X 2 is concentration of solvent here. Now, what we have to do is to find out, if we have a general operating curve, then we will have the operating line, something like this, with the slope here as L s by G s.

Now in this case, when the shape of the curve is like S shape here, then we have to be careful in the sense that from here, we have to draw a tangent like this to this curve here. In other words we can see that there is a pinch here, where the driving force for mass transfer del Y or small del Y, this has become 0 here. So, the driving force is 0 here, and we require infinitely long column here. So, the idea here is that the corresponding to this pinch, what concentration we will get here, as you know X 1 that will be X 1 mean, so, this is the maximum concentration or mole fraction of spent solvent. This is the maximum concentration or the mole fraction of the spent solvent here or the spent liquid.

If we take the slope here, this will correspond to L s by G s many more. In other words, if we decrease the liquid, amount or liquid flow rates, then the curve will move in this direction, thus operating line will move in this direction till it makes a tangent here. If we try to connect this point Y 2 X 2, with all the way till here, where this curve has intersected this Y 1 line, this will give here on less or wrong result here. So this has to be discarded. Instead of this one has to find a tangent, which will give you X mean. Once we know this L s G s Y mean, then we can write L s by G s operating equal to may be 1.5 or 1.2 times this should be prescribed L s by G s minimum.

Once we get this minimum solvent, so then you find 1.5 times, find a new operating curves, which would be anywhere like this here. So, average strategy is straightforward steps or a straightforward one first determine L s by G s mean from tangent, what we call pinch. We must be careful, first we should inspect and see the shape of the curve, which is like S shaped. So, in this case somewhere here there will be a tangent, if you try to connect right from here with this point like this that will give you a wrong result here.

First give this L s by G s mean find the tangent point number two point, L s by G s operating equal to 1.5 for example, L s by G s mean. Then from this once we get the operating curves L s like this from here, we can get X 1, which is the concentration or the mole fraction or the mole fraction of spent solvent. Alternatively, we can write down the operating line equation L s X 2 minus X 1, we have done this earlier G s Y 1 minus Y 2, so G s is given Y 1 Y 2 are given, L s we have found out from L s by G s operating, which we found out from 1.5 times minimum L s by G s minimum.

We know here L s, we know X 2, we can determine X 1. So idea is that X 1 concentration of this spent solvent can be determine graphically, from reading here or we can determine from the equations. Once we have this operating line Y versus X, we have this equilibrium curve here, and we have this operating line, then we can answer N T U we can determine, what is the N T U we can determine, height of a transfer unit or the height of this column, so we end today’s lecture right here. Thank you.