Upstream LNG Technology
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Lecture – 57
Fundamentals of absorption and stripping for natural gas processing

Welcome. After learning about some of the processes, which are used to remove the impurities from the natural gas, in this lecture, we shall be learning some fundamentals about the processes like absorption and stripping, which are used for some of this processing of the natural gas. So, this lecture concerns on the Fundamentals of absorption and stripping for natural gas processing.

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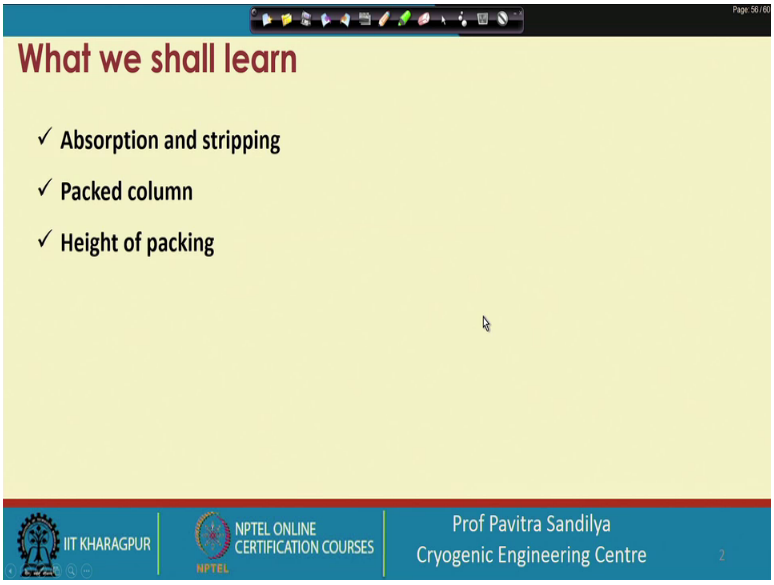

What we shall learn

- ✓ Absorption and stripping
- ✓ Packed column
- ✓ Height of packing

And in this, we shall be learning about absorption and stripping; so, packed column in which such kind of processor done; and the how to find out of the height of the packing, which is a part of the design of the packed columns.

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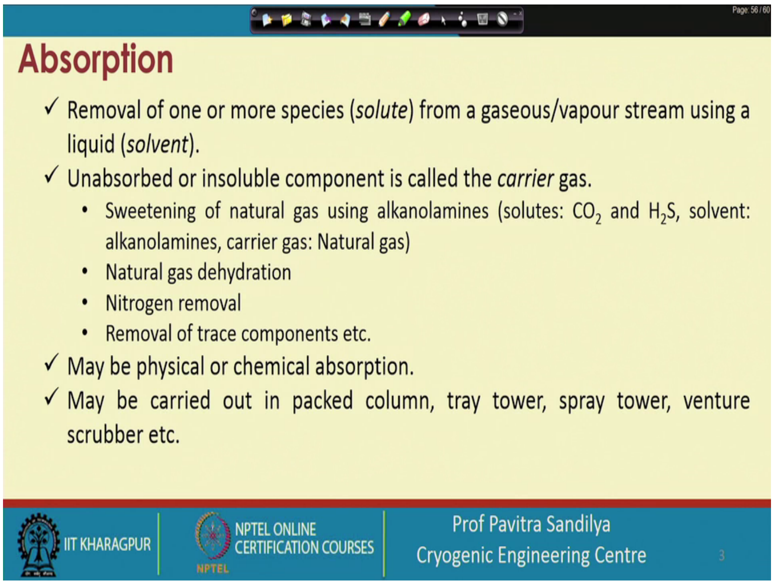

Absorption

✓ Removal of one or more species (*solute*) from a gaseous/vapour stream using a liquid (*solvent*).

✓ Unabsorbed or insoluble component is called the *carrier* gas.

- Sweetening of natural gas using alkanolamines (solutes: CO_2 and H_2S, solvent: alkanolamines, carrier gas: Natural gas)
- Natural gas dehydration
- Nitrogen removal
- Removal of trace components etc.

✓ May be physical or chemical absorption.

✓ May be carried out in packed column, tray tower, spray tower, venture scrubber etc.

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Now, let us first see what is absorption. Absorption means to remove one or more species, which are called solute from a gaseous or vapour stream using some liquid, and the liquid is called the solvent. So, in this absorption, what we have that one this species, which have to be absorbed will be carried in a gas stream. And, it is assume that the gas stream contains other components, which are unabsorbed or insoluble in the liquid, and that is why the rest of the gas other than the species, which is or are getting absorbed is called the carrier gas. So, carrier gas carries the various species, which need to be separated by absorption.

There are several examples of absorption processes, which we have already seen. For example sweetening of natural gas in this, we can say the solute is carbon dioxide, and H 2 S. The solvent is some kind of amine, and the carrier gas is natural gas, that is you are assuming that other than carbon dioxide into H 2 S, no other component is getting dissolved or absorbed by the solvent. Then we have the dehydration of natural gas; removal of nitrogen from natural gas; then removal of some trace components natural gas, and there are many other processes, which involve the absorption.

The absorption may be physical or chemical, and we shall be concerned in this particular lecture only on the chemical absorption that we shall not be considering any reaction, but whatever we are learning they can be easily extended for chemical reacting species too.

And these absorption may be carried out in packed columns, like tray tower, spray tower, venture scrubber etcetera.

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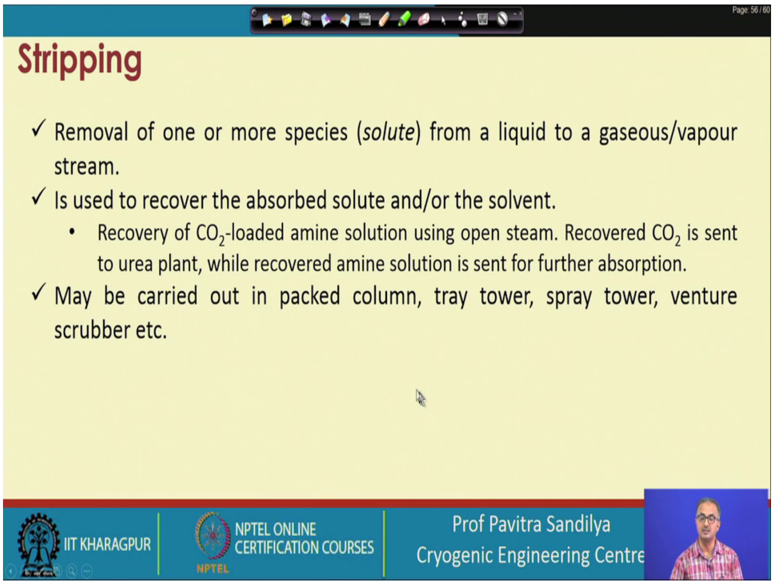

Stripping

- ✓ Removal of one or more species (*solute*) from a liquid to a gaseous/vapour stream.
- ✓ Is used to recover the absorbed solute and/or the solvent.
    - Recovery of CO_2-loaded amine solution using open steam. Recovered CO_2 is sent to urea plant, while recovered amine solution is sent for further absorption.
- ✓ May be carried out in packed column, tray tower, spray tower, venture scrubber etc.

Stripping is the reverse process of absorption. In this case, now one or more species again the solute is removed from a liquid to a gaseous or vapour stream. So, in this, this kind of stripping is done to recover the absorb solute or to regenerate the solvent. And example is which we have seen that, when we are absorbing carbon dioxide in amine, so to regenerate the amine and to recover the carbon dioxide, we use the stripping, and the agent with which it is done is the hot steam. And this again may be carried out in some packed column, tray towers, spray tower, etcetera.

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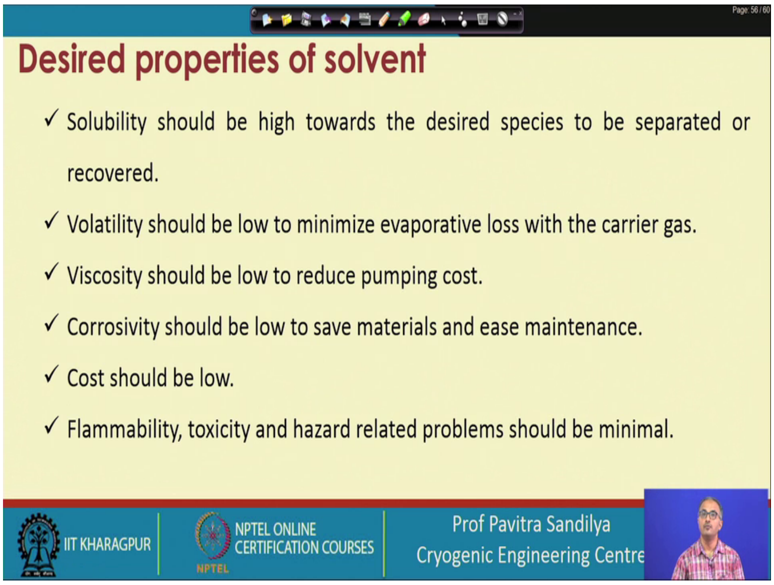

Desired properties of solvent

- ✓ Solubility should be high towards the desired species to be separated or recovered.
- ✓ Volatility should be low to minimize evaporative loss with the carrier gas.
- ✓ Viscosity should be low to reduce pumping cost.
- ✓ Corrosivity should be low to save materials and ease maintenance.
- ✓ Cost should be low.
- ✓ Flammability, toxicity and hazard related problems should be minimal.

Now, we see what are the desirable properties of the solvent. The first is the solubility. Now, the solubility of the solvent has to be high towards the desired species to be separated and it that means it should be there many many species may get absorbed, but it should have highest solubility towards the desired species that was should be it should be selective. Then it should have very low volatility, because if it is very volatile, it will be evaporating easily, and it will be going along with the carrier gas that will be resulting in the loss of the solvent. So, we want low volatility of the solvent.

Then it should be having lower you know viscosity, because high viscosity would mean the cost of it is pumping will be high. It should not be very corrosive, because if it is very corrosive, it will be difficult to maintain; And the materials which are coming in touch with the solvent, we will get corroded easily. And it should be costing low it should be cheap. And it should not pose any kind of hazard due to flammability, toxicity, and to the environment. So, these are some of the properties based on, which we select the solvent, and there would be some kind of trade of among these properties.

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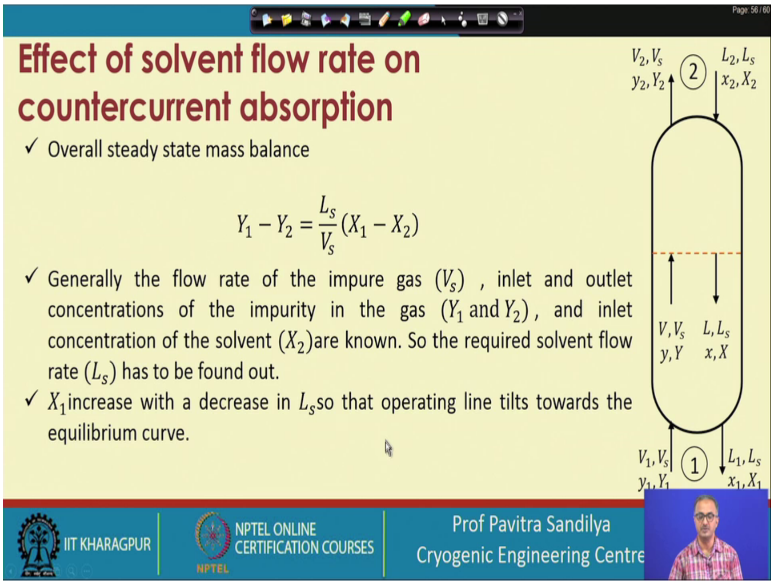

Effect of solvent flow rate on countercurrent absorption

- ✓ Overall steady state mass balance

$$Y_1 - Y_2 = \frac{L_S}{V_S}(X_1 - X_2)$$

- ✓ Generally the flow rate of the impure gas (V_S), inlet and outlet concentrations of the impurity in the gas (Y_1 and Y_2), and inlet concentration of the solvent (X_2) are known. So the required solvent flow rate (L_S) has to be found out.
- ✓ X_1 increase with a decrease in L_S so that operating line tilts towards the equilibrium curve.

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Now, here comes the typical absorption problem in a (Refer Time: 05:00) bid. So, it is see that what will happens if we change the solvent flow rate this particular equation, we have seen earlier in the multistate process only difference is this. In this case the L phase, which we called earlier the lighter phase is now heavier phase, if now is the liquid phase. Whereas the V phase, which was earlier the lighter phase is the vapor phase.

So, L is the liquid; and V is the vapor. And the nomenclatures are there, which we learned earlier in the multistate processes. And this is the overall material balance for the whole setup. Here, we have taken the whole column as our control volume. And, what we find that the flow rate of impure gas that is V S, the inlet and outlet concentrations of the impure gases that is Y 1 and Y 2 is Y 1, Y 2, V S are generally; and the X 2 that is that the inlet concentration of the lean solvent is are given.

So, we know this, we know this and this desired, how much that means Y 1, Y 2 means how much species have to be separated that is to be prescribed by the user. And the amount that is throughput of the particular vapor stream from, which we need to absorb, will also be specified. So these are all known so Y 1, Y 2, V S and X 2 unknown. So, only unknowns are L S and X 1. So, we see that if we decrease the value of the L S what happens, we find that X 1 increases from this equation X 1, increases you can decrease in the value of the L S.

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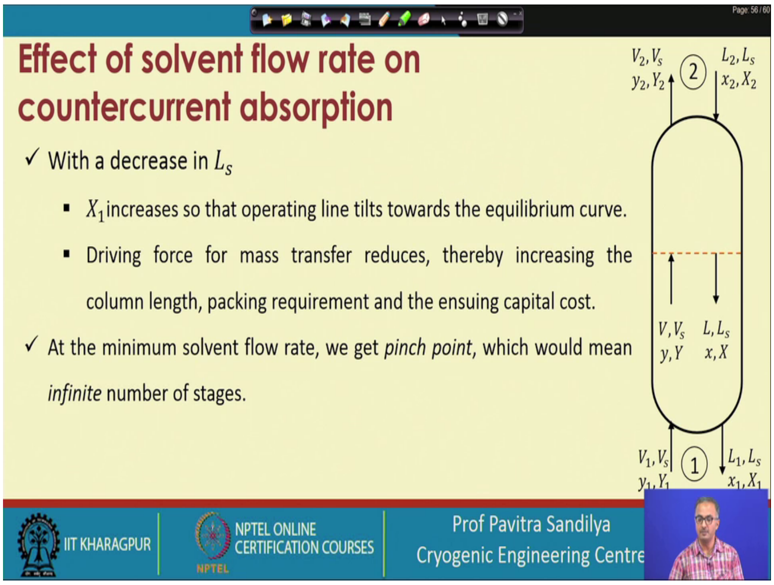
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Effect of solvent flow rate on countercurrent absorption

- ✓ With a decrease in L_s
  - X_1 increases so that operating line tilts towards the equilibrium curve.
  - Driving force for mass transfer reduces, thereby increasing the column length, packing requirement and the ensuing capital cost.
- ✓ At the minimum solvent flow rate, we get *pinch point*, which would mean *infinite* number of stages.

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Now, that means if I look from the point of view of the operating line, what we find that with decrease in the L S. X 1 increase, so that operating line tilts toward the equilibrium curve. And the driving force for mass transfer reduces, thereby increasing the column length, packing requirement and ensuing capital cost.

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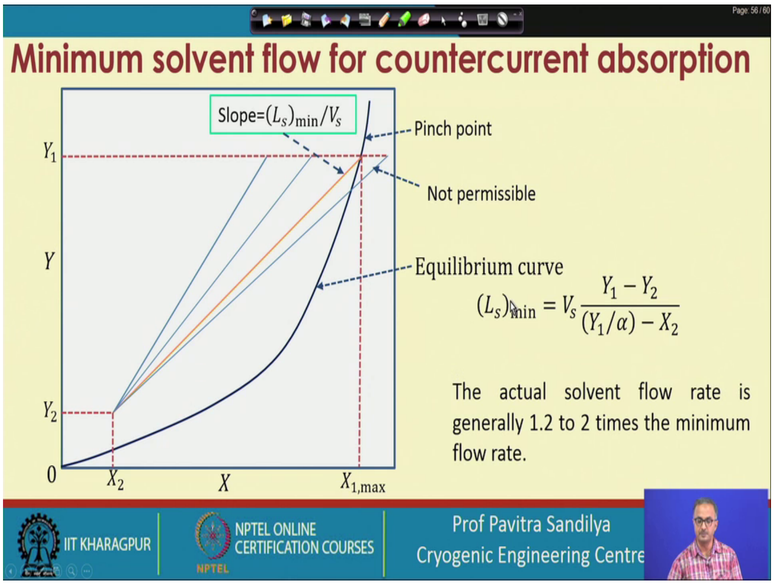
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Minimum solvent flow for countercurrent absorption

$$(L_s)_{\min} = V_s \frac{Y_1 - Y_2}{(Y_1/\alpha) - X_2}$$

The actual solvent flow rate is generally 1.2 to 2 times the minimum flow rate.

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So, this can be easily seen from this particular figure that if we keep decreasing the L S, we find that this is operating line, this is the equilibrium curve, it is operating line shifts towards the equilibrium curve. And that means the difference between this two concentrations on the operating line, and the equilibrium curve that is driving force that keeps decreasing. And the, if the driving force decreases, we with the size of the column for a given separation will also tend to increase. And ultimate what we will find this operating line touches the equilibrium line.

So, here we have kept the Y 1 constant, so we find that ultimately it touches the equilibrium curve. And when it touches it, we call that this particular thing, because it is a pinch point. So, at the pinch point, what we find that that this particular at this pinch point, you will find that this has been wrongly shown in this figure. This is not the curve, this particular points the pinch point. So, at this pinch point, we find that there will not be any more separation possible, because there is no driving force. But, whatever is the maximum concentration is this, this is the X 1 max that means, we can go only up to this much separation. And for this much concentration that is a maximum concentration of the particular solute in the solvent that is the X 1 max.

So, we can find out from the mass balance equation, the minimum value of the liquid, liquid this is the in solute free basis. So, this is found that we are finding this a value; and this Y 1 by alpha; alpha is the equilibrium constant; Y 1 is this value. So, this X 1 max is equal to Y 1 by alpha; so this X 1 max has been taken as Y 1 alpha; so this is the value of the minimum liquid flow rate. So, actual solvent flow rate should be about 1.2 to about 2 times the minimum flow rate, this is a general convention.

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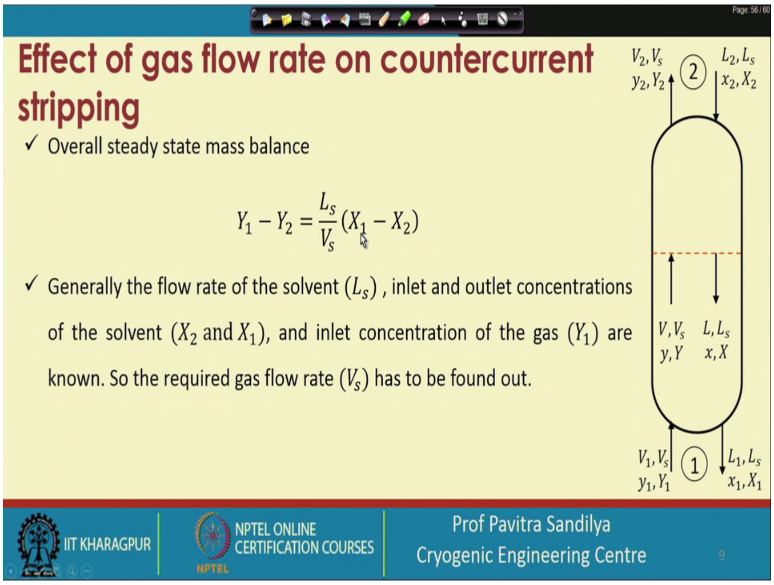

Effect of gas flow rate on countercurrent stripping

- ✓ Overall steady state mass balance

$$Y_1 - Y_2 = \frac{L_s}{V_s}(X_1 - X_2)$$

- ✓ Generally the flow rate of the solvent (L_s), inlet and outlet concentrations of the solvent (X_2 and X_1), and inlet concentration of the gas (Y_1) are known. So the required gas flow rate (V_s) has to be found out.

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Now, similar analysis can be done on the stripping also. In this case, the process is reverse that means we are trying to take the solute from the liquid back to the vapor. And this vapor is as I said maybe some kind of steam in case of amines, which are used for the absorption of the carbon dioxide and H 2 S.

Now, again we write this same equation. In this case, what you find that now the liquid flow rate that is the solvent flow rate will be given to us. And so will be the outlet and inlet composition of the solvent, because this inlet composition corresponds to the so to the rich solvent flow rate. And X 1 is that after taking out the solute from the solvent, what is the amount remaining in the solvent. And in this case, we find that the inlet concentration of a gas will be also given to us with which we are doing the stripping, and we have to find out the outlet concentration of the gas and the V S.

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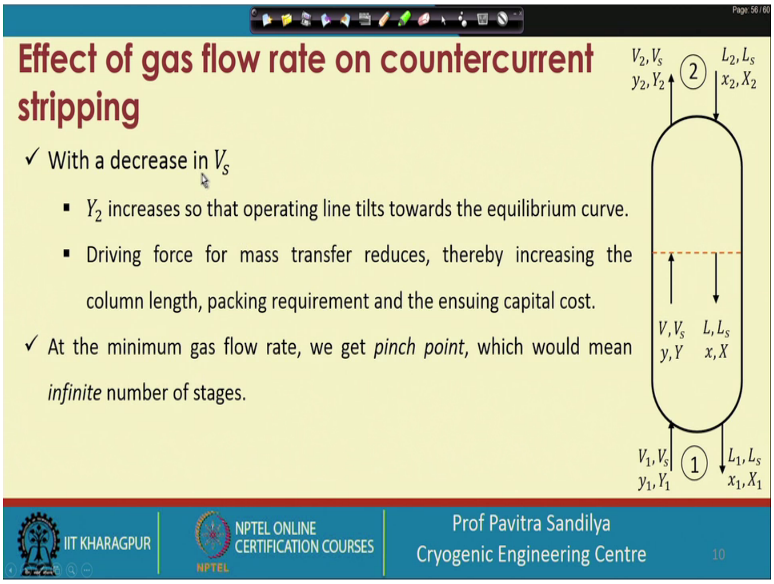

Effect of gas flow rate on countercurrent stripping

✓ With a decrease in V_s

- Y_2 increases so that operating line tilts towards the equilibrium curve.
- Driving force for mass transfer reduces, thereby increasing the column length, packing requirement and the ensuing capital cost.

✓ At the minimum gas flow rate, we get *pinch point*, which would mean *infinite* number of stages.

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So, here also if we find that, if we decrease the value of V S that is the vapor flow rate, then we find that Y 2 increases, so that again operating line tilts towards the equilibrium curve. So, here we can again see from this particular in thing that here our X 2 is given constant, and these are the operating lines. And as we know in this case for the stripping, the operating line will be lying below the equilibrium curve. So, what we find if we draw various operating lines on which are meeting at this particular X 2 value, we find when ultimately the operating line which touches the equilibrium points that is the pinch point.

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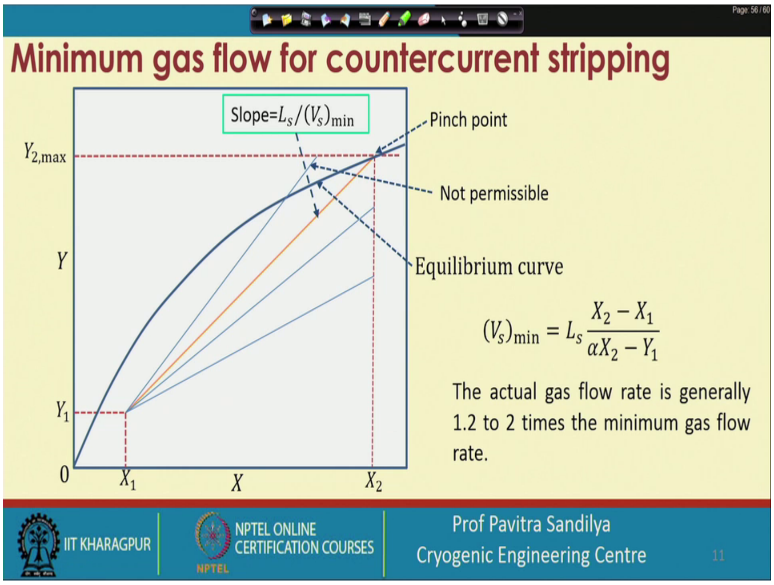

Minimum gas flow for countercurrent stripping

$$(V_s)_{\min} = L_s \frac{X_2 - X_1}{\alpha X_2 - Y_1}$$

The actual gas flow rate is generally 1.2 to 2 times the minimum gas flow rate.

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And corresponding to that whatever value maximum value of the Y 2 we find, so this is the maximum possible, separation possible by the particular vapor steam. And naturally we cannot in neither in case of stripping or case of absorption, we can cross these equilibrium curve. Because, crossing means there will be reverse mass transfer that means it will not be any more stripping, it will like an absorption, so we cannot cross this we have to stop here. So in this case also, we can find out the value of the minimum vapor fluid from this equation. In this case this Y 2 is nothing but the alpha into X 2. And similarly, in this case also the actual gas flow rate may be taken 1 2, 1.2 to 2 times the minimum gas flow rate.

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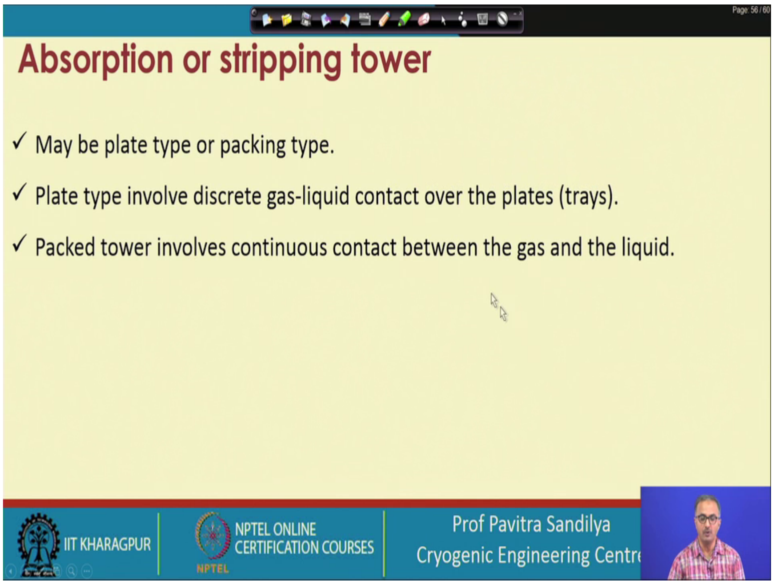

Absorption or stripping tower

- ✓ May be plate type or packing type.
- ✓ Plate type involve discrete gas-liquid contact over the plates (trays).
- ✓ Packed tower involves continuous contact between the gas and the liquid.

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Now, let us see that what is the way to carry out this absorption? Generally, this absorption or stripping is carried out in some kind of plate or packing the tower. And the plate type involves that discrete gas-liquid contact over the plates or the trays. Whereas, in of in case of packed column, we find that that there is a continuous contact between the gas and the liquid, as these two phases flow in the column.

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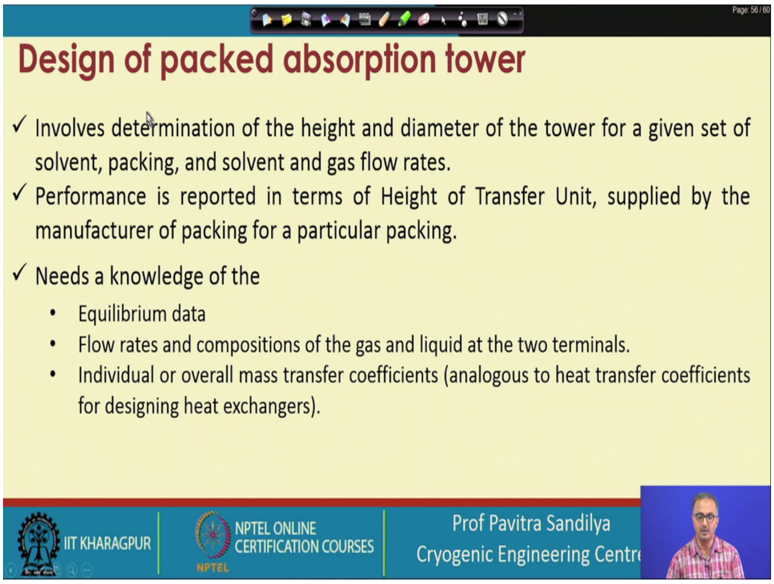

Design of packed absorption tower

- ✓ Involves determination of the height and diameter of the tower for a given set of solvent, packing, and solvent and gas flow rates.
- ✓ Performance is reported in terms of Height of Transfer Unit, supplied by the manufacturer of packing for a particular packing.
- ✓ Needs a knowledge of the
  - Equilibrium data
  - Flow rates and compositions of the gas and liquid at the two terminals.
  - Individual or overall mass transfer coefficients (analogous to heat transfer coefficients for designing heat exchangers).

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Now, here we are have the design basis. In this design of the packed absorption column tower, what we generally do that, it involves determination of the height and diameter of the tower for a given set of solvent, packing, solvent and gas flow rates. So, given some kind of packing, some kind of solvent, and some flow rates of the solvent and the gas, we need to know the height and diameter of the tower. And performance is generally reported in terms of height of transfer unit, which we shall be looking into later. And this height of transfer unit is generally supplied by the manufacturer of the packing.

Then to find out this to do the design of the packed tower, we need to know the equilibrium behavior. The flow rates and compositions of the gas and liquid at the two terminals that was top and bottom and the individual or overall mass transfer coefficients, these mass transfer coefficients or analogous to the heat transfer coefficients, which are used for the designing of the heat exchangers.

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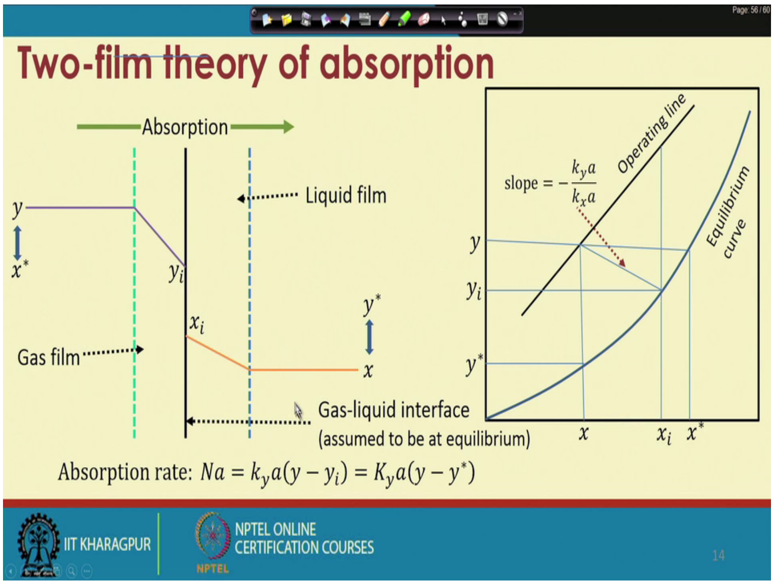

Two-film theory of absorption

Absorption rate: $Na = k_y a(y - y_i) = K_y a(y - y^*)$

So, let us now see the two-film theory of absorption. In this what we say that there is an interface, which is the imaginarily line of separation between the two phases, which is represented here by a black straight line. And this particular interface on both the sides of the interface, there are two fictitious film on the gas side, we have a film. In this particular film, we assume that the total resistance to the mass transfer in the gases phase is confined, that is outside the film there is no resistance to the mass transfer.

Similarly, on the liquid side also, we have a fictitious film; within this film the total resistance to mass transfer is confined; and outside this film there is no resistance to the mass transfer. And what happens that due to there is no resistance. So, the bulk concentration, remains same throughout the gas side up to the film. And then on the same thing happens on the liquid side also that the concentration of the particular solute remains same throughout the bulk up to the film. But, within the film due to resistance to mass transfer, there is a fall in the particular concentration of the particular solute.

And when it is absorption, the solute is coming from the vapor side or gas side to the liquid side, so that the bulk concentration in the gas is more than the concentration, we find at the interface. And once it comes to interface, it attains the concentration of y i. And after y i there is we assume that the interface is always at equilibrium, so that there will be a corresponding concentration of the solute for the liquid side. So, x i represents a corresponding concentration the solute in equilibrium with y i. And this from x i again this the concentration falls up within the film due to resistance in the film, and attains the value of the bulk concentration. So, this is how we take the two-film theory for the absorption.

This film theory is an assumption, but it I am simplifies the analysis of the absorption problem. And the rate of absorption is given like this that in this N is the mass flux, and a is the specific surface area of the packing. This is equal to this k y a y minus y i that is from this to this from this y to y i, and this is k y is the mass transfer coefficient in the gases side. And the resistance to this is reciprocal of this k y. And this is also given in terms of some overall k y overall gas side coefficient the, it is similar to the overall heat transfer coefficient. And, now in this case, we have y minus y star, now y star is shown here. This y star is the value of the gas side concentration in equilibrium with the bulk solute concentration.

Now, this whole thing can be put in this graphically here. Now, here we find that if we consider a binary system, we can put on this kind of a graph. Here, we see that on this x axis, we are plotting the liquid side mole fraction, on the y axis we have plotting the vapor side or gas side mole fraction. And here, which is assume this is the equilibrium curve, and here that is assume this is the operating line.

So, at any given point on the operating line, we have the value of x, and we have the value of y, corresponding to this x, and this y. And then this because this x i, y i at in equilibrium. So, this x i, y i will be somewhere on the equilibrium curve. And, how to find out this without going to detail of the theory, what we do that from this point of x y, we draw a line with a slope of minus k y a by k x a up to the equilibrium curve.

So, wherever this line with this slope touches the equilibrium curve from there, we find out the value of the x i and y i. And this y star is in equilibrium with x. So, what we do from x, we draw up to the equilibrium curve, and whatever is the value of the y here that is the y star. Similarly, in case of the gas side we have them x star, which is in equilibrium with the bulk value of the y. And here similar is the what we do this y value we extend up to the equilibrium curve, and correspondingly find the value of the x star from the equilibrium curve, so that is how we locate all the values x, xi, x star; and y, y i, y star. So, in this case, we are putting the mass rate in terms of this difference y and y i; and y and y star. So, depending on which is the driving, which driving force we are using, whether it is y minus y i or y minus y star, we shall be having different types of the coefficients.

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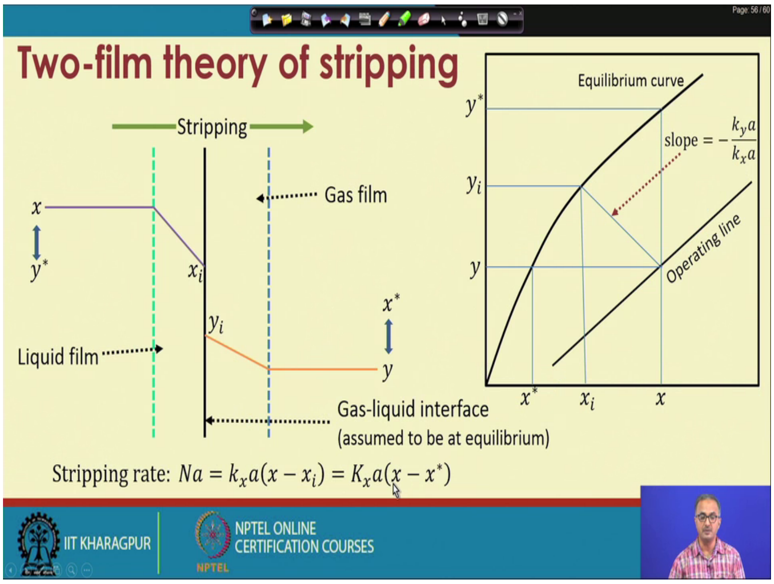

Two-film theory of stripping

Stripping rate: $Na = k_x a(x - x_i) = K_x a(x - x^*)$

The similar film theory may be used for the stripping also. Now, in this case, the situation reversed. In this case, we have the liquid side here, gas side here. Again we see that the this is the bulk constitutional solute in the liquid, which is remaining same up to the film and then falling within the liquid film. And then it there is a corresponding value of the y i in at the interface, which is the again falling within the film, and going to the bulk concentration. And again, we have this x star and y star.

But, in this case when we represent graphically, we find this is the equilibrium curve, this is the operating line. And similar to what we learned earlier, we first figure out x y, and we draw a line with the slope of minus k y a by k x a wherever, it touches this equilibrium curve from there, we can read the value of the x i and y i. And if we extend this line up to the equilibrium curve, we get the value of y star. And, if we extend these value from y equilibrium curve, we get the value of the x star. So, here we find that we can from this particular graph we can locate the value of the various concentrations. And here is the stripping rate that this is in given in terms of x minus xi for if it is x minus xi, then we are using k x the liquid film mass transfer sufficient. If we are using x minus x star then, we are using the overall mass transfer coefficient based on the liquid side.

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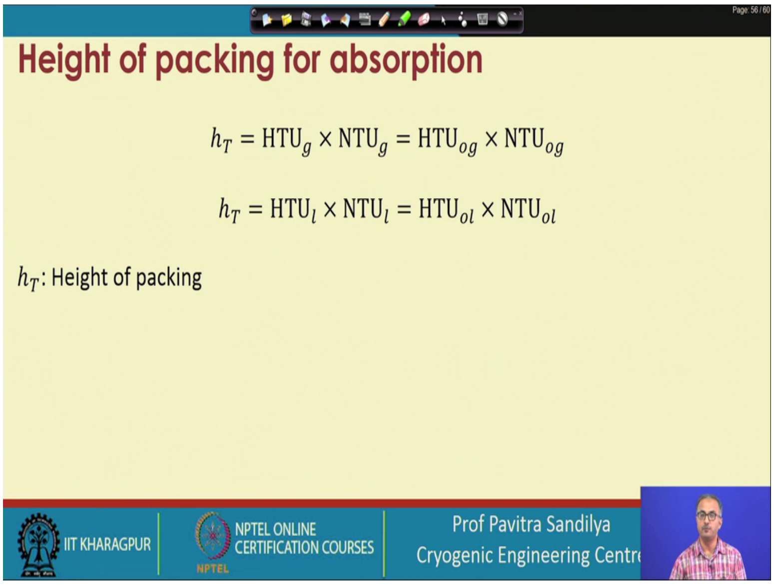

Height of packing for absorption

$$h_T = \mathrm{HTU}_g \times \mathrm{NTU}_g = \mathrm{HTU}_{og} \times \mathrm{NTU}_{og}$$

$$h_T = \mathrm{HTU}_l \times \mathrm{NTU}_l = \mathrm{HTU}_{ol} \times \mathrm{NTU}_{ol}$$

h_T: Height of packing

Now, to find the height of the packing again without a derivation, we are seeing the formula to be used that whether we can put in terms of HTU g into NTU g, we shall be looking into their expressions bit later or in terms of HTU o g and into NTU o g. And similarly, we can also based in terms of the liquid size HTU l NTU l, and HTU o l and NTU o l. So, this HTU is the height of transfer unit; N is the number of transfer units.

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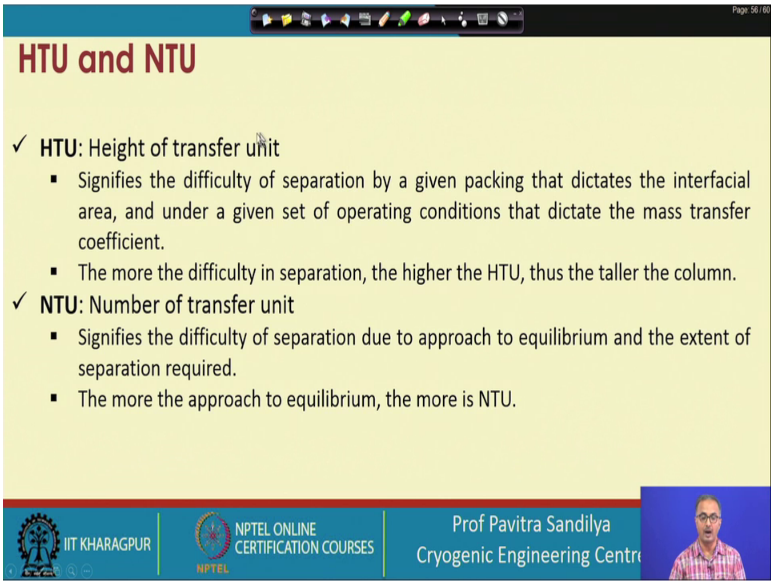

HTU and NTU

- ✓ **HTU**: Height of transfer unit
  - Signifies the difficulty of separation by a given packing that dictates the interfacial area, and under a given set of operating conditions that dictate the mass transfer coefficient.
  - The more the difficulty in separation, the higher the HTU, thus the taller the column.
- ✓ **NTU**: Number of transfer unit
  - Signifies the difficulty of separation due to approach to equilibrium and the extent of separation required.
  - The more the approach to equilibrium, the more is NTU.

So, height of transfer unit it signifies the difficulty of separation by a given packing that dictates the interfacial area, and under a given set of operating conditions, mainly the flow rates of the two phases. The more the difficulty in separation, the higher the value of the HTU, and so will be the taller the column.

Similarly, in case of NTU this is the number of transfer units, and this signifies the difficulty of the separation due to approach to equilibrium and the extent of separation required. So, this NTU depends on the equilibrium relationship with, and the bulk concentration, whereas HTU depends on the type of the packing. And the more the approach to equilibrium that is the less the driving force, the more will be the NTU; and the more the NTU that is the taller the column.

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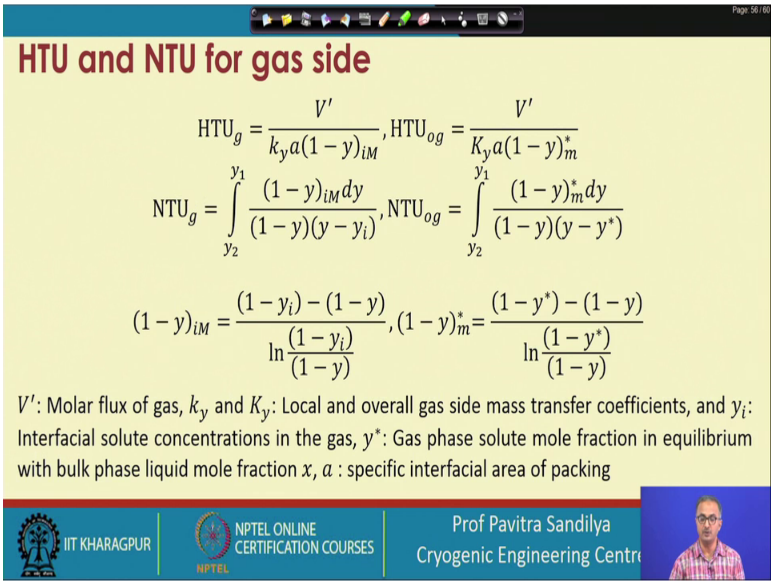

HTU and NTU for gas side

$$\mathrm{HTU}_g = \frac{V'}{k_y a(1-y)_{iM}}, \mathrm{HTU}_{og} = \frac{V'}{K_y a(1-y)^*_m}$$

$$\mathrm{NTU}_g = \int_{y_2}^{y_1} \frac{(1-y)_{iM}dy}{(1-y)(y-y_i)}, \mathrm{NTU}_{og} = \int_{y_2}^{y_1} \frac{(1-y)^*_m dy}{(1-y)(y-y^*)}$$

$$(1-y)_{iM} = \frac{(1-y_i)-(1-y)}{\ln\frac{(1-y_i)}{(1-y)}}, (1-y)^*_m = \frac{(1-y^*)-(1-y)}{\ln\frac{(1-y^*)}{(1-y)}}$$

V': Molar flux of gas, k_y and K_y: Local and overall gas side mass transfer coefficients, and y_i: Interfacial solute concentrations in the gas, y^*: Gas phase solute mole fraction in equilibrium with bulk phase liquid mole fraction x, a : specific interfacial area of packing

Now, again without derivation these are the various expressions for the NTU and HTU. We shall not be going to this is the derivations ok. And we shall be looking into a the simpler version of these ones. So, these are the simple version of this, we find that these are the ways, we can find out the HTU, NTU from here. This is the overall gas side HTU, this is the with the individual HTU. Similarly, based on the liquid side also, we can find out these equations.

And here, we have this y, 1 minus y these are kind of some these are some kind of the driving forces. So, here we have find that these are the expression for the HTU and NTU g; and HTU o g and NTU o g. Here, we find that the V represents the molar flux of the gas; and k y K y and it is capital K y the local and overall gas side mass transfer coefficient; y i is the interfacial solid concentration; y star is the gases phase solute mole fraction in the equilibrium with the bulk phase liquid mole fraction x; and a is the specific interfacial area. All these things we have already seen in the in the graphical representation, and these are the expressions for the NTU.

So, what we find here that HTU decreases with an increase in the mass transfer coefficient; with an increase in the specific surface area; and with an increase in the with a decrease in the flow rate. So, all these things are to be seen to find out the value of HTU. And we have to always try to minimize the HTU, that the less the HTU the more effective is the packing. But, in case of NTU, we find that this basically depends on the approach to equilibrium between the bulk concentration, and the interfacial concentration, and the how much separation is needed.

So, this 1 minus y i M that is given by this logarithmic concentration difference and this y 1 minus y star m, which is used here is given by this particular expression. So, these are representing the logarithmic mean driving force as it is similar to analogous to the LMTD, which we use in the heat transfer.

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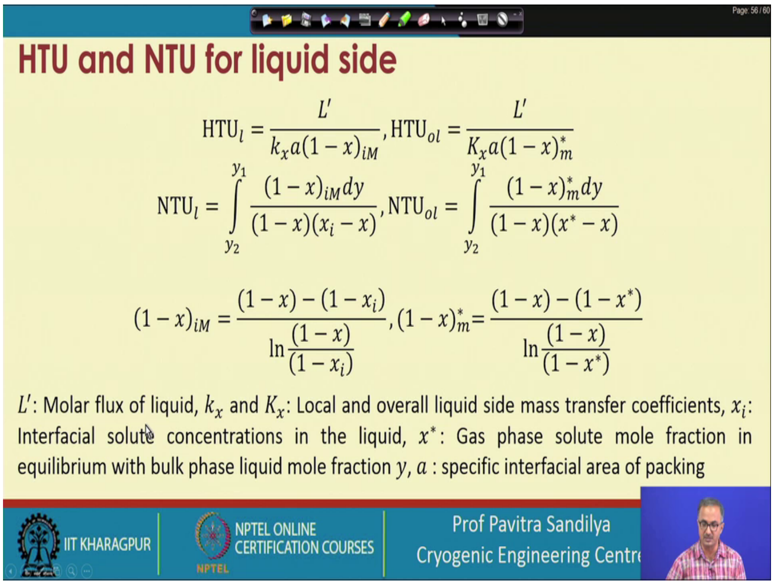

HTU and NTU for liquid side

$$\mathrm{HTU}_l = \frac{L'}{k_x a(1-x)_{iM}}, \mathrm{HTU}_{ol} = \frac{L'}{K_x a(1-x)^*_m}$$

$$\mathrm{NTU}_l = \int_{y_2}^{y_1} \frac{(1-x)_{iM} dy}{(1-x)(x_i - x)}, \mathrm{NTU}_{ol} = \int_{y_2}^{y_1} \frac{(1-x)^*_m dy}{(1-x)(x^* - x)}$$

$$(1-x)_{iM} = \frac{(1-x)-(1-x_i)}{\ln\frac{(1-x)}{(1-x_i)}}, (1-x)^*_m = \frac{(1-x)-(1-x^*)}{\ln\frac{(1-x)}{(1-x^*)}}$$

L': Molar flux of liquid, k_x and K_x: Local and overall liquid side mass transfer coefficients, x_i: Interfacial solute concentrations in the liquid, x^*: Gas phase solute mole fraction in equilibrium with bulk phase liquid mole fraction y, a : specific interfacial area of packing

Now, this is on the liquid side these are analogous to the HTU, NTU expressions for the gas side here, we replace all the mass transfer coefficients for the gas side with respect to the liquid side mass transfer coefficients. So, I will not be going into the detail of this expressions.

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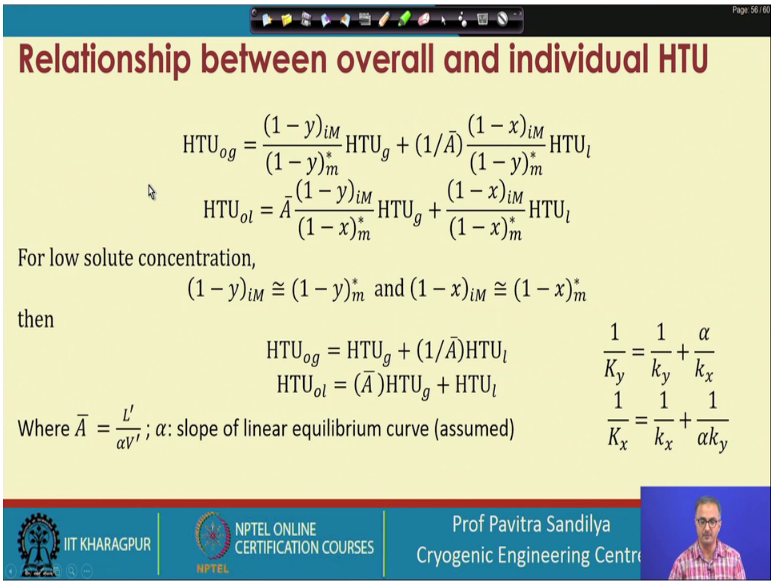

Relationship between overall and individual HTU

$$\mathrm{HTU}_{og} = \frac{(1-y)_{iM}}{(1-y)^*_m}\mathrm{HTU}_g + (1/\bar{A})\frac{(1-x)_{iM}}{(1-y)^*_m}\mathrm{HTU}_l$$

$$\mathrm{HTU}_{ol} = \bar{A}\frac{(1-y)_{iM}}{(1-x)^*_m}\mathrm{HTU}_g + \frac{(1-x)_{iM}}{(1-x)^*_m}\mathrm{HTU}_l$$

For low solute concentration,

$$(1-y)_{iM} \cong (1-y)^*_m \text{ and } (1-x)_{iM} \cong (1-x)^*_m$$

then

$$\mathrm{HTU}_{og} = \mathrm{HTU}_g + (1/\bar{A})\mathrm{HTU}_l$$

$$\mathrm{HTU}_{ol} = (\bar{A})\mathrm{HTU}_g + \mathrm{HTU}_l$$

Where $\bar{A} = \frac{L'}{\alpha V'}$; α: slope of linear equilibrium curve (assumed)

$$\frac{1}{K_y} = \frac{1}{k_y} + \frac{\alpha}{k_x}$$

$$\frac{1}{K_x} = \frac{1}{k_x} + \frac{1}{\alpha k_y}$$

Ultimately, we can also see that this is the way, we can correlate the overall mass transfer coefficients on the gas side, and the liquid side with the individual gas side, and liquid side mass transfer coefficients. In this case, we have this value of alpha that is the equilibrium constant. And based on this, we can have these expressions to correlate the overall HTU with the individual HTU on the gas, and the liquid side. And this is the overall HTU based on the liquid side. Again this is given in terms of the individual gas side and the liquid side HTU. If the concentration of the solute is low then, we find that these logarithmic mean concentrations with respect to the interfacial and the bulk are almost the same, so that these values these ratios become 1.

So, in this case we can reduce these expressions for the overall HTU like this. And in this case, we have this a at the adjacent factor, which is given by the ratio of l prime by alpha V prime. And this is the adjacent factor. And this 1 minus A over bar is the stripping factor. So, this is how we find out the overall HTU and N HTU values from the individual HTU values, which are again used for the determination of the height of the packing.

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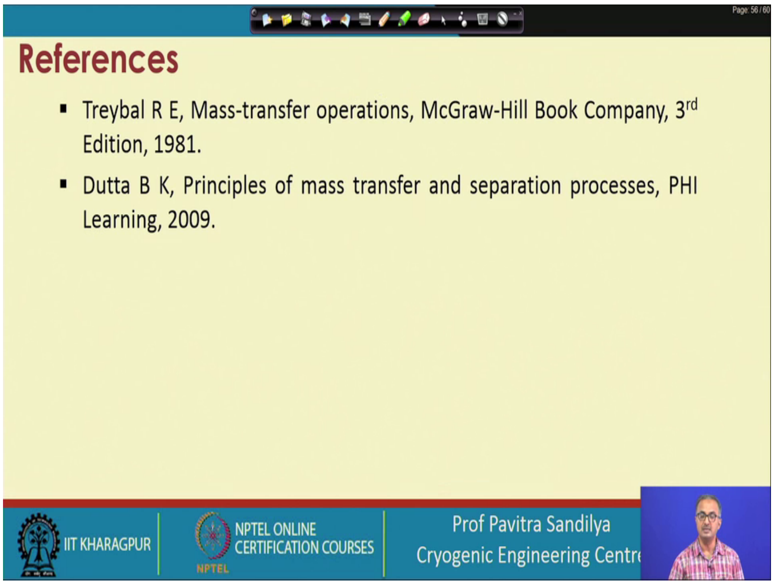

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- Dutta B K, Principles of mass transfer and separation processes, PHI Learning, 2009.

And these are the differences from which you can learn more about the derivations and detail about this theories.

Thank you.