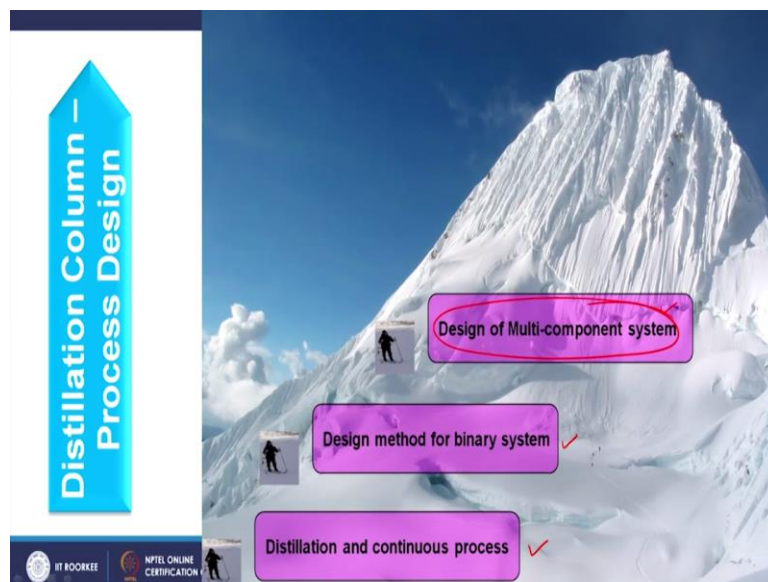


Process Equipment Design
Prof. Shabina Khanam
Department of Chemical Engineering
Indian Institute of Technology – Roorkee

Lecture –50
Distillation Column – 3

Hello everyone. This is the 50th lecture of the course Process Equipment Design and in this lecture we are going to discuss the distillation column. So, let us start this lecture. So, as far as this lecture is concerned we are covering the process design over here.

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And previously I have covered distillation and continuous process then design of binary system using McCabe Thiele method and then we also have discussed the multi component system. And in this lecture we will further elaborate this topic. So, let us start this lecture.

(Refer Slide Time: 01:10)

Design Method of Multi-Component System

Light and Heavy Key Components

If a four-component mixture A–B–C–D, in which A is the most volatile and D the least volatile. Then B is the lightest component appearing in the bottoms and is termed the light key component. C is the heaviest component appearing in the distillate and is called the heavy key component. The main purpose of the fractionation is the separation of B from C.

Feed	Top product	Bottoms
A ✓	A ✓	
B ✓	B ✓	B (light key)
C ✓	C (heavy key)	C
D ✓		D

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So, here we are going to discuss design of multi component system and before start the design of this we should consider light as well as heavy key component. So, what is basically light key and what is basically heavy key? If we consider the basic definition light key is basically which has more volatility and heavy key which has less volatility. And that is very easy to choose when I am having two component.

One would have larger volatility or higher volatility we consider that as lighter component other one will definitely be a heavier component, but how we have to choose this when I am having multi component system that is important. So, let us say I am having four component A, B, C and D in the feed. And we can arrange these component in the feed top product and bottom product with respect to the volatility.

So, highest component should be placed at top and then we can keep on arranging on component which has lower volatility. So, in this way we can arrange the component with respect to their volatility. So, how I can choose the light key and heavy key. The condition is like lightest component in bottom. Please listen it carefully lightest component in the bottom is represented by light key and heaviest component in the top is represented as heavy key.

So, with this definition if I consider lightest component in bottom and that component is B. So, this is considered as the light key. Similarly, heaviest component in top is the heavy key and which is basically this C component so this we consider as the heavy key. So, in this way we can consider B as the light key and C as the heavy key and we will design the system based on the separation between B and C.

I will not focus on A and B that will be separated along with these components only, but my main focus will be to separate B component from C. So, let us see how we can design the multi component system and for that we have the method like Hengstebeck's Method.

(Refer Slide Time: 04:07)

Design Method of Multi-Component System

Hengstebeck's method

For any component i the Lewis-Sorel material balance equations and equilibrium relationship can be written in terms of the individual component molar flow rates; in place of the component composition:

$$V_{n+1} = L_n + D \quad \rightarrow \quad v_{n+1,i} = l_{n,i} + d_i$$

$$y_i = K_i x_i \quad \rightarrow \quad v_{n,i} = K_{n,i} \frac{V}{L} l_{n,i}$$

For the stripping section:

$$l_{n+1,i} = v'_{n,i} + b_i$$

$$v'_{n,i} = K_{n,i} \frac{V'}{L'} l'_{n,i}$$

$l_{n,i}$ = the liquid flow rate of any component i from stage n
 $v_{n,i}$ = the vapour flow rate of any component i from stage n
 d_i = the flow rate of component i in the tops,
 b_i = the flow rate of component i in the bottoms,
 K_n = the equilibrium constant for component i at stage n
 The superscript denotes the stripping section.
 V and L are the total flow-rates, assumed constant.

So, according to this method for any component i the Lewis-Sorel material balance equation and equilibrium relationship can be written in terms of individual component molar flow rate in place of component composition. So, what we can consider over here that there are two points. First is we have to consider individual molar flow rate of each component and second is at the place of composition I should consider molar flow rate.

So, let us see the material balance changes with respect to this consideration. So, here I am having the balance at the top and that is basically above feed so V_{n+1} should be equal to $L_n + D$ this equation we already have seen previously and equilibrium relation will be y_i should be equal to $K_i x_i$. So, K_i basically equilibrium constant and when we consider this in Hengstebeck's Method it is represented by small v .

You can see here I am having total V which is here I am having capital V which is nothing, but the total flow rate. So, here for each component we can have small v so small $v_{n+1,i}$ should be equal to $l_{n,i} + d_i$ where i is the i th component. So, in the similar line I can write this equilibrium relationship as small $v_{n,i}$ divided by capital V . So, it will give the value of this. And that should be equal to $K_{n,i}$ and it should be multiplied with $l_{n,i}$ divided by L . So, that will be this value.

So, in the similar line we can consider equations in stripping section as $L_{n+1,i}$ and $V_{n,i}$ you can understand this is basically for stripping section it should be equal to $V_{n,i} + b_i$ and similarly this is the equilibrium relationship. So, here we have different nomenclature which we have used. And these are basically $L_{n,i}$ which is the liquid flow rate of any component i from stage n .

$V_{n,i}$ vapour flow rate of any component i from stage n and d_i is the i th component which is available in the distillate, b_i is the i th component available in the bottom product, $K_{n,i}$ equilibrium constant of component A and here we can consider prime or dash to denote stripping section that is the known fact. Capital V and capital L are the total flow rate that we consider as constant.

So, in this way we consider Hengstebeck's Method where flow rate of each component is considered. Now, why it is considered so? When we consider Hengstebeck's Method it basically counts the fact and that fact is basically when I am having heavy key as well as light key. So, obviously I will have some non key component also. Like light non key and heavy known keys.

So, this method considers that flow rates of non key components are constant and that we consider as the limiting flow rates. So, if I consider the constant flow rate of non key component I already know the total flow rate like Capital V and capital L I already know. So, if I deduct the non key component flow rates from the total what I will get? I will get the flow rate of key components only.

So, in that case what basically we are considering? We are considering that the multi component system is now transpose to binary system where I have only two component the light component and heavy key component. So, that is the basic fact about the Hengstebeck's Method that it considers or it transposes multi component system into binary system. And then we consider that as pseudo binary system.

So, now I am having binary system only so we can solve the same problem considering McCabe Thiele method. So, Hengstebeck's Method is basically pseudo binary system based method.

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The slide is titled "Design Method of Multi-Component System" in a blue header. Below it, a pink banner reads "Hengstebeck's method". The main content consists of three bullet points, each preceded by a square icon. The text in the bullet points is underlined. At the bottom of the slide, there are logos for "IIT ROORKEE" and "NPTEL ONLINE CERTIFICATION COURSE".

- ❑ To reduce a Multicomponent system to an equivalent binary it is necessary to estimate the flow-rate of the key components throughout the column.
- ❑ Hengstebeck makes use of the fact that in a typical distillation the flow-rates of each of the light non-key components approaches a constant, limiting rate in the rectifying section; and the flows of each of the heavy non-key components approach limiting flow-rates in the stripping section.
- ❑ Putting the flow-rates of the non-keys equal to these limiting rates in each section enables the combined flows of the key components to be estimated.

So, let us see how we can proceed further with this method. So, to reduce the multi component to the equivalent binary it is necessary to estimate the flow rate of key components throughout the column. And to do that Hengstebeck's make use of the fact that in a typical distillation the flow rate of each light non key component approaches a constant which we consider as limiting flow rate and that we consider as the limiting flow rate in rectifying section.

In the similar line; flows of each heavy non key component approach limiting flow rates in stripping section. So, this is the fact that we have already discuss that it considered the flow rate of non key component as constant which we also consider as limiting flow rates. And further putting the flow rates of non key is equal to these limiting rates in each section enables the combined flow rate of key components to be estimated.

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Design Method of Multi-Component System

Hengstebeck's method

Rectifying section ✓

Stripping section

$$\begin{aligned} \checkmark L_e &= L - \Sigma l_i \\ \checkmark V_e &= V - \Sigma v_i \\ \checkmark L'_e &= L' - \Sigma l'_i \\ \checkmark V'_e &= V' - \Sigma v'_i \end{aligned}$$

V_e and L_e are the estimated flow rates of the combined keys.
 l_i and v_i are the limiting liquid and vapour rates of components lighter than the keys in the rectifying section.
 l'_i and v'_i are the limiting liquid and vapour rates of components heavier than the keys in the stripping section.

So, let us see how to do that? Here, I am having the rectifying section and here we have the equation. So, L_e and V_e are basically the flow rate of key components. And here we have summation l_i and summation v_i these are basically the limiting flow rates of non key component. And if I deduct these from the total flow rate I can find out the flow rate of key component.

And this we are considering in rectifying section only and therefore l_i and v_i are basically considered for non light key component. And similarly here I am having summation l_i dash and summation v_i dash. These will be for the components which are non heavy key and these are the limiting flow rates. These we deduct from the total flow rate to find the flow rates of key components.

So, as far as that L_e V_e L_e dash V_e dash is concerned these are the flow rates of combined keys as it is shown over here. So, l_i and v_i are basically the limiting liquid and vapour rates of the component lighter than the keys in the rectifying section. And similarly l_i dash and v_i dash are limiting liquid and vapour rates of components heavier than the keys in stripping section.

So, in this way we can represent the complete multi component problem into binary system and now we can see how to find out limiting flow rates of non key components.

(Refer Slide Time: 12:34)

Design Method of Multi-Component System

Hengstebeck's method

The method used to estimate the limiting flow-rates is that proposed by Jenny (1939).

The equations are:

$$\underline{l}_i = \frac{d_i}{\alpha_i - 1}$$

$$\underline{v}_i = \underline{l}_i + d_i$$

$$\underline{v}'_i = \frac{\alpha_i b_i}{\alpha_{LK} - \alpha_i}$$

$$\underline{l}'_i = \underline{v}'_i + b_i$$

α_i relative volatility of component i , relative to the heavy key (HK),
 α_{LK} = relative volatility of the light key (LK), relative to the heavy key.



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So, to do that we have these equations where $\underline{l}_i$ is equal to $d_i / (\alpha_i - 1)$ and $\underline{v}_i$ is basically $\underline{l}_i$ over here and that should be added to d_i . So, this will be used over here. Similarly, for stripping section we can consider this and this should be used over here, so it is basically $\underline{v}'_i$. So, this correction you can consider and we can have α_i which is the relative volatility of component i relative to the heavy key.

And α_{LK} is basically relative volatility of light key relative to the heavy key. So, when we consider multi component system relative volatility we can always obtain based on heavy key.

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Design Method of Multi-Component System

Hengstebeck's method

Estimates of the flows of the combined keys enable operating lines to be drawn for the equivalent binary system.

The equilibrium line is drawn by assuming a constant relative volatility for the light key:

$$y = \frac{\alpha_{LK} x}{1 + (\alpha_{LK} - 1)x}$$

y and x refer to the vapour and liquid concentrations of the light key.



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And now we will consider the Hengstebeck's Method as it estimates the flows of combined key which enable the operating lines to be drawn for equivalent binary system. So, for

equilibrium line we can find out the relation as $y = \alpha LKx$ divided by $1 + \alpha LK - 1$ into x . So, this we have already discussed this is basically the relative volatility of light key with respect to heavy key

And y and x refer to the vapour and liquid concentration in light key. So, now once the problem is transpose into binary system we can consider McCabe Thiele method to find out number of trays for such system so that is basically the Hengstebeck's Method. Now, we will illustrate this method with the help of some examples.

(Refer Slide Time: 14:43)

Design Method of Multi-Component System

Example – 3

A multicomponent distillation column has following compositions with relative volatilities:

Component	Compositions			Volatilities	
	Feed	Top	Bottom	Top (°C)	Bottom (°C)
C_1	5	4	1	5.0	4.5
C_2	15	13	2	3.0	2.8
C_3 (LK)	30	28	2	2.0	1.8
C_4 (HK)	20	1	19	1.0	1.0
C_5	30	0	30	0.8	0.82

Using Hengstebeck's method calculate slope of top and bottom operating lines.
Consider reflux ratio=3

Handwritten notes on slide:
 - Under Feed: 100
 - Under Top: 46
 - Under Bottom: 54
 - Brackets group components C1-C2, C3-C4, and C5.
 - C3 is circled and labeled (LK).
 - C4 is circled and labeled (HK).
 - Reflux ratio=3 is circled.

So, let us say we have example 3. In this example multi component distillation has following compositions with relative volatility. So, you see here I am having the component like C_1 , C_2 to C_5 and we can already have the light key as well as heavy key and the compositions of feed top and bottom are given to us. So, if you consider this feed total is basically 100 and here at the top it is 46 and at the bottom it is 54.

And as far as volatilities are concerned at top temperature and bottom temperature of distillation column these are the volatilities. So, what we have to do? We have to use Hengstebeck's Method to calculate slope of top and bottom operating line where reflux ratio is considered as 3. So, in this way we need to find out the top and bottom operating line slopes. So, let us start this using Hengstebeck's Method.

So, as far as that Hengstebeck's Method is concerned first of all we need to find out the average volatility.

(Refer Slide Time: 16:14)

Design Method of Multi-Component System			
Solution			Volatilities
	Top (°C)	Bottom (°C)	Average Volatilities
C_1	5	4.5	4.743
C_2	3	2.8	2.8983
(LK) C_3	2	1.8	1.8974
(HK) C_4	1	1	1
C_5	0.8	0.82	0.8099

	α_i	d_i	$l_i = d_i / (\alpha_i - 1)$	$v_i = l_i + d_i$
C_1	4.743	4	1.068	5.068
C_2	2.898	13	6.849	19.849
			$\Sigma l_i = 7.917$	$\Sigma v_i = 24.917$

So, as far as average volatilities are concerned these are basically relative volatilities because if you see corresponding to heavy key we have value 1. So, all these volatilities at top and bottom temperature are relative volatility. So, we can simply make the geometric mean of that to find out average relative volatilities of different components so that you can do it is not difficult.

And now we have to find out limiting flow rates of non key. Now, if you consider C_3 as a light key. So, C_1 and C_2 are non light keys and if C_4 is the heavy key C_5 will be non heavy key. So, accordingly you can choose the limiting flow rates of non key components. So, here if I am having C_1 and C_2 we can find out relative volatilities which are already available and here we have the flow rate in distillate corresponding to C_1 and C_2 .

So, you can see here I am having 4 and 13 so these values are given over here and then we can have limiting flow rates of l_i as well as v_i so that is so that is basically the l_i underscore and v_i underscore in usual expressions which we have discussed previously. So, simple calculation is there you can find these values and addition of this will give the summation l_i and summation v_i .

(Refer Slide Time: 18:07)

Design Method of Multi-Component System

Solution

	α_i	b_i	$v_i^1 = \frac{\alpha_i b_i}{(\alpha_{LK} - \alpha_i)}$	$l_i^1 = v_i^1 + b_i$
C5	0.81	30	22.3469	52.3469

$\Sigma v_i^1 = 22.3469$ $\Sigma l_i^1 = 52.3469$

Flows of combined keys:

$L_e = 3 \times 46 - 7.917 = 130.083$
 $V_e = (3 + 1) \times 46 - 24.917 = 159.083$
 $v_e^1 = (3 + 1) \times 46 - 22.3469 = 161.653$
 $l_e^1 = (3 + 1) \times 46 + 54 - 52.3469 = 185.6531$

$L_e = L - \Sigma l_i$
 $V_e = V - \Sigma v_i$
 $L_e' = L' - \Sigma l_i'$
 $V_e' = V' - \Sigma v_i'$

$L' = L + B$
 $V' = V + D$

And in the similar line we can find out the limiting rates of non heavy key as C 5 is the only component available in that category. So, we can find out alpha i for that and bi which is given as 30 in the table and here we have v i dash this is not 1 so you consider all these as prime or dash and here you can find out vi prime underscore as this and then we can simply add 30 to this to find out this value. So, summation you can find like this.

And now we have to find out flow rates of top operating line and bottom operating line and that flow rate is L / V at top and L dash / V dash at the bottom. So, in that case we first consider the flow rate of key components and how we do this? We know total flow rate and from that we will deduct limiting flow rate of non keys. So, here we have the flow of combined keys.

So, L e is basically the combined key flow rate in liquid phase so that should be 3 into 46, 46 is the total distillate and 3 is the reflux ratio so that is nothing, but the L. So, you can see L e is basically L – summation l i. So, that we can consider over here this value we have already calculated. So, this is the value of L e. Similarly, for V e how we can consider for that I need to V and that V should be equal to L + D.

So, we can consider 4 into D and minus this factor so 159.083 we can obtain V e dash we can obtain as V prime minus this factor. So, this will be nothing, but equal to this only. So, that we can consider and deduct this value and so we can find V e prime as 161.653 and L e prime we can obtain considering this equation where L dash is basically V dash + B. So, that B is

54 and V dash we already have computed over here so that we can consider here as well. And from this we will deduct this value and we can find the L e dash as 185.65.

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Design Method of Multi-Component System

Solution

$$\text{Slope of top operating line} = \frac{L_e}{V_e} = 0.8177$$

$$\text{Slope of bottom operating line} = \frac{L_e^1}{V_e^1} = 1.1485$$

$$x_b = \frac{\text{flow (LK)}}{\text{flow (LK+HK)}} = \frac{2}{2+19} = 0.09524$$

$$x_d = \frac{28}{28+1} = 0.9655$$

$$x_f = \frac{30}{30+20} = 0.6$$



And similarly we can simply calculate the slope of operating line like this.

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Design Method of Multi-Component System

Example – 4 ✓

A multicomponent distillation column has following compositions. Using Hengstebeck's method calculate slope of top and bottom operating lines. Consider reflux ratio=3

Component	Compositions			Equilibrium constant at average temperature
	Feed	Top	Bottom	
C ₁	2	2	0	2.4
C ₂	5	4.5	0.5	2.0
C ₃	15	14.5	0.5	1.6
C ₄ (LK)	25	24.5	0.5	1.2
C ₅ (HK)	20	7.5	12.5	0.4
C ₆	10	4	6	0.32
C ₇	15	2	13	0.24
C ₈	8	1	7	0.16

$\frac{k_i}{k_{HK}} = \frac{2.4}{0.4} = 6$



So, here I am considering another example where Hengstebeck's Method is used to again calculate the top and bottom operating line reflux ratio is 3, but here we have more number of components and in this case I am giving equilibrium constant at average temperature. So, how I can find the relative volatility that should be $k_i / k_{\text{heavy key}}$. So, considering this we can simply find for this 2 / 4 divided by this that is 0.4 and that should be equal to 6.

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Design Method of Multi-Component System

Solution

Components	Feed (f)	Top (d)	Bottom (b)	Rel. Vol. i
C1	2	2	0	6
C2	5	4.5	0.5	5
C3	15	14.5	0.5	4
C4 (LK)	25	24.5	0.5	3
C5 (HK)	20	7.5	12.5	1
C6	10	4	6	0.8
C7	15	2	13	0.6
C8	8	1	7	0.4
	100	60	40	

So, in this way you can find out relative volatility and accordingly we can calculate relative volatility of other component.

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Design Method of Multi-Component System

Solution

$$l_i = d_i / (\alpha_i - 1) \quad v_i = l_i + d_i \quad v'_i = \alpha_i b_i / (\alpha_{LK} - \alpha_i)$$

$$l'_i = v'_i + b_i$$

	alpha	di	li	vi
C1	6	2	0.4	2.4
C2	5	4.5	1.125	5.625
C3	4	14.5	4.8333	19.333
Summation			6.3583	27.358
	alpha	bi	vi'	li'
C6	0.8	6	2.18182	8.18182
C7	0.6	13	3.25	16.25
C8	0.4	7	1.0769	8.0769
Summation			6.5087	32.5087

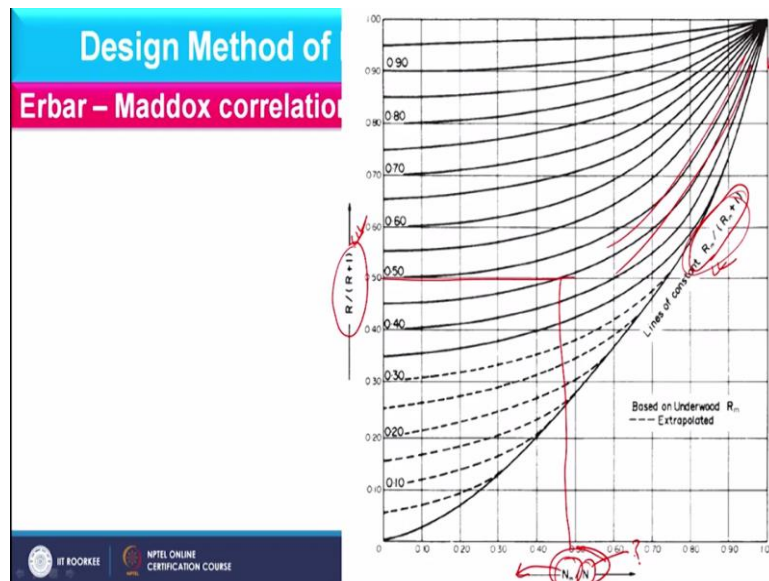
Le	173.6417
Ve	212.6417
Ve'	233.4913
Le'	247.4913
Le/Ve	0.8166
Le'/Ve'	1.05996

And we can simply find out all these values which are shown in these tables and L_e , V_e , V_e dash L_e dash we can find as we have discussed in previous example and these are basically the slopes of operating lines at top and bottom. So, in this way we consider the Hengstebeck's Method. Now we can have another method to calculate number of trays in multi component system and that is Erbar-Maddox method.

You can ask that in Hengstebeck's Method we have not calculated number of trays. So, that you can obtain by considering McCabe Thiele method once you have transpose the problem

from multi component to binary component. So, that is basically the repeated exercise so I have not considered that.

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So, let us discuss Erbar-Maddox method now and that is the empirical correlation based. And here we have this graph which is all about this method. If you consider x axis of this that is N_m/N N_m is basically minimum number of trays and N is the actual number of trays which you have to find. If you see here I am having different lines and these lines correspond to $R_m/R_m + 1$ and that R_m is basically minimum reflux ratio.

So, that we can consider in these lines and on y axis we have $R/R_m + 1$ so that is the actual reflux ratio given in the problem. So, you basically know this and you can also calculate this so depending upon all these value you can find the N_m/N . N_m number of trays you can also calculate and so you can find out N number of trays that is the actual number of trays for the given separation. I hope method is clear.

Now, we will see the value of different terms. First of all we will find the value of N_m that is the minimum number of trays and that we can obtain at total reflux condition.

(Refer Slide Time: 24:48)

Design Method of Multi-Component System

Erbar – Maddox correlation
Empirical Correlations

To use this figure, estimations of the number of stages at total reflux and the minimum reflux ratio are needed.

Minimum number of stages (Fenske equation)

$$\left[\frac{x_i}{x_r} \right]_d = \alpha_i^{N_m} \left[\frac{x_i}{x_r} \right]_b$$

$$N_m = \frac{\log \left[\frac{x_{LK}}{x_{HK}} \right]_d \left[\frac{x_{HK}}{x_{LK}} \right]_b}{\log \alpha_{LK}}$$

$[x_i/x_r]$ = the ratio of the concentration of any component i to the concentration of a reference component r, and the suffixes d and b denote the distillate (tops) (d) and the bottoms (b),
 N_m = minimum number of stages at total reflux
 α_i = average relative volatility of the component i with respect to the reference component.

So, for minimum number of stages calculation we can consider Fenske's equation as you can see over here. So, this is the Fenske's equation where x_i / x_r is the ratio of concentration of any component i to the concentration of a reference component r and the suffix d and b denotes distillate as well as bottom. So, here I am having N_m as minimum number of stages, α_i is the average relative volatility of the component i with respect to reference component.

And reference component is usually the heavy component. So, when we resolve this we can find this expression to find out minimum number of trays based on light key as well as heavy key. So, here also we should consider selection of key component first and based on that we can use this equation.

(Refer Slide Time: 25:56)

Design Method of Multi-Component System

Erbar – Maddox correlation
Empirical Correlations

Minimum reflux ratio

Underwood's equation gives: $\sum \frac{\alpha_i x_{i,d}}{\alpha_i - \theta} = R_m + 1$

α_i = the relative volatility of component i with respect to some reference component, usually the heavy key
 R_m = the minimum reflux ratio,
 $x_{i,d}$ = concentration of component i in the tops

θ is computed using: $\sum \frac{\alpha_i x_{i,f}}{\alpha_i - \theta} = 1 - q$

$x_{i,f}$ = the concentration of component i in the feed, and q depends on the condition of the feed
 The value of θ is found by trial and error

The value of θ must lie between the values of the relative volatility of the light and heavy keys

So, once I am having R_m value we can find minimum reflux ratio value and that we can obtain through Underwood's equation. And Underwood's equation is given as where summation $\alpha_i \times x_{iD} / \alpha_i - \theta$ should be equal to $R_m + 1$. So, this R_m is basically minimum reflux ratio α_i is the relative volatility of component i with respect to reference component and that is usually the heavy key.

R_m minimum reflux ratio that we have already discussed x_{iD} is the i th component in distillate. And how we can compute θ so for this we can have another equation which depends on the feed composition of i th component and we can also consider q line over here. So, based on that we can find the; θ value which can be obtained by trial and error method. So, how I can use the correct value of θ ?

The correct value of θ must lie between the values of relative volatilities of light and heavy key. So, in this case you may have number of values of θ so wherever the value will lie between relative volatility of light key and heavy key that value you can consider for θ . So, this is basically Erbar-Maddox method and quickly we will cover the example related to that.

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Design Method of Multi-Component System

Example – 5

A multicomponent distillation column has following compositions with relative volatilities:

Component	Compositions			Volatilities	
	Feed	Top	Bottom	Top (°C)	Bottom (°C)
C_1	5	4	1	5.0	4.5
C_2	15	13	2	3.0	2.8
C_3 (LK)	30	28	2	2.0	1.8
C_4 (HK)	20	1	19	1.0	1.0
C_5	30	0	30	0.8	0.82

Calculate number of trays using Erbar-Maddox method. The feed is at its boiling point. Consider reflux ratio=3. q=1



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So, in this case we can have the same example which we have discussed as example 3 for Hengstebeck's Method. So, all these points you know already and here we have to compute number of trays using Erbar-Maddox method. So, feed is at boiling point where q should be 1. We have to consider reflux ratio as 3. So, let us start that.

(Refer Slide Time: 28:02)

Design Method of Multi-Component System

Solution

Erbar – Maddox method:

$$N_m = \frac{\log \left[\frac{x_{LK}}{x_{HK}} \right]_d \left[\frac{x_{HK}}{x_{LK}} \right]_b}{\log \alpha_{LK}}$$

$$= \frac{\log \left(\frac{28}{15} \right) \left(\frac{19}{2} \right)}{\log 1.8974} = 8.7176$$

$$\sum \frac{\alpha_i x_{i,f}}{\alpha_i - \theta} = 1 - q$$

[Since $q = 1$ at boiling point]

$$\theta = 1.274$$

Component	Compositions			Volatilities	
	Feed	Top	Bottom	Top (°C)	Bottom (°C)
C ₁	5	4	1	5.0	4.5
C ₂	15	13	2	3.0	2.8
C ₃ (LK)	30	28	2	2.0	1.8
C ₄ (HK)	20	1	19	1.0	1.0
C ₅	30	0	30	0.8	0.82

4.743	2.8983
1.8974	1.8974
1	1
0.8099	0.8099

So, here we have relative volatility with respect to heavy key at top as well as bottom and average of that we have already calculated in previous examples that you can refer. So, these values are already available to you and now we consider Erbar-Maddox method and first of all we will find minimum number of trays that is N_m and that is the expression. So, you can see we have to focus on this condition so x LK in distillate.

So, this is basically 28 and that is heavy key in distillate so that should be 1. So, that you can consider over here LK at bottom that is basically 2 divided by 19. So, here you can consider this is basically H and this is L. So, this correction you should consider and here if you consider heavy key is bottom so that should be 19 and light key in bottom as 2 so that you can consider as $19 / 2$ and that should be divisible alpha LK.

So, that is nothing, but this value. So, you can find N_m as 8.7176 and this equation we can use to find out theta value. And in this equation this $X_{i,f}$ is basically the fraction of component i in feed. So, if you see the total feed is basically 100 so that we can consider $1 / 100$ over here and then we keep on expanding this expression. So, that should be alpha i. So, for first component 4.743 into 5 that is given over here divided by this alpha i – theta + second component this is alpha i and this is the xi and again alpha i we can consider.

And so we keep on adding this for 5 different components and that will be equal to $1 - q$ where q will be equal to 1. So, that we can consider as 0. So, when we solve this we can find theta value as 1.274. We can obtain more values also, but we should choose the value which

will fall between relative volatility of light key as well as heavy key as you can consider this value.

So, in this way we can find out theta value and further we have to find out minimum reflux ratio using Underwood's equation.

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Design Method of Multi-Component System

Solution

$$\sum \left(\frac{\alpha_i x_{i,d}}{\alpha_i - \theta} \right) = R_m + 1$$

$$\frac{4.743 \times \frac{4}{46}}{4.743 - 1.274} + \frac{2.8983 \times \frac{13}{46}}{2.8983 - 1.274} + \frac{1.8974 \times \frac{28}{46}}{1.874 - 1.274} + \frac{1 \times \frac{1}{46}}{1 - 1.274} = R_m + 1$$

$$0.1189 + 0.5043 + 1.8526 - 0.07934 = R_m + 1$$

$$R_m = 1.39645$$

$$\frac{R_m}{R_m + 1} = 0.5827$$

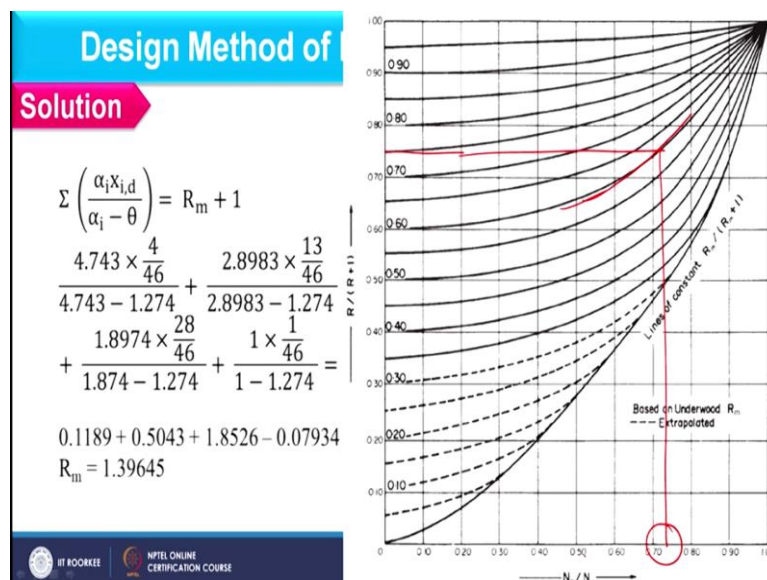
$$\frac{R}{R + 1} = \frac{3}{3 + 1} = 0.75$$

$$\frac{N_m}{N} = 0.74 \text{ (from graph)}$$

$$N = \frac{8.7176}{0.74} = 11.78 = 12 \text{ stages}$$

So, this is the Underwood's equation. Solving this equation because all components you know here we can have R_m value as 1.39645 I think you can solve this very easily. There is no problem. So, once I am having R_m value we can find out $R_m / R_m + 1$ and reflux ratio in the problem is given as 3 so we can find $R / R + 1$ and now we can use the graph. You can see $R_m / R_m + 1$ is 0.58 and this is 0.75.

(Refer Slide Time: 31:45)



So, this is the graph where $R_m / R_m + 1$ is 0.58 so that should be almost 0.6. So, this is the curve and 0.75 is $R / R + 1$ so that you can consider this line. So, wherever it will cut this line we can find N_m / N using this point.

(Refer Slide Time: 32:19)

Design Method of Multi-Component System

Solution

$$\Sigma \left(\frac{\alpha_i X_{i,d}}{\alpha_i - \theta} \right) = R_m + 1$$

$$\frac{4.743 \times \frac{4}{46}}{4.743 - 1.274} + \frac{2.8983 \times \frac{13}{46}}{2.8983 - 1.274}$$

$$+ \frac{1.8974 \times \frac{28}{46}}{1.874 - 1.274} + \frac{1 \times \frac{1}{46}}{1 - 1.274} = R_m + 1$$

$$0.1189 + 0.5043 + 1.8526 - 0.07934 = R_m + 1$$

$$R_m = 1.39645$$

$$\frac{R_m}{R_m + 1} = 0.5827$$

$$\frac{R}{R + 1} = \frac{3}{3 + 1} = 0.75$$

$$\frac{N_m}{N} = 0.74 \text{ (from graph)}$$

$$N = \frac{8.7176}{0.74} = 11.78 = 12 \text{ stages}$$

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So, accordingly N_m / N you can find as 0.74 and so the number of stages N you can find as 11.78 so that should be equal to 12 stages. So, in this way Erbar-Maddox method works.

(Refer Slide Time: 32:35)

Design Method of Multi-Component System

Example – 6

A multicomponent distillation column has following compositions. Calculate number of trays using Erbar-Maddox method. The feed is at boiling point and reflux ratio is 0.67.

Components	Feed (f)	Top (d)	Bottom (b)	Rel. Vol. at avg temp
C1	5	5	0	6
C3	15	15	0	4
C4	22	22	0	3
C5	30	25	5	2
C6	10	3	7	1
C7	18	0	18	0.8

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And so we will cover the second example of Erbar-Maddox method quickly and that is this example where this is basically the light key and this is the heavy key based on the simple definition of it.

(Refer Slide Time: 32:50)

Design Method of Multi-Component System

Solution

Erbar – Maddox method:

$$N_m = \frac{\log \left[\frac{x_{LK}}{x_{HK}} \right]_d \left[\frac{x_{LK}}{x_{HK}} \right]_b}{\log \alpha_{LK}} = 3.544$$

$$\sum \frac{\alpha_i x_{i,f}}{\alpha_i - \theta} = 1 - q \quad \text{where } q = 0$$

theta			1.5	1.8	1.118
xif	alpha i	alpha*xif	alpha*xif/alpha-theta		
0.05	6	0.3	0.0667	0.07143	0.0615
0.15	4	0.6	0.24	0.27273	0.2082
0.22	3	0.66	0.44	0.55	0.3507
0.3	2	0.6	1.2	3	0.6803
0.1	1	0.1	-0.2	-0.125	-0.8475
0.18	0.8	0.144	-0.2057	-0.144	-0.4528
			1.54095	3.6252	0.0003

And we can find minimum number of trays using Fenske's equation. So, this you please change to this and the N_m we can find as 3.54, q value should be 1. So, we can find the theta value also. So, this is another method to find out theta value either you can simply calculate that from the calculator by putting the whole equation or you can simply keep on assuming the theta value and keep on calculating this till you will find the value should be equal to this and that should be 0. So, this is almost 0 so we can choose theta value as 1.118.

(Refer Slide Time: 33:41)

Design Method of Multi-Component System

Solution

xid	alpha i	alpha*xid	alpha*xid/alpha-theta
0.0714	6	0.4286	0.0878
0.2143	4	0.8571	0.2974
0.3143	3	0.9429	0.5010
0.3571	2	0.7143	0.8098
0.0429	1	0.0429	-0.3632
0	0.8	0	0
			1.3328

$$\sum \frac{\alpha_i x_{i,d}}{\alpha_i - \theta} = R_m + 1$$

$R_m + 1$	1.3328
R_m	0.3328
$R_m / (R_m + 1)$	0.2497
$R / R + 1$	0.4012
N_m / N	0.62
N	5.717

Total number of trays = 6

And after that we can find out R_m by this calculation so that R_m is 0.3328 then $R_m / R_m + 1$ we can find $R / R + 1$ we can find and so the number of trays we can find using the graph which we have discussed in previous example. So, total number of trays we can find as 6.

(Refer Slide Time: 34:11)



References

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And here I am having some of the references about this and this is the summary of the video and this is the summary of last three lectures of distillation column.

(Refer Slide Time: 34:23)

Summary of the video

- ✓ Distillation process is discussed in detail. ✓
- ✓ Reflux ratio (Total reflux, Minimum reflux and Optimum reflux) is described.
- ✓ Design method of binary system is discussed. ✓
- ✓ Design methods of multi-component systems are discussed. ✓
- ✓ Hengstebeck's and Erbar – Maddox methods are described.

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26

And summary goes as distillation process is discussed in detail. Reflux ratio that is total reflux, minimum reflux and optimum reflux is described. Designed method for binary system is discussed, design method of multi component system is discussed and we also have discussed Hengstebeck's as well as Erbar-Maddox method and that is all for now. Thank you.