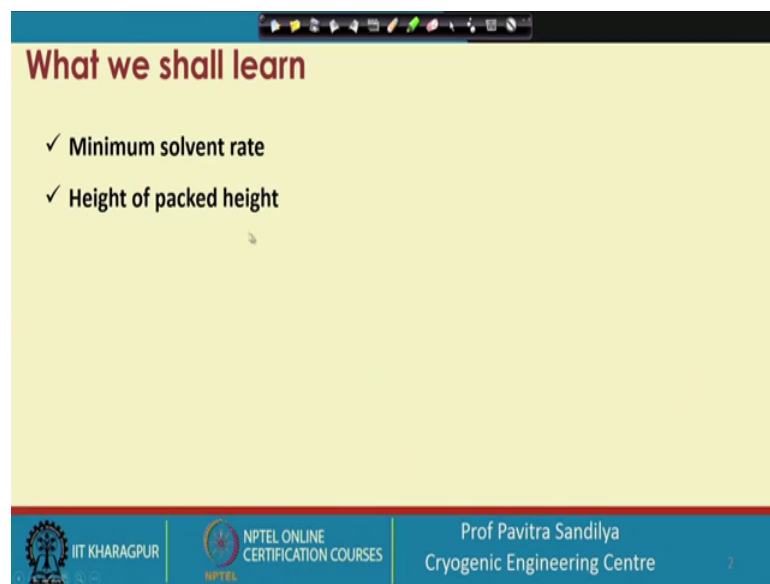


Upstream LNG Technology
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Lecture – 58
Tutorial on absorption and stripping

Welcome after learning about the absorption and stripping and their analysis in this particular lecture we shall be looking into some problems on the absorption and stripping

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The slide is titled "What we shall learn" and lists two bullet points: "✓ Minimum solvent rate" and "✓ Height of packed height". The slide has a yellow background and a blue footer. The footer contains the IIT Kharagpur logo, the NPTEL Online Certification Courses logo, and the text "Prof Pavitra Sandilya, Cryogenic Engineering Centre".

So, what we shall be learning to how to compute the minimum solvent rate and the height of a packed bed.

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Problem Statement 1

✓ In a petro chemical plant, a gas containing 4% cyclo hexane and 96% inerts has to be treated with a non-volatile absorption oil in a packed tower. It is required to remove 98% of the cyclo hexane of the feed gas. The feed solvent is free from cyclo hexane. If the feed gas rate is 80 kmol per hour, calculate the minimum solvent rate. The equilibrium relation is given as

$$Y = \frac{0.2X}{1 + 0.8X}$$



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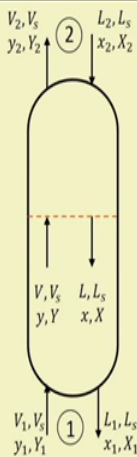
So, let us see the problem one in this we are assuming that, we have some petro chemical plant where the gas contains about 4 percent cyclo hexane and 96 percent inerts this has to be treated with a non volatile absorption oil in a packed tower. And it is required to remove 98 percent of the cyclo hexane from feed gas. And some suitable solvent will be used to remove this cyclo hexane and it is assumed that the solvent is fresh; that means, it does not have any cyclo hexane to start with.

If the feed gas is about 80 kilomole per hour we have to calculate the minimum solvent rate and here we are given the equilibrium relationship in terms of the mole ratio of the particular component in this case cyclo hexane in the vapour phase and liquid phase.



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Solution

$V_1 = 80 \text{ kmol/h}$
 $y_1 = 0.04$
 $Y = \frac{0.2X}{1 + 0.8X}$



X	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1	0.11	0.12
Y	0.000	0.002	0.004	0.006	0.008	0.010	0.011	0.013	0.015	0.017	0.019	0.020	0.022

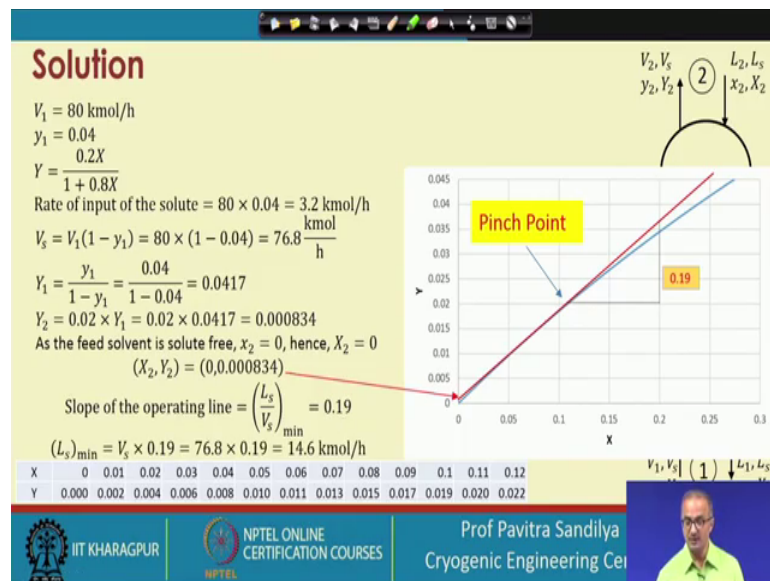
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Now, let us see how to go on analysing this problem. So first let us recapitulate this is the typical packed column packed tower therefore, in this some absorption is going on. So, on this particular thing we are given this V I are given to us that this is the feed which have to be treated and here we are using a solvent. So, we are also given this particular thing so these two information are available to us and here also we are given that how much we want to extract how much cyclo hexane is want to be extracted. So, we also know the outlet concentration of the cyclo hexane in the vapour phase.

So, here we are given the vapour phase flow rate that is V1 as 80 kilomole per hour and this will change from with V1 will be different from this V2 because cyclo hexane has been taken out from this particular vapour phase. So, and this is the mole fraction it is given here and this is the equilibrium relationship in terms of the mole ratio. And if we use this relationship and we put the various values of x it is seen that if we are going from 0 to about 0.12 and corresponding to each x we are having the values of the y.

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And here then we plot this x and y over here in terms of the mole ratio for it is the equilibrium the curve. Now we find that the rate of the solute input is how much it is the y 1 into V1 that is 80 into 0.04 that is 3.2 kilomole per hour of the cyclo hexane is going inside the column with the vapour. And now we find out the cyclo hexane free vapour flow rate that is V1 into 1 minus y 1 it is mentioned in the problem that the rest of the

components can be taken to be inert that means, we are assuming that those components are not being absorbed by the solvent.

So, this is the cyclo hexane free vapour flow rate and this is coming out to 76.8 kilomole per hour and we see that this value has to be less than the total vapour flow rate because in this particular we do not have the cyclo hexane present and this particular flow rate will remain constant throughout the particular column. Now from the given value of the mole fraction we find out the mole ratio from this formula and we find that this is coming out to this value, and once we know this mole fraction we find that Y_2 is equal to the 20 percent is being ejected out that is 98 percent is absorbed.

So, if 20 this 20 percent of this is the this value which is coming out from the column and since the solvent is assumed to be fresh without any cyclo hexane. So, we find that x_2 is equal to 0, so that the mole ratio is also 0. Now what we do we locate the x_2 or X_2 Y_2 on this particular thing and here we find it is located here.

Now, from these equilibrium relationship curve we find that the some kind of a convexity towards the top. So, because of this what we do that we simply draw a line from this thing which will be tangent to this particular curve. And wherever it becomes tangent there we read that means, here we get the pinch point was this this operating line touches the equilibrium curve we get the pinch point.

So, we get the pinch point and for this particular thing we find out the slope of the operating line and this slope will be able to give us the minimum solvent flow rate. So, we find out this particular slope and we know that this slope is L_s by V_s min and this is equals to 0.19 we are given the value of the V_s .

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Problem Statement 2

A gas mixture containing 10 mol% SO₂ and 90 mol% air at 1 atm total pressure and 30°C is to be scrubbed with water to remove 97% of the SO₂ in a tower packed with 25 mm ceramic Raschig rings. The feed gas rate is 1500 kg per hour. Calculate:

- Minimum liquid rate
- Packed height

The equilibrium data is given below.

$x \times 10^4$	0	0.562	1.403	2.8	4.22	8.42	14.03	19.65	27.9
$y \times 10^3$	0	0.79	2.23	6.19	10.65	25.9	47.3	68.5	104

The volumetric mass transfer coefficients are given as:

$$k_x a = 1.25 \frac{\text{kmol}}{\text{m}^3 \text{s} \Delta x}$$
$$k_y a = 0.075 \frac{\text{kmol}}{\text{m}^3 \text{s} \Delta y}$$

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So, once we know the value of the V s we can find the value of the L s that is the minimum flow rate of the solvent. Now, we come to the second problem in this problem we are given a gas mixture with 10 percent, SO₂ and 90 mole percent of air at one atmosphere total pressure at 30 degree centigrade and this has to be scrubbed using water to remove 97 percent of the sulphur dioxide in a tower with a packing which is having a ceramic packing Raschig ring and this is the 25 mm. So, we know that there are different types of packing which are made from different types of material, so in this case we are using Raschig ring and which is made this is of size of 25 million metre.

The feed gas flow rate is about 1500 kg per hour so we are required to calculate the minimum liquid rate and the height of the packing. And here we are given the equilibrium relationship in terms of the mole fractions in the two phases and here we are given the volumetric mass transfer coefficient values for the liquid phase and the vapour phase in terms of kilomole per cubic metre per second and per delta x or delta y is the driving force per unit driving force in the liquid phase and in the vapour phase.

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Problem Statement 2

A gas mixture containing 10 mol% SO₂ and 90 mol% air at 1 atm total pressure and 30°C is to be scrubbed with water to remove 97% of the SO₂ in a tower packed with 25 mm ceramic Raschig rings. The feed gas rate is 1500 kg per hour. Calculate:



- Minimum liquid rate
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Now, we go to solution what we do we first we find out the average molecular weight by summing up the product of the mole fraction and the individual molecular weight. So, we get the this as the average molecular weight of the gas and here we are given the vapour flow rate in terms of kg per hour and we divide it by the molecular weight to get in terms of the kilomole per hour. And then we do what we do we plot this equilibrium curve in terms of the mole ratios capital X and capital Y.

So, we are given the value of the mole fraction in the incoming vapour as 0.1 and so we can find out the value of the mole ratio in the incoming gas as 0.111 and this we find out somewhere it will be located here. Now to find out the minimum flow rate what we do that we first find out that it will be wherever it intersects with this equilibrium curve at this point we have to find out that vapour minimum solvent flow rate we have to find out. So, what we do first we find out the V_s and that is equal to V_1 into $1 - y_1$ this is y_1 and we get this is the value of the 41.7 kilomole per hour. And then we find out that how much sulphur dioxide is entering this is the value of the V_1 into this 0.1 that is the total molar flow rate into the mole fraction.

So, this is the amount of solvent that is going inside and 3 percent of this particular sulphur goes in the outlet. So, this three percent of this particular value is this 0.14 kilomole per hour is coming out from the packed column and 97 percent is getting absorbed that is the rest of the things are getting absorbed by the solvent. Now Y_2 is again given by in terms of the 0.14 divided by the V_s and this is the mole ratio of sulphur dioxide at the outlet of the column and this is located somewhere here because

we are assuming that there is no this solvent is fresh that is there is no sulphur dioxide in the solvent so x_2 is equal to 0.

So, we locate this x_2 y_2 here and then we make a straight line operating line which will be touching the intersection point of this horizontal line from the y_1 . And wherever it intersects from this is the operating line for the minimum solvent flow rate and if we can find out the value of this particular this slope we can get the value of the minimum solvent flow rate. And here we find that we drop a horizontal line from this point of intersection and this will give us the value of the x_1 max that is the highest amount of the sulphur dioxide in the liquid phase and that is coming out to be 0.00272 from this particular graph.

Once we know these Y_1 Y_2 etcetera what we do we now go with the material balance which is same same that Y_1 minus Y_2 divided by X_1 max by X_2 it is the slope of the particular line. So, this is nothing, but the material balance and here from this we can find out the minimum solvent flow rate by plugging the values and this is coming coming out to be this value.

Now the actual solvent flow rate will be more than this and as we learnt earlier it is about 1.25 to 2 times the minimum flow rate. So, here we are assuming that it is about 1.25 times the minimum solvent flow rate and we are getting the actual solvent flow rate on the solute free basis that is the sulphur dioxide free basis has this particular value.

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Solution

Overall material balance

$$V_S \left(\frac{y_1}{1-y_1} - \frac{y_2}{1-y_2} \right) = L_S \left(\frac{x_1}{1-x_1} - \frac{x_2}{1-x_2} \right)$$

$$41.7 \left(\frac{0.10}{1-0.10} - \frac{0.00335}{1-0.00335} \right) = 2069 \left(\frac{x_1}{1-x_1} - \frac{0}{1-0} \right)$$

Solving $\rightarrow x_1 = 0.00217$ (conc of SO_2 at exit)

$$X_1 = \frac{x_1}{1-x_1} = 0.002175$$

$$h = HTU_g NTU_g$$

$$HTU_g = \frac{V}{k_y a}$$

$$NTU_g = \int_{y_2}^{y_1} \frac{(1-y)_M}{(1-y)(y-y_i)} dy = \int_{y_2}^{y_1} f(y) dy$$

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So, once we find that value we make this material balance and now what we do that in this case this V s L s we know now now we are putting back the mole ratios in terms of the mole fractions. And we find that we plugging the values over here we and we find the value of X_1 that is the amount of sulphur dioxide which is actually going with the liquid at the will be about this the mole fraction at the exit of the solvent and from this we can find out the mole ratio of the sulphur dioxide at the solvent exit.

And now we come to the calculation of the height of the packing and here we go with this particular formula that we learnt earlier this is the product of the height of transfer unit of the gaseous phase. And the number of transfer units in the gaseous phase and height of transfer unit is given in terms of the volumetric flow rate and the mass transfer coefficient and the specific surface area we have been given the value of this $k_y a$ and this is the value of the number of transfer units which we derived earlier. And so this is this two things we have to find out to find out the height of the packing.

Now, what we do now in this case we redraw the graph what now this is in terms of the mole fraction and not mass fraction. So, we redraw the graph in terms of the mole fractions and we locate all these points x_1 y_1 and x_2 y_2 over here.

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Solution

Overall material balance

$$Vs \left(\frac{y_1}{1-y_1} - \frac{y_2}{1-y_2} \right) = Ls \left(\frac{x_1}{1-x_1} - \frac{x_2}{1-x_2} \right)$$

$$41.7 \left(\frac{0.10}{1-0.10} - \frac{0.00335}{1-0.00335} \right) = 2069 \left(\frac{x_1}{1-x_1} - \frac{0}{1-0} \right)$$

Solving $\rightarrow x_1 = 0.00217$ (conc of SO_2 at exit)

$$X_1 = \frac{x_1}{1-x_1} = 0.002175$$

$$h = HTU_g NTU_g$$

$$HTU_g = \frac{V}{k_y a}$$

$$NTU_g = \int_{y_2}^{y_1} \frac{(1-y)_M}{(1-y)(y-y_i)} dy = \int_{y_2}^{y_1} f(y) dy$$

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Solution

Overall material balance

$$Vs \left(\frac{y_1}{1-y_1} - \frac{y_2}{1-y_2} \right) = Ls \left(\frac{x_1}{1-x_1} - \frac{x_2}{1-x_2} \right)$$

$$41.7 \left(\frac{0.10}{1-0.10} - \frac{0.00335}{1-0.00335} \right) = 2069 \left(\frac{x_1}{1-x_1} - \frac{0}{1-0} \right)$$

Solving $\rightarrow x_1 = 0.00217$ (conc of SO₂ at exit)

$$X_1 = \frac{x_1}{1-x_1} = 0.002175$$

$$h = \text{HTU}_g \text{NTU}_g$$

$$\text{HTU}_g = \frac{V}{k_y a}$$

$$\text{NTU}_g = \int_{y_2}^{y_1} \frac{(1-y)_M}{(1-y)(y-y_i)} dy = \int_{y_2}^{y_1} f(y) dy$$

Slope = $\frac{-k_x a}{k_y a} = \frac{1.25}{0.075}$
 $M_1 = (0.00255, 0.0937)$

y	0.00335	0.00887	0.0237	0.0427	0.0569	0.0734	0.1
y _i	0.00178	0.00633	0.02	0.0376	0.0513	0.068	0.047
f(y)	640	395	273	198	180	170	190

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Now after locating this two what we now do is this that we find this this minus $k_x a$ by $k_y a$ this is the slope of a line, which will be coming from this particular operating line to the equilibrium curve and we learnt as we learnt earlier that wherever a line a straight line with a slope of this comes from operating line to the equilibrium curve and when touches it we will be able to get the value of the interfacial concentrations in the liquid phase and the vapour phase.

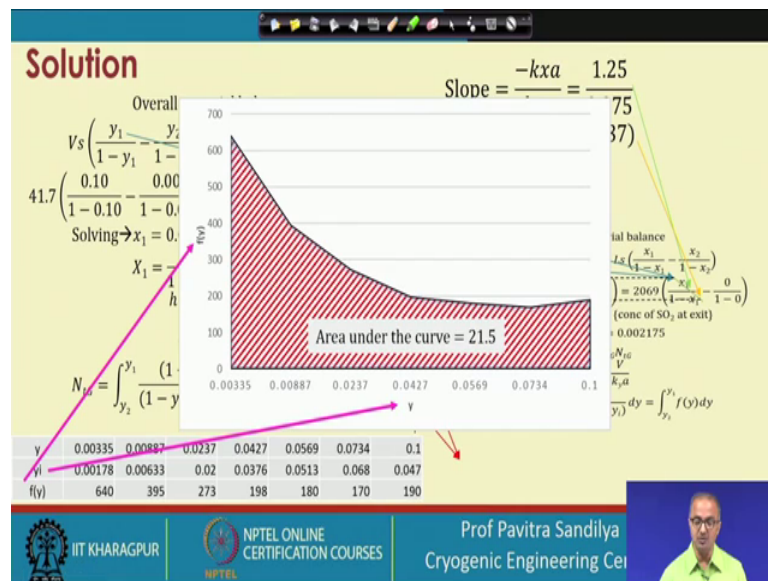
So, what we do that to find out this evaluate this particular integral we have to go from y_1 to y_2 that means, we shall be arbitrarily taking many points between y_1 and y_2 and we shall be drawing this lines straight lines with this particular slope. And we shall be looking into this particular values which are there on this equilibrium curve and this equilibrium curve will give the values of the x y and y_i between these two points y_1 and y_2 . There is small mistake it will be given negative sign over here which has been missing over here.

So, this is a that means, this is a negative slope, so with this negative slope we shall draw many many lines and these from this we can see that we can suppose we are seeing that here we have the value of the x y y and this is the value we are getting. And if you draw this kind of thing, we find that we can span the whole range between the y_1 and y_2 and we get all this value of the interfacial mole fraction in the gaseous phase. So, there

is no need of reading out the value of the x axis because in this particular formula we do not need the value of the x or even the value of the y.

So, we get the all the values of y and from this using this formula and we know this is a logarithmic mean value. So, all this formula have been given earlier in our theory so we get the value of the f y.

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And now after getting the value of the f y we can either we can draw this particular curve that is f y versus y and find out the area under the curve as the integral value or you can also use some numeral technique like some simpsons rule or trapezoidal rule etcetera to evaluate this particular integration so ok.

So, you can use any numerical technique or graphical technique in this particular problem we are showing that how you can do it graphically. So, once we can find out the area below this curve then we can find out the NTU value and this area is coming out to be about 21.5.

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Solution

$$NTU_g = \int_{y_2}^{y_1} \frac{(1-y)_{iM}}{(1-y)(y-y_i)} dy = \int_{y_2}^{y_1} f(y) dy$$

$$= 21.5$$

$$HTU_g = \frac{V'}{k_y a}$$

Cross sectional area of the tower = 0.781 m²

$$V_1' = \frac{V_1}{0.781} = \frac{46.41}{0.781} = 59.42 \frac{\text{kmol}}{\text{h.m}^2}$$

$$V_2' = \frac{V_2}{0.781} = \frac{V_s}{(1-y_2)0.781} = 53.66 \frac{\text{kmol}}{\text{h.m}^2}$$




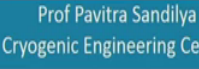

$$V' = \frac{V_1' + V_2'}{2} = \frac{59.42 + 53.66}{2}$$

$$= 56.54 \frac{\text{kmol}}{\text{h.m}^2}$$

$$k_y a = (0.075)(3600) = 270 \frac{\text{kmol}}{\text{h.m}^2.\Delta y}$$

$$H_{tg} = \frac{56.54}{270} = 0.21 \text{ m}$$

$$h = HTU_g NTU_g$$

$$= 0.21 \times 21.5 = 4.52 \text{ m}$$






Now, to find out this particular NTU HTU now we will take this value of the volumetric flow rate and because this now in this case we understand this that this is the volumetric flux. So, to find the flux what we have to do that we have to divide the flow rate with the area of cross section of the tower and which is given as this particular value. So, once we do it at the inlet and outlet side because we know that the volumetric flow rate will change at inlet and outlet. So, we find that we are getting two values of the fluxes at the inlet and outlet of the gas.

So, what we do we take the average of these two flow rates, and this value we take in to calculate the value of the HTU. So, we take the value of this and $k_y a$ is this we just convert it in terms of the hour and we get the HTU value as 0.21 metre and from this we get the value of the height of the packed tower as HTU g into NTU g . So, this 0.21 into 21.5 and we get this 4.52 so this is how we can get the height of a packed column using this HTU NTU method for the absorption.

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References

- Treybal R E, Mass-transfer operations, Mc=Graw Hill Book Company, 3rd Edition, 1989.
- Dutta B K, Principles of mass transfer and separation processes, PHI Learning, 2009.

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You can know more about these methods from these references.

Thank you.