Process Design Decisions and Project Economics
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Module - 4
Design Separation Processes
Lecture - 19
Design of Distillation Columns - Part I
(Sequencing of Columns, Energy Integration/Thermal Coupling of the Columns)

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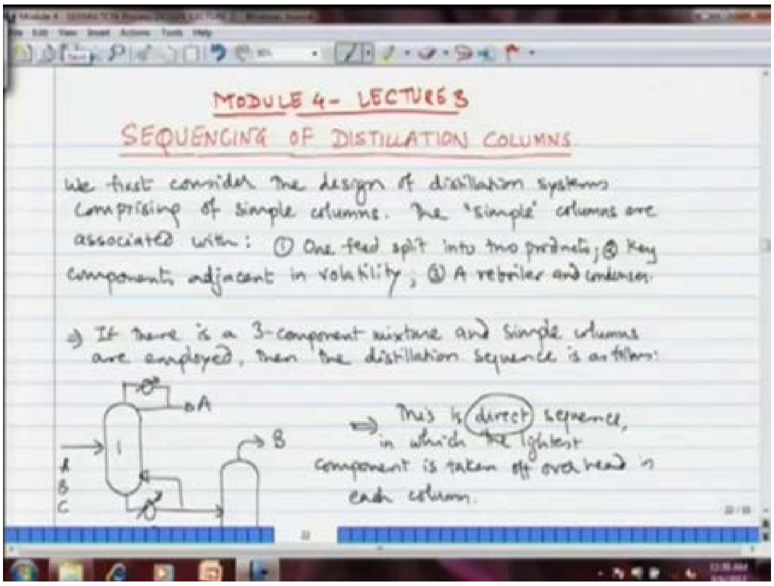

MODULE 4- LECTURES

SEQUENCING OF DISTILLATION COLUMNS

We first consider the design of distillation systems comprising of simple columns. The 'simple' columns are associated with: ① One feed split into two products; ② Key components adjacent in volatility; ③ A reboiler and condenser.

⇒ If there is a 3-component mixture and simple columns are employed, then the distillation sequence is as follows:

⇒ This is direct sequence, in which the lightest component is taken off overhead in each column.

Welcome, in the previous lecture we saw some basic guidelines for design of the separation system, as what kind of system should be used, we saw the gas vapour separation system, the liquid separation system, the basic guidelines that govern the location of the system or type of the process that we use for separation, etcetera. Finally, we had seen the applicability of distillation and some basic aspects of distillation, as what should be the sequence of separation of a mixture comprising of different or more than 3, 4 or 5 components.

In this lecture, we take ahead this theme and deal with the sequencing of distillation column first and later on we shall see some other aspects of distillation columns such as thermal coupling and a pre fractionators system and so on and so forth. So, we start our lecture with sequencing of the distillation column. In the earlier lecture I told you that for separation of 3 component mixture, we need minimum 2 simple columns and then we can go for either a direct sequence or indirect sequence of separation.

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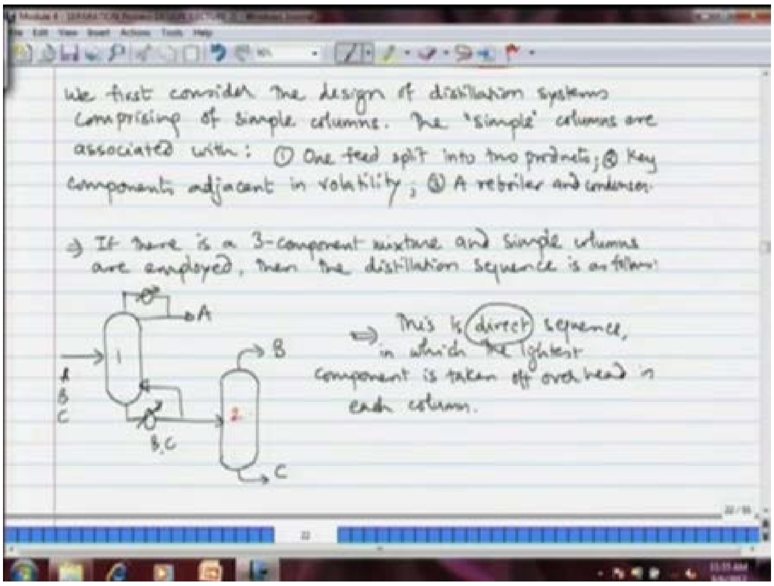

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⇒ If there is a 3-component mixture and simple columns are employed, then the distillation sequence is as follows:

⇒ This is direct sequence, in which the lightest component is taken off over head in each column.

So, the simple column are associated with 1 feed split into 2 products and key components adjacent in the relative volatility, a re-boiler and a condenser. So, what is shown on the screen is a 3 component mixture A B C and simple columns are employed. Then the distillation sequence is shown. First, A being separated from mixture of B and C and then B and C split in the second column is a direct sequence. In this sequence the lightest component is taken off over head in each column.

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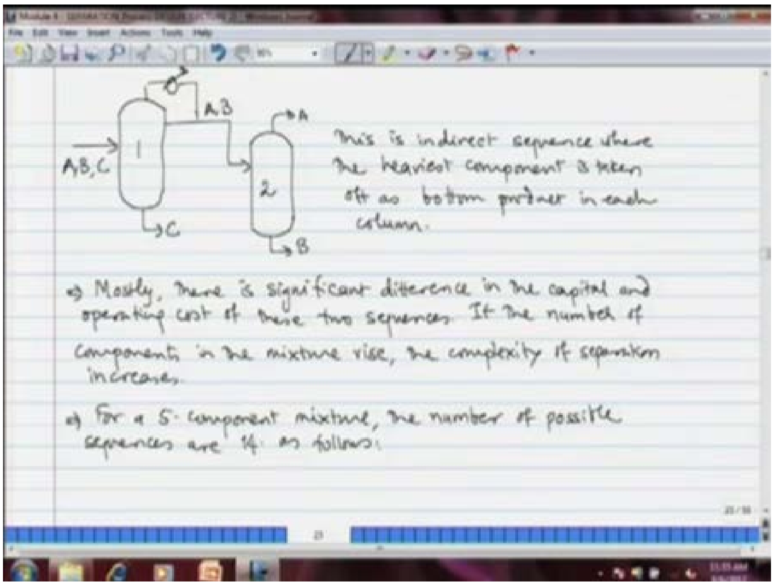

This is indirect sequence where the heaviest component is taken off as bottom product in each column.

⇒ Mostly, there is significant difference in the capital and operating cost of these two sequences. If the number of components in the mixture rise, the complexity of separation increases.

⇒ For a 5-component mixture, the number of possible sequences are 14 as follows:

Then, we have an indirect sequence. The mixture A B C being split as A B together and C is separate. E being taken off as the bottom product from the first column, the mixture of A and B flows to the next column and then it is split. So, this is an indirect sequence in which the heaviest component is taken off as a bottom product in each column. Mostly, there is significant difference in the capital and operating cost of these 2 sequences.

If the number of components in the mixture rise, then the complexity of separation also increases. We have done many options or many possible sequences of separation. I have given here, a typical example in which 5 component mixture is considered. We have 5 components A, B, C, D and E. For this purpose we can have 14 different sequences as shown.

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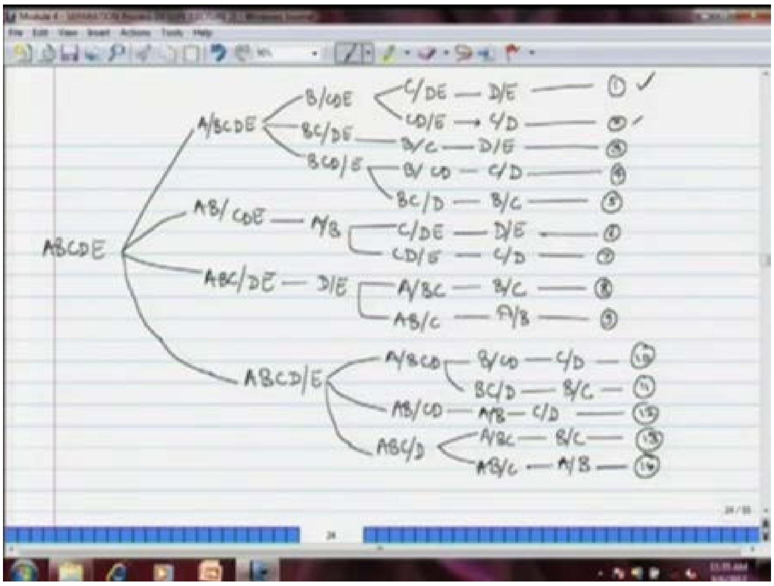

We have A B C D E being split in complete direct sequence, A being separated from B C D E, then B being separated from C D and E. Then C being separated from D and E and then D and E being split in the fourth column. In each sequence, you will see that 4 columns are required. Then the second sequence is A B C D E mixture. A taken off first from B C D. Then B C D mixture split into half B C together being recovered at the top and D E together recovered at the bottom. Then these binary mixtures are further split as B C and D E.

Then, in the third possible sequence we have separation of A again from B C D mixture first. Then B C D E quaternary mixture is split as B C D together and E being separated. That is indirect sequence and then we are left with the B C D ternary mixture which is again splitting direct and indirect sequence like B being separate from C and D. The same D being split in the fourth column or B C being separated from D and the binary mixture B C is split in another column. So, in this way if you start writing you can write 14 different sequences as shown in this figure.

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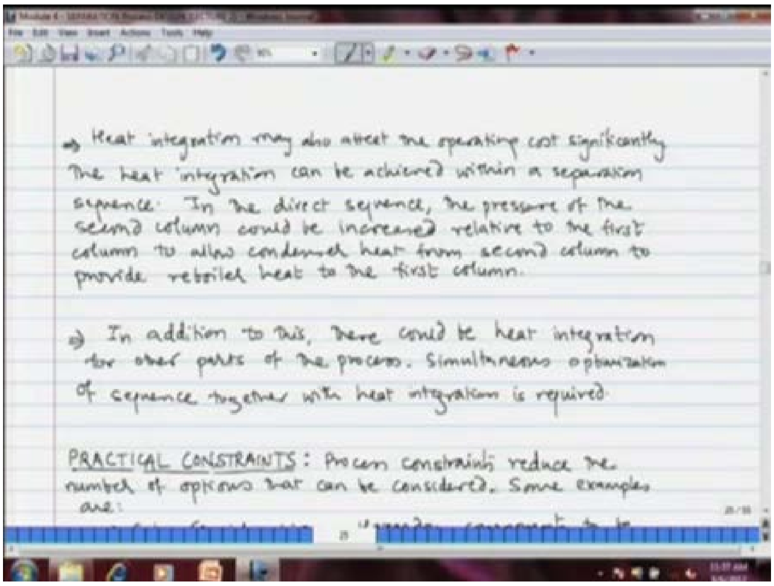

⇒ Heat integration may also affect the operating cost significantly. The heat integration can be achieved within a separation sequence. In the direct sequence, the pressure of the second column could be increased relative to the first column to allow condensed heat from second column to provide reboiled heat to the first column.

⇒ In addition to this, there could be heat integration for other parts of the process. Simultaneous optimization of sequence together with heat integration is required.

PRACTICAL CONSTRAINTS: Process constraints reduce the number of options that can be considered. Some examples are:

Heat integration is another issue. In this case we cannot have luxury of providing utilities for the re-boiler and bottoms of each of these column separately we have to have heat integration. We have to see where the surplus heat is being available and that surplus heat as far as possible should be utilized to meet the energy demands. That way we bring down the operating cost of the process. So, heat integration is an important issue. Heat integration may also effect the operating cost significantly.

Heat integration can be achieved within a separation sequence like columns coupled together and that is straight forward when you have vapour at the top of each column and liquid at the bottom of each column. Then you can have coupling of the columns such that the vapour from one column condenses into the re-boiler of another column and then drives the re-boiler. But, to achieve that you have to have sufficient temperature difference.

You have already learnt the boiling heat transfer in the NPTEL course on heat transfer. You should always have your re-boiler which is typically kettle type re-boiler. It should always operate in the nuclide boiling region. So, you have to have about 40 to 50 degrees centigrade of difference between the condensation temperature of the vapour and a boiling point of the liquid. Now, you can achieve that difference by shifting the pressures of the column.

You reduce the pressure of the second column, so that the boiler temperature reduces. Increase the pressure of the first column such that the condensation temperature increases. Then we have the coupling. So, that is heat integration within a sequence. These sequences can also couple other streams in the process. So, when we select a best possible sequence, then we have to take into consideration this important aspect. So, it may not be possible that you will have out of these 14 or if you consider 6 component mixture and there are 46 sequences for 6 component mixture so on and so forth. It is very difficult that you will end up with a single best sequence. You will always end up with certain set of sequences which have more or less similar benefits or similar operating and capital cost.

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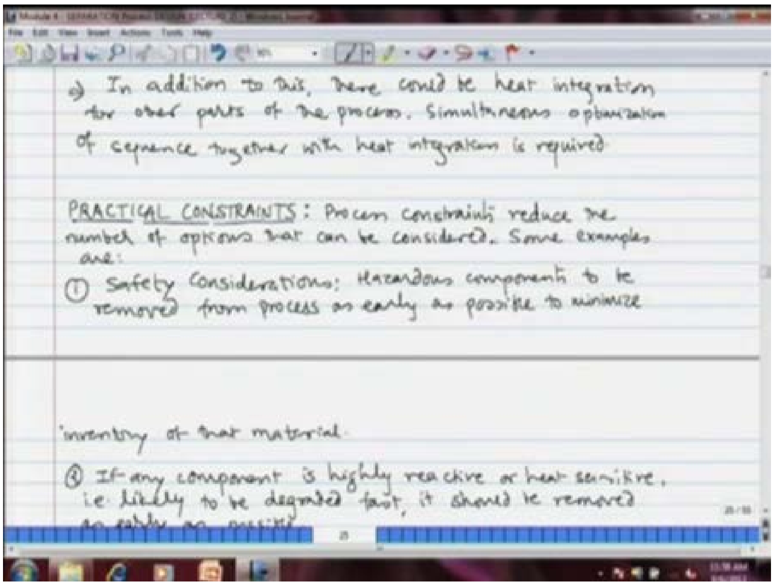

c) In addition to this, there could be heat integration for other parts of the process. Simultaneous optimization of sequence together with heat integration is required

PRACTICAL CONSTRAINTS: Process constraints reduce the number of options that can be considered. Some examples are:

① Safety considerations: Hazardous components to be removed from process as early as possible to minimize inventory of that material.

② If any component is highly reactive or heat sensitive, i.e. likely to be degraded fast, it should be removed as early as possible

So, at this point you need to know. However, only the least total vapour load or flexibility in heat integration may not be a criteria. There are some practical constraints in choosing the best sequence of a distillation column.

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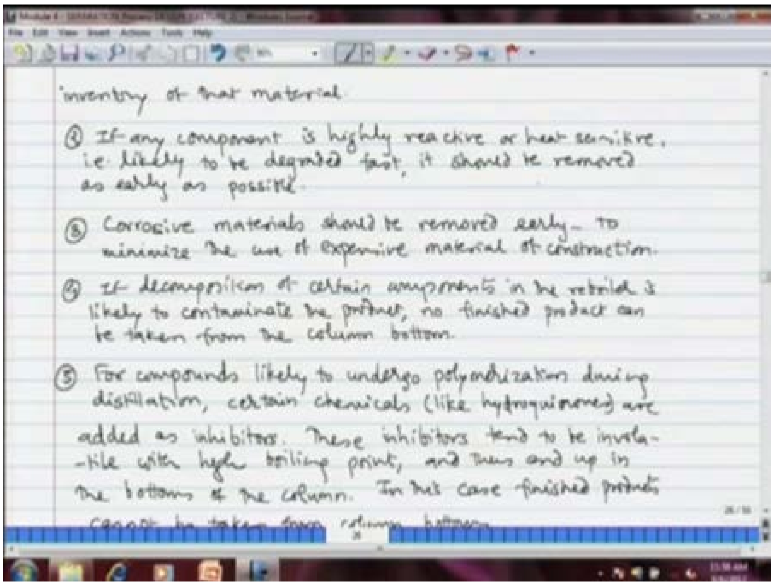

inventory of that material

② If any component is highly reactive or heat sensitive, i.e likely to be degraded fast, it should be removed as early as possible.

③ Corrosive materials should be removed early to minimize the use of expensive material of construction.

④ If decomposition of certain components in the reboiler is likely to contaminate the product, no finished product can be taken from the column bottom.

⑤ For compounds likely to undergo polymerization during distillation, certain chemicals (like hydroquinones) are added as inhibitors. These inhibitors tend to be involatile with high boiling point, and thus end up in the bottoms of the column. In this case finished products cannot be taken from column bottom.

The practical constraints are as follows and these reduce the number of options that can be considered. First, is the safety consideration. Hazardous components need to be removed from the process as early as possible to minimize inventory of that material. Then if a component is highly reactive or heat sensitive, it should be removed as early as possible. This is because as you go on separating the mixture, the temperature of the column is likely to increase with the heavier components left in the stream. Then it is likely that the component which is heat sensitive may get degraded.

Then, if a component is corrosive, it should be removed as early as possible to minimize the use of expensive material of construction. Then if a component is likely to decompose in the re-boiler and contaminate the product, it should be removed as early as possible. In such cases, the finished product or final product should not be removed as the bottom product.

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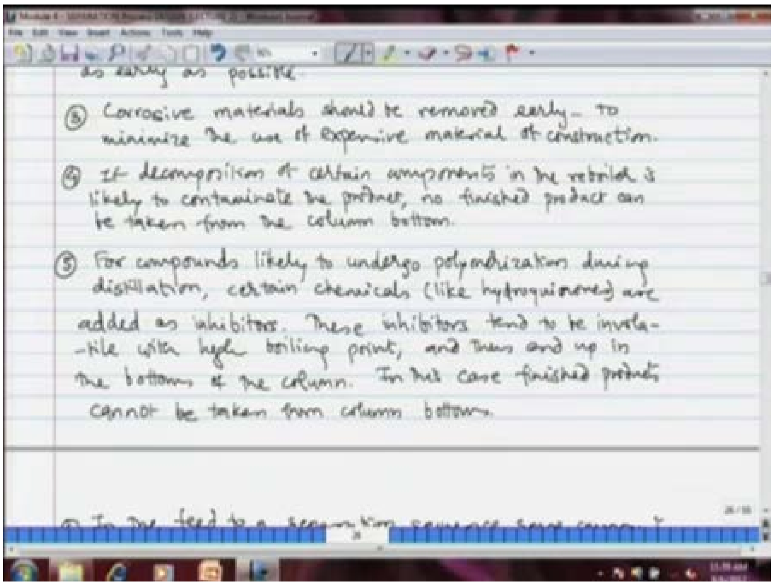

as early as possible.

③ Corrosive materials should be removed early to minimize the use of expensive material of construction.

④ If decomposition of certain components in the reboiler is likely to contaminate the product, no finished product can be taken from the column bottom.

⑤ For compounds likely to undergo polymerization during distillation, certain chemicals (like hydroquinones) are added as inhibitors. These inhibitors tend to be involatile with high boiling point, and thus end up in the bottoms of the column. In this case finished products cannot be taken from column bottom.

It should always be removed from the top. Then for the compounds which are likely to undergo polymerization during distillation, we have to add certain chemicals like hydroquinones as inhibitor.

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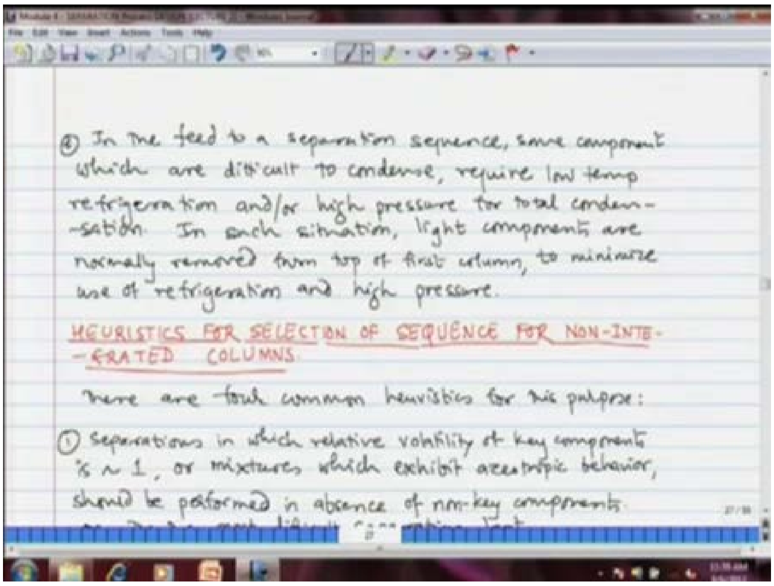

⑥ In the feed to a separation sequence, some component which are difficult to condense, require low temp refrigeration and/or high pressure for total condensation. In such situation, light components are normally removed from top of first column, to minimize use of refrigeration and high pressure.

HEURISTICS FOR SELECTION OF SEQUENCE FOR NON-INTEGRATED COLUMNS

There are four common heuristics for this purpose:

① Separations in which relative volatility of key components is ~ 1, or mixtures which exhibit azeotropic behavior, should be performed in absence of non-key components.

These inhibitors tend to accumulate in the bottom of the column. So, they contaminate the product. So, again you cannot withdraw the final product as the bottom product. In the feed if you have some components which are difficult to condense which have low condense temperature, then they require low temperature refrigeration or high pressure for total condensation. These are basically the light ends. In such situation the light components should be removed from the top of the first column. So, that in the subsequent columns you are left with only the components which condense at temperature higher than about 30 to 40 degrees centigrade.

So, you can use cooling water for their condensation and no refrigeration or higher pressure is required. So, these are some of the qualitative guidelines for deciding the column sequence or the practical constraints that may occur. There is a very interesting set of heuristics for selection of sequence for non integrated columns. This means a non integrated column is each column having its own condenser and own re-boiler which is driven by independent utilities.

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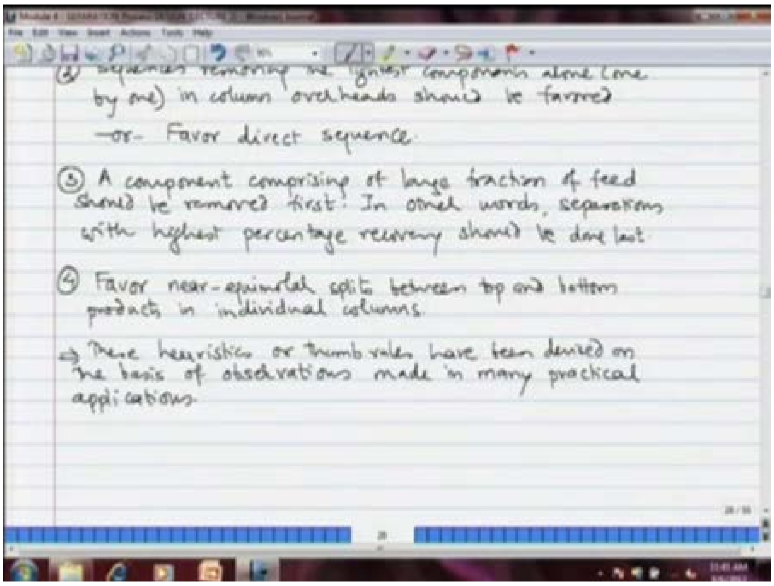

② Sequences removing the lightest components alone (one by one) in column overheads should be favored
—or— Favor direct sequence.

③ A component comprising of large fraction of feed should be removed first. In other words, separations with highest percentage recovery should be done last.

④ Favor near-equimolal splits between top and bottom products in individual columns.

⇨ These heuristics or thumb rules have been derived on the basis of observations made in many practical applications.

So, let us see these heuristics. There are 4 common heuristics. First heuristic says that separation in which relative volatility of key components is close to one or a component which show azeotropic behaviour should be performed in absence of non key components. This is what we have already seen earlier or let us say do the most difficult separation last. Then the second heuristic says that sequences removing the lightest component alone one by one in the column over head would be favoured in a direct sequence.

The third heuristic says that a component comprising of large fraction of the feed should be removed first or in other words separation with the highest percentage recovery should be done last. In this way the net amount of liquid that you are handling or net amount of mixture that you are handling will be lesser and thus the cost of operation will go down. Finally, the fourth heuristic says about the favour near equimolar splits between top and bottom product in individual columns. Now, these heuristics have been devised on the basis of practical observations, that is the data that has been operation data or you know log books that have been operated for long time. So, these are merely practical thumb rules.

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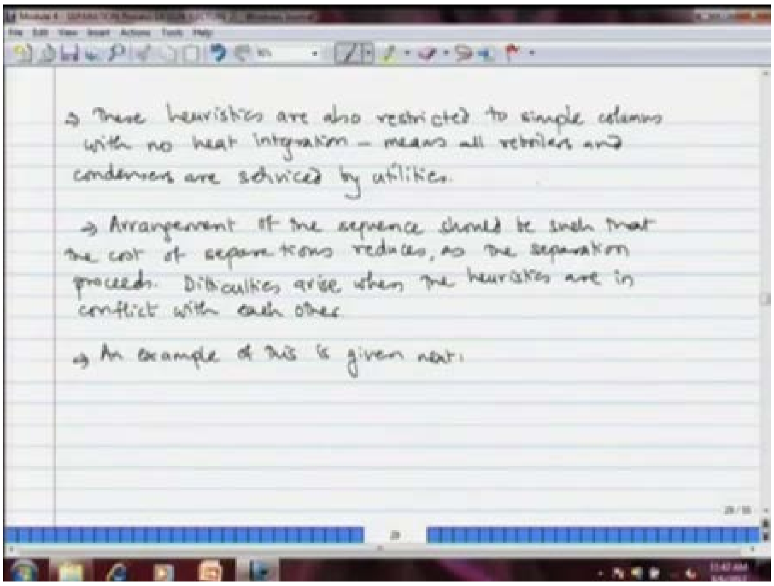

⇒ These heuristics are also restricted to simple columns with no heat integration – means all reboilers and condensers are serviced by utilities.

⇒ Arrangement of the sequence should be such that the cost of separations reduces, as the separation proceeds. Difficulties arise when the heuristics are in conflict with each other.

⇒ An example of this is given next.

These are not devised on any theoretical considerations. Secondly, these heuristics are restricted to simple columns with no heat integration. We solve the re-boilers and condenser service by utilities as I just said. Then arrangement of sequences should be such that the cost of separation reduces as the separation proceeds and difficulties arise when the heuristics are in conflict with each other, like one heuristic will recommend one sequence and another heuristic will recommend another sequence. So, this kind of situation may arise very frequently. Now, let us see an example to which we shall apply the 4 heuristics that we stated just now.

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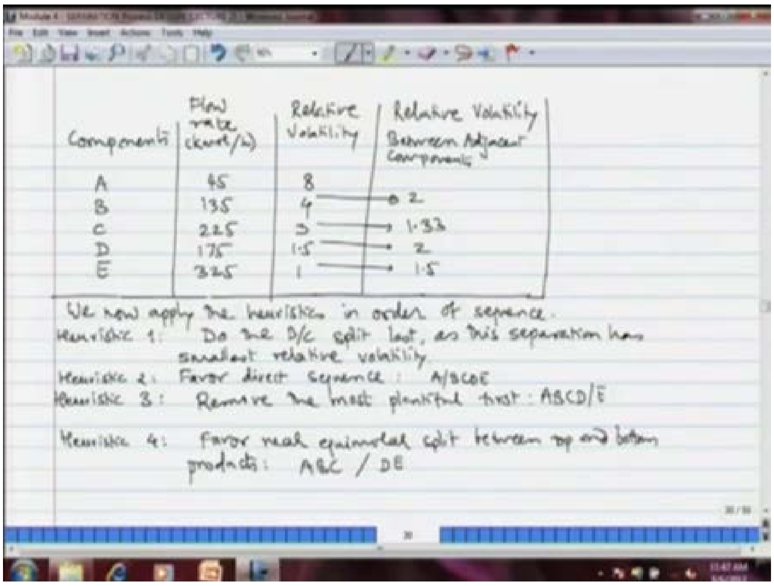

Components	Flow rate (kmol/h)	Relative Volatility	Relative Volatility Between Adjacent Components
A	45	8	
B	135	4	2
C	225	3	1.33
D	175	1.5	2
E	325	1	1.5

We now apply the heuristics in order of sequence.

Heuristic 1: Do the B/C split last, as this separation has smallest relative volatility

Heuristic 2: Favor direct sequence : A/BCDE

Heuristic 3: Remove the most plentiful first : ABCD/E

Heuristic 4: Favor near equimolar split between top and bottom products: ABC / DE

Let us say, we have 5 components in a mixture, so that we have 14 different sequences. The flow rates are given in kilo mole per hour. Component A has 45 kilo mole per hour, component B 135 kilo mole per hour, component C has 225, component D has 175 and component E has three 325. E is the heaviest component. So, we define the relative volatility with respect to it. D has the relative volatility of 1.5, C 3, D 4 and A 8. So, A is the lightest component with highest relative volatility. The relative volatility between components can be calculated by ratio of their relative volatilities with respect to E. For example, the relative volatility of A with respect to B is a divided by 4, that is 2.

Then, relative volatility of B with respect to C is 1.33 whole divided by 3, and so on and so forth. Now, we apply the heuristics in order of sequence. Heuristic, one says that do the most difficult separation last. Now, if you look into all these relative volatilities the relative volatility of B with respect to C is the least, that is 1.33. So, this heuristic says that do the B C split last, as this 6 separation has smallest relative volatility.

Then, heuristic 2 says that favour direct sequence. So, remove A from 4 components. A being the lightest element, so that should be removed first. So, the sequence A B C D E should be favoured. Then heuristic 3 says that remove the most plentiful or highest molar component with highest molar flow rate first. So, that component is E. So, the heuristic 3 recommends the split A B C D from E first. Heuristic 4 which states that favour a near equimolar splits between top and bottom will recommend A B C being separated from D as the first column separation.

So, you can see that 4 heuristics recommend 4 different sequences which are in conflict which each other. Now, what to do in this case? In this case, we have to apply the other constraints based on other practical constraints, etcetera or other considerations like how material is corrosive, heat sensitive, so on and so forth. We have to choose any of these sequence and then reapply the sequences again. So, we start with 1 decision here. We say that we favour direct sequence.

We remove A from the B C D mixture so that we do not require refrigeration or high pressure in the subsequent columns to condense A. So, after removal of A we are left with B C D E mixture. Then you apply the same sequence of heuristics for B C D E mixture and proceed. Again, you will see that these are in conflict with each other again. You have to choose based on your other consideration. You have to choose 1 of the sequence and then apply the 4 heuristics. Now, due to these conflicts it is difficult to establish a good sequence with these heuristics. Although you can arrive at few good sequences, but it is difficult to devise the single best sequence. So, more skill is needed in application of these heuristics and they could be ranked in order of importance.

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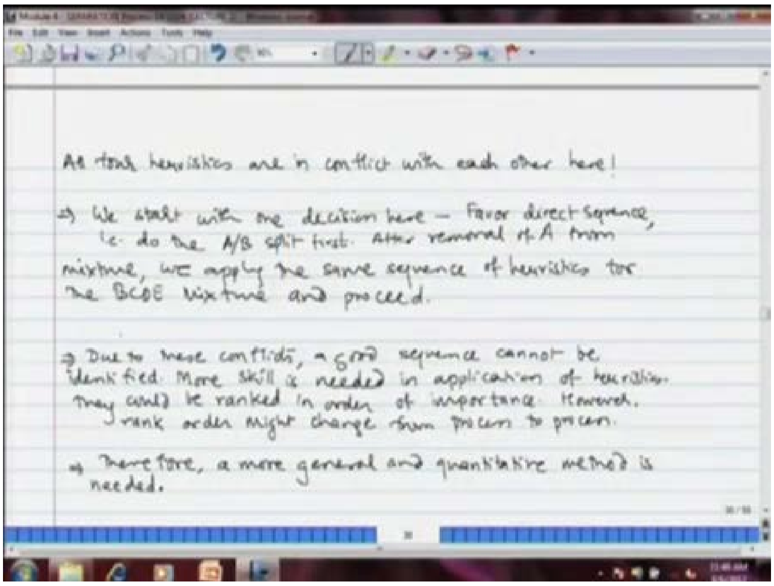

All four heuristics are in conflict with each other here!

⇒ We start with one decision here – Favor direct sequence, i.e. do the A/B split first. After removal of A from mixture, we apply the same sequence of heuristics for the BCDE mixture and proceed.

⇒ Due to these conflicts, a good sequence cannot be identified. More skill is needed in application of heuristics. They could be ranked in order of importance. However, rank order might change from process to process.

⇒ Therefore, a more general and quantitative method is needed.

However, the rank order might change from process to process depending on components of the process and nature of process. Therefore, we need a more general and quantitative method for deciding between the column sequences.

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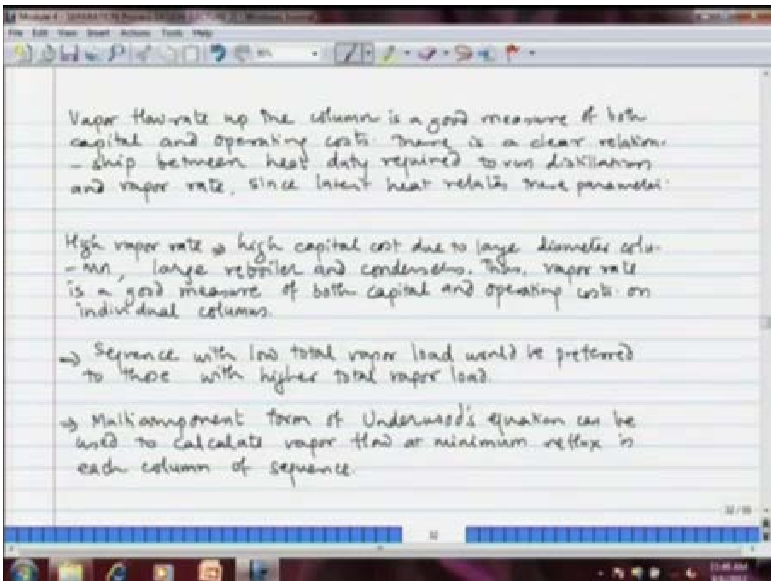

Vapor flow-rate up the column is a good measure of both capital and operating costs. There is a clear relationship between heat duty required to run distillation and vapor rate, since latent heat relates these parameters.

High vapor rate ⇒ high capital cost due to large diameter column, large reboiler and condensers. Thus, vapor rate is a good measure of both capital and operating costs on individual columns.

⇒ Sequence with low total vapor load would be preferred to those with higher total vapor load.

⇒ Multicomponent form of Underwood's equation can be used to calculate vapor flow at minimum reflux in each column of sequence.

Now, vapour flow rate up the column or vapour flow rate inside the column is a good measure of both capital and operating cost. Higher vapour flow rate means you require a fatter column and that increases the fixed cost as well as operating cost. Higher vapour flow rate will also mean higher heat duty at the re-boiler. That means increase in operating cost. Also, by fatter column due to high vapour flow rate increases capital cost. Higher heat duty at re-boiler increases operating cost.

So, you can assume or you can take the vapour flow rate inside the column as a measure of capital and operating cost. You have to choose a sequence that has the minimum vapour flow rate. Now, there are 4 columns in each sequence. So, you have to consider the total vapour flow rate of all 4 columns. Now, how do we determine the vapour flow rate inside a column? We can use the multi component form of Underwood’s equation. These equations, I am sure you have dealt with in the course of mass transfer. So, we take these equations directly. We do not go into the derivation of these equations, but you can find them in the very common textbooks like Perry’s hand book or book by Trebal.

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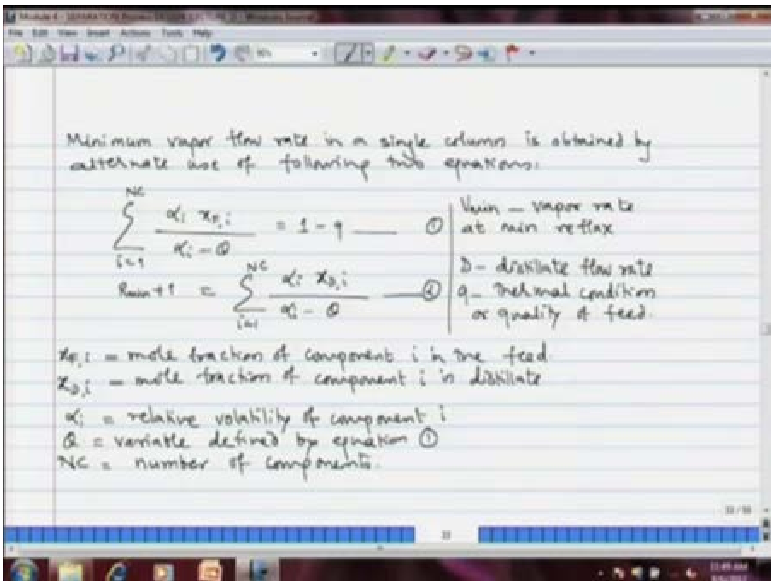

Minimum vapor flow rate in a single column is obtained by alternate use of following two equations:

$$\sum_{i=1}^{NC} \frac{\alpha_i x_{F,i}}{\alpha_i - \theta} = 1 - q \text{ —— } ①$$

$$R_{min} + 1 = \sum_{i=1}^{NC} \frac{\alpha_i x_{D,i}}{\alpha_i - \theta} \text{ —— } ②$$

V_{min} – vapor rate at min reflux

D – distillate flow rate

q – thermal condition or quality of feed.

$x_{F,i}$ = mole fraction of component i in the feed

$x_{D,i}$ – mole fraction of component i in distillate

α_i = relative volatility of component i

θ = variable defined by equation ①

NC = number of components.

The minimum vapour flow rate in a single column is obtained by alternate use of the following 2 equations under Underwood's equations which are a set of two equation. First equation, summation i running from 1 to NC where NC is the total number of components alpha i into x f i, where x f i is the composition of the feed x, f stands for feed and i stands for component.

So, x f i is the mole fraction of component i in the feed. So, alpha i into x f i divided by alpha i minus theta is equal to 1 minus q. Now, q is the thermal condition or quality of the feed. This aspect also you have dealt with in the course of mass transfer. The quality of the feed when the feed is saturated liquid or liquid is at its bubble point, then value of q is 1. If the feed is at its bubble point, then the second equation is R minimum plus 1 is equal to summation i running from 1 to NC alpha i into x D i divided by alpha i minus theta d, stands for distillate. So x D i is essentially mole fraction of component i in distillate. Then you have to solve to first obtain a value of theta which is a variable defined by equation 1 and then substitute that in the second equation.

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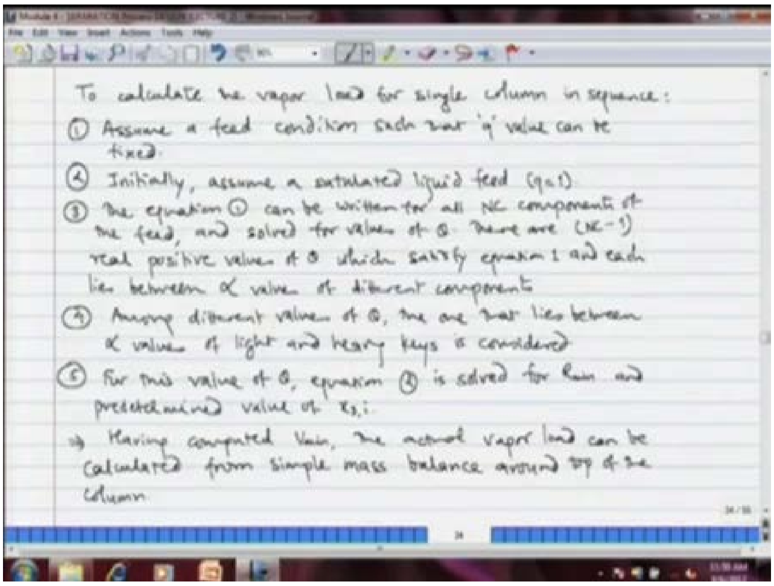


To calculate the vapor load for single column in sequence:

① Assume a feed condition such that 'q' value can be fixed.

② Initially, assume a saturated liquid feed ($q=1$).

③ The equation ① can be written for all NC components of the feed, and solved for values of θ. There are $(NC-1)$ real positive values of θ which satisfy equation 1 and each lies between α values of different components.

④ Among different values of θ, the one that lies between α values of light and heavy keys is considered.

⑤ For this value of θ, equation ② is solved for R_{min} and predetermined value of $x_{D,i}$.

⇒ Having computed V_{min}, the actual vapor load can be calculated from simple mass balance around top of the column.

Now depending on how many components you have, the number of theta values will vary. To calculate the total vapour flow rate for a single column in sequence, first assume a feed condition such that q value can be fixed. As I just said the most common value of q is equal to 1 which corresponds to liquid at its saturation point or liquid at its bubble point. This is the case for most of the columns that are designed k. Then equation 1 can be written for all NC components of the feed and solved for values of theta.

There will be N C minus 1 real positive value of theta which will result as the routes of that polynomial, which satisfy equation 1. Each of these theta values will lie between the alpha values of different components. This is very important that each theta value will lie between the alpha value, between the components. Now among different values of theta, the one that lies between alpha values of the light and heavy key is considered. Let us say B is our light key element and D is our heavy key element. So, the one that lies between alpha B E and alpha D E should be considered.

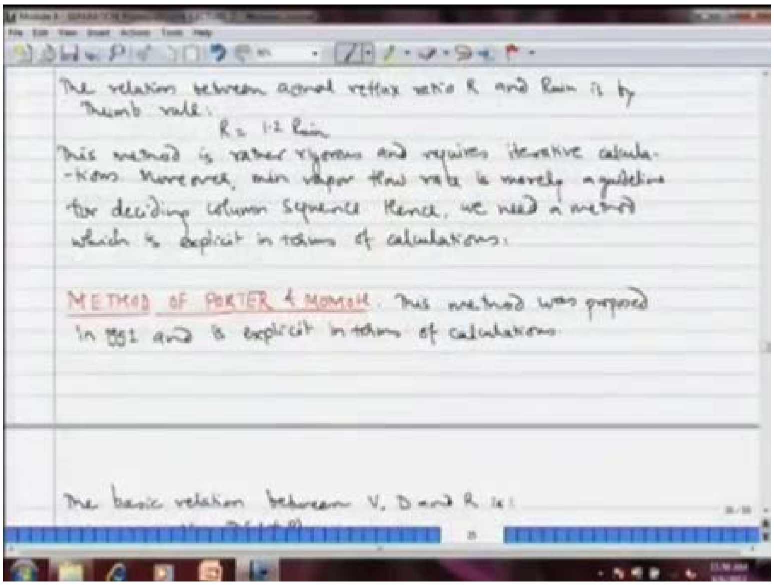
Now, once you get these value of theta. Substitute it in equation 2 and solve it for R minimum. That is the minimum reflex ratio for a predetermined values of x B i. Depending on the purity level that is desired you decide values of x D i, the mole fractions of various components in distillate. If the split is sharp, let us say you are splitting between B and C, if you are using value of or if you have designed your column with alpha B C, then that is ratio of alpha B E and alpha CE.

We have defined usually the relative volatility values are defined with respect to heavy key element. We assume that the heaviest element is the heavy key element. Therefore, all values of alpha are defined with respect to E in a f i component mixture. So, let us say you are splitting between B and C, if B being your light key element and C being your heavy key element, then you split between B and C. Then use value of alpha B C and you use the value of theta that lies between alpha B E and alpha C E.

On the basis of that if the split is sharp, then all components heavier than C will not end up in distillate. All components lighter than B will not end up in the bottoms and then you can decide the values of x D i. Otherwise, you have to calculate the values of x D i depending on the purity or recovery of different components there. Once you do this, then you can substitute these values into the second equation, that is R minimum is equal to summation i equal to 1 to N C. Now, this equation is an explicit equation. It is not implicit as the first one. You can directly solve it and get the value of R minimum, that is the minimum reflex ratio. There is a thumb rule that the actual reflex ratio should be 1.2 times the minimum reflex ratio.

Reflex ratio is a parameter which determines the total cost of a distillation column. You are going learn this particular aspect in the course of mass transfer, where you will be taught as how the operating cost and the fixed cost varies with respect to R. If you have reflex ratio much higher than minimum reflex ratio, we are going to have very few plates. However, the total amount of liquid that will be handling will be high. So, the operating cost will rise. The vapour flow rate will be high.

The liquid boil rate will be high. If you reduce R, that is if you keep it just at R minimum, you require infinite number of plates. So, that is out of question. But, if you keep it just above R minimum, then you are you are going to end up with very large number of plates. That will also increase the total fix cost of your column, however the operating cost will be low. So, if you plot these two cost with respect to reflex ratio somewhere, you are going to hit an optimum. That optimum is usually at 1.2, which means when the actual reflex ratio is 1.2 times the minimum reflex ratio, you have the optimum.



The relation between actual reflux ratio R and R_{min} is by thumb rule:

$$R = 1.2 R_{min}$$

This method is rather rigorous and requires iterative calculations. Moreover, min vapor flow rate is merely a guideline for deciding column sequence. Hence, we need a method which is explicit in terms of calculations.

METHOD OF PORTER & MOMOH. This method was proposed in 1991 and is explicit in terms of calculations.

The basic relation between V, D and R is:

Now, using this thumb rule and the R minimum which is determined from equation 1, you can calculate the vapour flow rate as V is equal to D into 1 plus R, where D is the distillate flow rate and R is the reflex ratio. Now, distillate flow rate again you can calculate by overall mass balance depending on the feed composition recovery, etcetera. Again, these aspects you are going to learn in the course of mass transfer. So, I do not cover it here.

These calculations are explained in course of mass transfer. So, with this you can determine the vapour flow rate of each column and then you add the total vapour flow rate of 4 columns in each sequence and find out which sequence has the minimum total vapour flow rate. However, this method is implicit. It is rigorous. It requires iterative calculations, especially to determine the values of theta from the first equation. Then the minimum vapour flow rate is merely a guideline for deciding column sequence. Therefore, we would like to go for some method which is of explicit nature, which can be easily solved using simple calculator.

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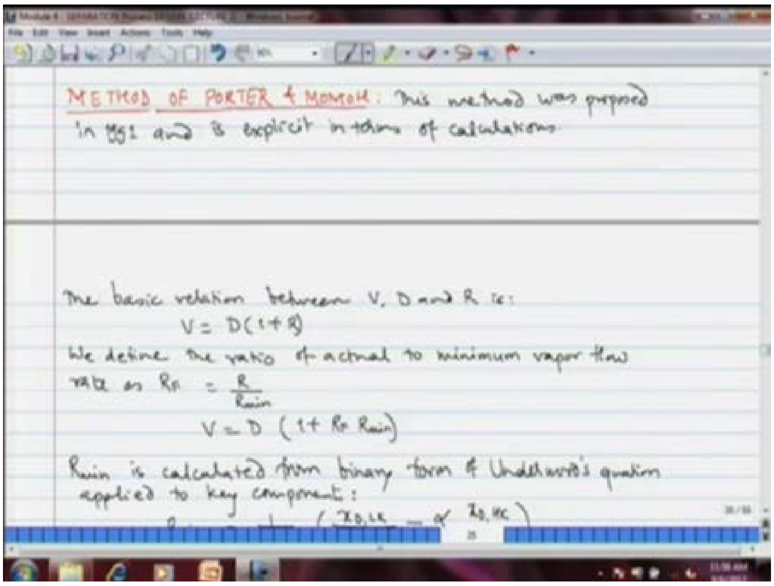

METHOD OF PORTER & MOMOH: This method was proposed in 1991 and is explicit in terms of calculations.

The basic relation between V, D and R is:

$$V = D(1+R)$$

We define the ratio of actual to minimum vapor flow rate as $R_F = \frac{R}{R_{min}}$

$$V = D(1 + R_F R_{min})$$

R_{min} is calculated from binary form of Underwood's equation applied to key component:

Now, Porter and Momoh, these two scientist invented a method in 1991, which is a simpler form of this Underwood’s equation. It is explicit in nature. Now, let us see what the method is the basic relation between the vapour flow rate V, distillate flow rate D and reflex ratio R? It is V is equal to D into 1 plus R. As we just saw, then we define the ratio of actual to minimum vapour flow as R F which is equal to R by R minimum. Then we substitute for R as R f into R minimum. So V becomes equal to D into 1 plus R F by R minimum.

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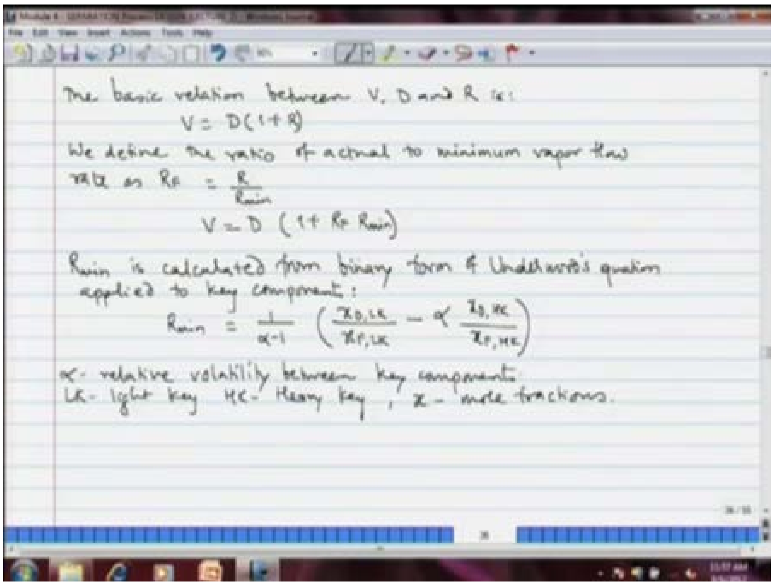

The basic relation between V, D and R is:

$$V = D(1+R)$$

We define the ratio of actual to minimum vapor flow rate as $R_F = \frac{R}{R_{min}}$

$$V = D(1 + R_F R_{min})$$

R_{min} is calculated from binary form of Underwood's equation applied to key component:

$$R_{min} = \frac{1}{\alpha - 1}\left(\frac{x_{D,LK}}{x_{F,LK}} - \alpha \frac{x_{D,HK}}{x_{F,HK}}\right)$$

α - relative volatility between key components

LK - light key HK - Heavy key ; x - mole fractions.

R minimum is then calculated from the binary form of Underwood’s equation applied between key components. So, R minimum is equal to 1 divided by alpha minus 1 into x D l K divided by x K l K minus alpha into x D h K divided by x K h K. Now, this equation for R minimum is derived by solving simultaneously the equation for operating line in the enrichment section in the striping section and the q line that is the quality feed line. Again, this is covered in the course of mass transfer.

So, I do not cover it. When at the minimum reflex ratio, the point of intersection between the striping section and enrichment section falls on the equilibrium curve, so assuming Rout’s law you have the equation for equilibrium curve. That equation plus the equation for operating the enrichment line and the q line should be solved together to get R minimum so that the derivation could be found. In the book by Trebal, however that equation is derived for binary mixture.

Now, here although we have a multi component mixture, we assume it to be binary where the 2 components are heavy key component and light key component. That is how the equation for R minimum is obtained. Alpha is the relative volatility between key components. L k stands for light key, h K stands for heavy key and x stands for mole fraction in this equation

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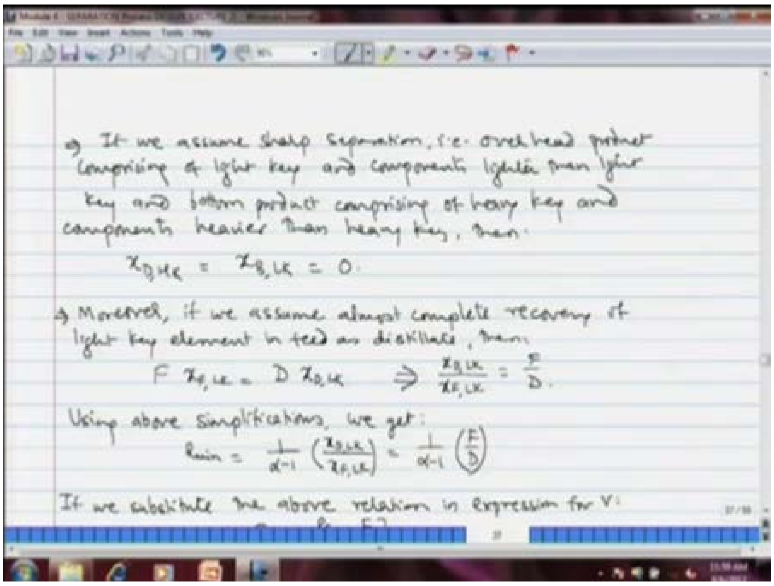

⇒ If we assume sharp separation, i.e. overhead product comprising of light key and components lighter than light key and bottom product comprising of heavy key and components heavier than heavy key, then:

$$x_{D,HK} = x_{B,LK} = 0.$$

⇒ Moreover, if we assume almost complete recovery of light key element in feed as distillate, then:

$$F\, x_{F,LK} = D\, x_{D,LK} \Rightarrow \frac{x_{D,LK}}{x_{F,LK}} = \frac{F}{D}.$$

Using above simplifications, we get:

$$R_{min} = \frac{1}{\alpha-1}\left(\frac{x_{D,LK}}{x_{F,LK}}\right) = \frac{1}{\alpha-1}\left(\frac{F}{D}\right)$$

If we substitute the above relation in expression for V:

Now, if we assume sharp separation, as I just mentioned that if the relative volatilities are different sufficiently large, then you are likely to have a sharp separation. This means, in a 5 component mixture if you have splitting between B and C, then only A and B will appear in the distillate and C D E will appear in the bottoms. No component heavier than C will appear in distillate and no component lighter than B will appear in the bottoms.

That is obvious, so that is the sharp separation that is over head product comprising of light key components. Components lighter than light key bottom product comprising of heavy key components and components heavier than heavy key. If that applies then x D h K, that is mole fraction of heavy key in distillate as well as x B l K, that is mole fraction of light in bottoms is 0. Moreover, if you assume almost complete recovery of light key element in the feed as distillate, then we can say that F into except l K, which is the total light key element molar flow rate into the column, F is the total molar flow rate of the mixture and x F l K is the mole fraction of the light key element in it.

So, F into x F l K is the total light key molar flow rate into the column which is equal to D into x D l K, where x D l K is the mole fraction of light key component in distillate. D is the total distillate flow. So, if the recovery is complete then F into x F l K is equal to D into x D l K. Then for the ratio x D l K divided by x F l K. We can substitute F by D and that exactly we do. We first substitute x D h K is equal to x B l K is equal to 0. Then x D l K divided by x F l K is equal to F by D.

Then R minimum becomes 1 divided by alpha minus 1 into x d l K divided by x F l K. This is then equal to alpha. The same thing simplified further, R minimum is equal to 1 divided by alpha minus 1 into F by D. Then if you substitute this particular value of R minimum into the expression for vapour flow rate, we get V is equal to D into 1 plus R f divided by alpha minus 1 into F by D.

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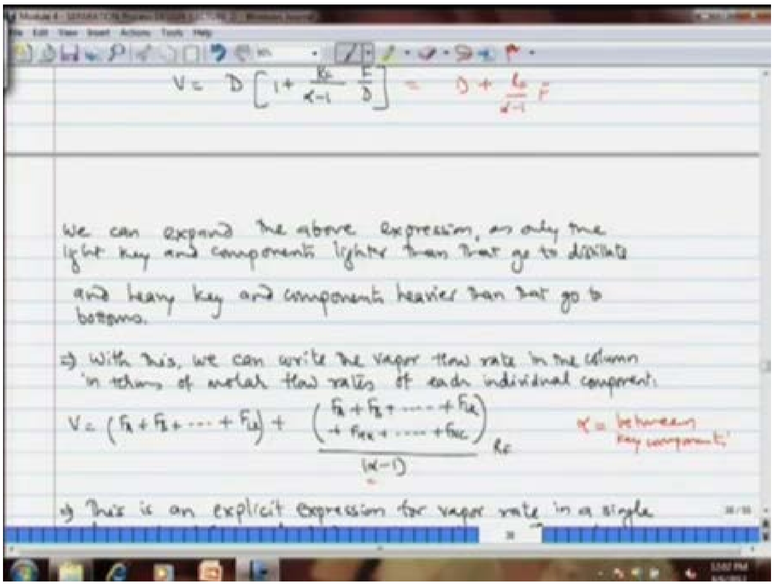

$$V = D\left[1 + \frac{R_f}{\alpha-1}\,\frac{F}{D}\right] = D + \frac{R_f}{\alpha-1}F$$

We can expand the above expression, as only the light key and components lighter than that go to distillate and heavy key and components heavier than that go to bottoms.

⇒ With this, we can write the vapor flow rate in the column in terms of molar flow rates of each individual component.

$$V = (F_A + F_B + \cdots + F_{LK}) + \frac{\begin{pmatrix} F_A + F_B + \cdots + F_{LK} \\ + F_{HK} + \cdots + F_{NC} \end{pmatrix}}{(\alpha-1)} R_f$$

α = between key components

⇒ This is an explicit expression for vapor rate in a single

You can expand this particular expression because we have assumed a sharp separation. That means distillate contains light key and components lighter than light key. So, you can expand the expression as follows V is equal to D. D comprises of F A plus F B up to f l K light key element plus R F into F divided by alpha minus 1. Because once you expand this particular expression, then you get D plus R F into alpha minus 1 into F. That is how and feed comprises of all components F A plus F B up to f N C where N C is the number of components divided by alpha minus 1 into R f. But, remember one important thing that this alpha is alpha between key components.

So, when you apply this particular expression for each column you have to see carefully as where the column is splitting the feed. So, if the column is separating A, let us say you have 5 component mixture, and the first column separates A from B C D E. So, the split is between A and B, because components heavier than B are all going to end up in the bottom. So, for this alpha you have to use alpha A B, but in the next column, let us say B, C is being split from D E as in one of the sequences.

We saw after separation of A from B C D E, we are left with quaternary mixture B C D E. Let us say that the quaternary mixture is being split as B C and D E. Then you have to use alpha C D, because there the split is between the key element C and D. So, when you apply this particular expression we have to be very careful for using the value of alpha to be between the keys elements.

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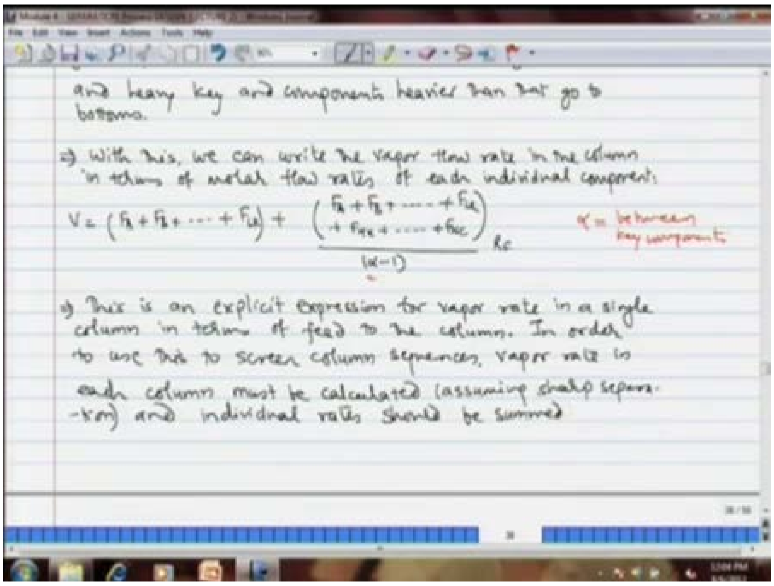

and heavy key and components heavier than that go to bottoms.

⇒ With this, we can write the vapor flow rate in the column in terms of molar flow rates of each individual component:

$$V = (F_A + F_B + \cdots + F_{LK}) + \frac{\begin{pmatrix} F_A + F_B + \cdots + F_{LK} \\ + F_{HK} + \cdots + F_{NC} \end{pmatrix}}{(\alpha - 1)}_{Rc}$$

α = between key components

⇒ This is an explicit expression for vapor rate in a single column in terms of feed to the column. In order to use this to screen column sequences, vapor rate in each column must be calculated (assuming sharp separation) and individual rates should be summed

Alpha has to be that that alpha between the adjacent elements which are being split in each case. Let us say quaternary mixture is being split as A B C D and E in the indirect sequence. Then you have to use alpha D E, because the split is essentially between B and D. The components lighter than D are all going to end up in the distillate. So, this expression is very easy to handle. The only thing you need to known is the flow rate of all components to the column and relative volatilities.

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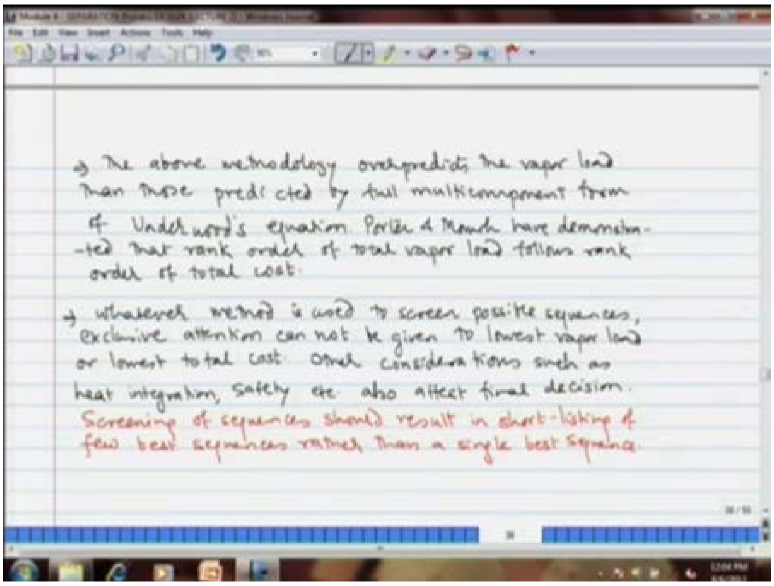

⇒ The above methodology overpredicts the vapor load than those predicted by full multicomponent form of Underwood's equation. Porter & Momoh have demonstrated that rank order of total vapor load follows rank order of total cost.

⇒ Whatever method is used to screen possible sequences, exclusive attention can not be given to lowest vapor load or lowest total cost. Other considerations such as heat integration, safety etc. also affect final decision.

Screening of sequences should result in short-listing of few best sequences rather than a single best sequence.

So, this is an, a very handy tool or very simple explicit expression for determination of the vapour flow rate in a single column in terms of the feed to the column. Then you apply this expression for each column in the sequence and then sum up the total vapour flow rate in the sequence. Now, the short coming of method of Porter and Momoh is that it over predicts the vapour load than that predicated from the full multi component form of Underwood’s equation.

However, Porter and Momoh have demonstrated that the rank order of total vapour of load follows the rank order of total cost. That is proven, also although quantitative vapour flow rate predicated by Porter and Momoh is higher than Underwood’s equation which is a more rigorous method. It has been demonstrated that the total cost follows the total vapour load. So, when we are in the process of short listing from a very larger number of sequences, this method is very useful although quantitatively it may not be very accurate. We are only in the screening process. So, we in that process do not bother much about the quantitative accuracy. Then we can work with this expression to shortlist, let us say 10 best sequences out of 100. When these 10 sequences are obtained, we can further distinguish by more rigorous method.

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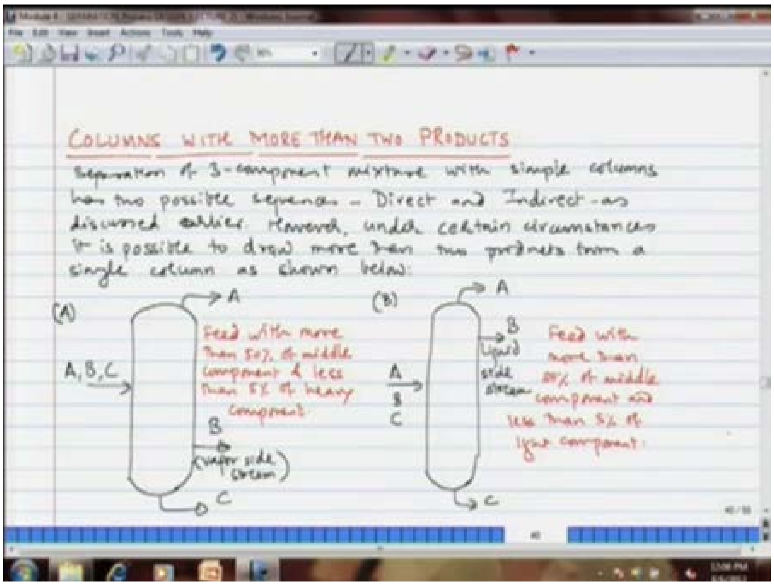

COLUMNS WITH MORE THAN TWO PRODUCTS

Separation of 3-component mixture with simple columns has two possible sequences – Direct and Indirect – as discussed earlier. However, under certain circumstances it is possible to draw more than two products from a single column as shown below:

Feed with more than 50% of middle component & less than 5% of heavy component

Feed with more than 50% of middle component and less than 5% of light component.

Now, we can also have columns with more than 2 product. It is not necessary that each column will have only 1 product at the top and 1 product at the bottom. What I have shown here is an interesting case of a ternary mixture being spit in single column rather than 2 columns separation of 3 component mixture. This simple column has 2 possible sequences, direct and indirect sequence. However, under certain circumstances it is possible to draw more than 2 products from a single column.

Now, if you have a feed such that the middle component B comprises more than 50 percent and either of A and C is less than 5 percent, then case A which is shown here on, the left hand side is for feed with more than 50 percent of the middle component and less than 5 percent of the heavy component. The case B which is show on the right hand side is feed with more than 50 percent of the middle component and less than 5 percent of the light component.

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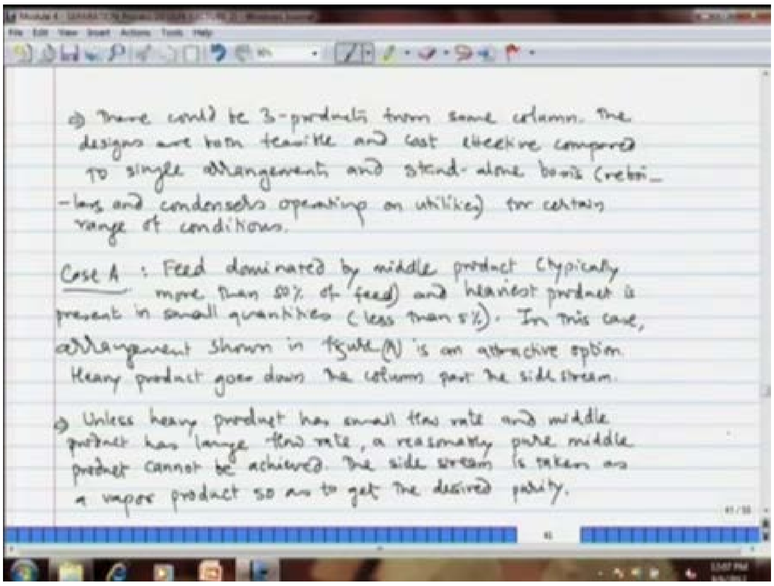

⇒ There could be 3-products from same column. The designs are both feasible and cost effective compared to single arrangements and stand-alone basis (reboi-lers and condensers operating on utilities) for certain range of conditions.

Case A : Feed dominated by middle product (typically more than 50% of feed) and heaviest product is present in small quantities (less than 5%). In this case, arrangement shown in figure (A) is an attractive option. Heavy product goes down the column past the side stream.

⇒ Unless heavy product has small flow rate and middle product has large flow rate, a reasonably pure middle product cannot be achieved. The side stream is taken as a vapor product so as to get the desired purity.

In this case there could be 3 products from the same column. The designs are both feasible and cost effective compared to the single arrangement and stand alone bases. This means that re-boiler and condenser operates on utilities for certain range of conditions if the feed is dominated by middle product and heaviest product is present in small quantities less than 5 percent. That was the case A.

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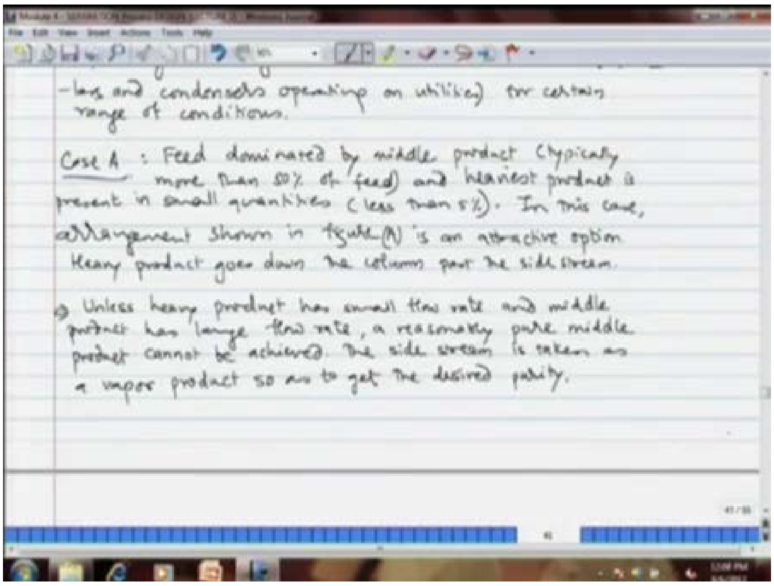

-lers and condensers operating on utilities) for certain range of conditions.

Case A : Feed dominated by middle product (typically more than 50% of feed) and heaviest product is present in small quantities (less than 5%). In this case, arrangement shown in figure (A) is an attractive option. Heavy product goes down the column past the side stream.

⇒ Unless heavy product has small flow rate and middle product has large flow rate, a reasonably pure middle product cannot be achieved. The side stream is taken as a vapor product so as to get the desired purity.

Here, in this case you can go for configuration such that you draw a side product from one of the bottom plates as a vapour side stream, the heavy product goes down the column and passes the side stream. Unless the heavy product has small flow rate and middle product has large flow rate, a reasonably pure middle product cannot be achieved. The side stream is taken off as a vapour product so as to get the desired purity.

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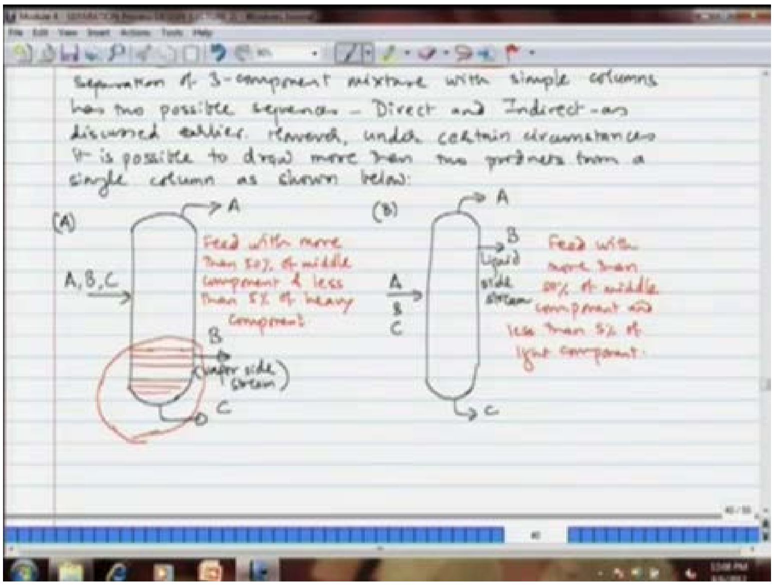

Separation of 3-component mixture with simple columns has two possible sequences - Direct and Indirect - as discussed earlier. However, under certain circumstances it is possible to draw more than two products from a single column as shown below:

Here, what you see is that in the near the bottom plates C will go down. So, the mole frication of C will increase very rapidly in the bottom most plate in the last few plates.

Because the feed is dominated by B, if you take plates which are somewhat somewhere higher than the bottom plates somewhere here, let us say that among the last 10 plates somewhere near the bottom you will see that the mole frication of B is sufficiently high. It may not be 99.9, but it is sufficiently high, say 0.92. If B is not required in that high purity, then you can take off B as a vapour side stream. C is heavier component, so it will be in liquid phase mostly. You take off a vapour side stream.

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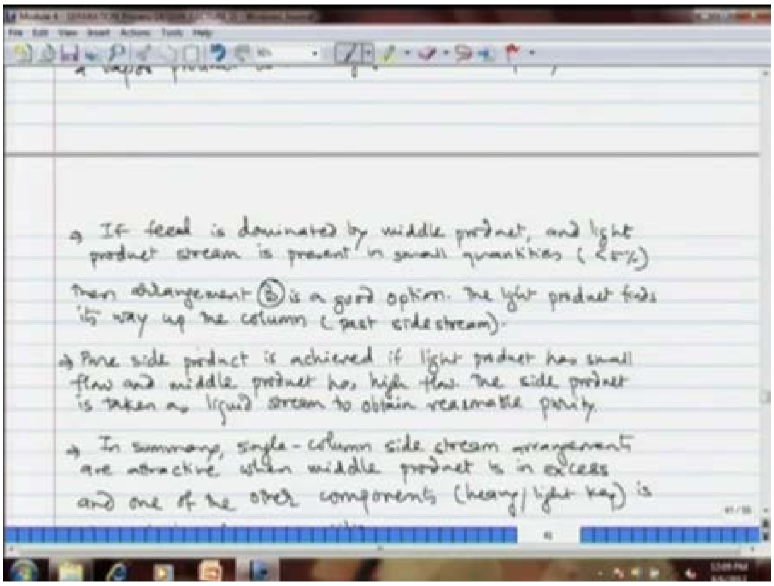

→ If feed is dominated by middle product, and light product stream is present in small quantities (< 5%) then arrangement ⓑ is a good option. The light product finds its way up the column (past side stream).

→ Pure side product is achieved if light product has small flow and middle product has high flow. The side product is taken as liquid stream to obtain reasonable purity.

→ In summary, single - column side stream arrangements are attractive when middle product is in excess and one of the other components (heavy / light key) is

Then, obtain 3 products from the same column. Now, if the feed is dominated by middle product and light product stream is present in small quantities less than 5 percent, then arrangement B is the good option.

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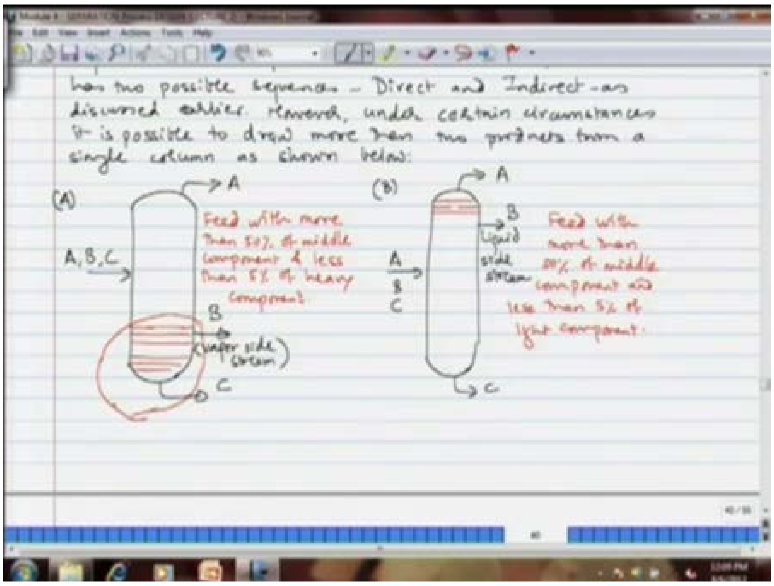

has two possible sequences – Direct and Indirect – as discussed earlier. However, under certain circumstances it is possible to draw more than two products from a single column as shown below:

(A) Feed with more than 50% of middle component & less than 5% of heavy component

(B) Feed with more than 50% of middle component and less than 5% of light component.

Now, here what is happening? Both, A and B flow upward, but the composition of vapour in the top most plates increases very rapidly. The recovery of A is 99.9 percent and purity is also 99.9 percent. So, if you take the top most plates, the vapour rising from these plates will be almost pure A, but if you see the liquid near the top most plates then liquid may have a sufficiently high composition of B, let us say 90 percent, because the total feed is dominated by the middle product.

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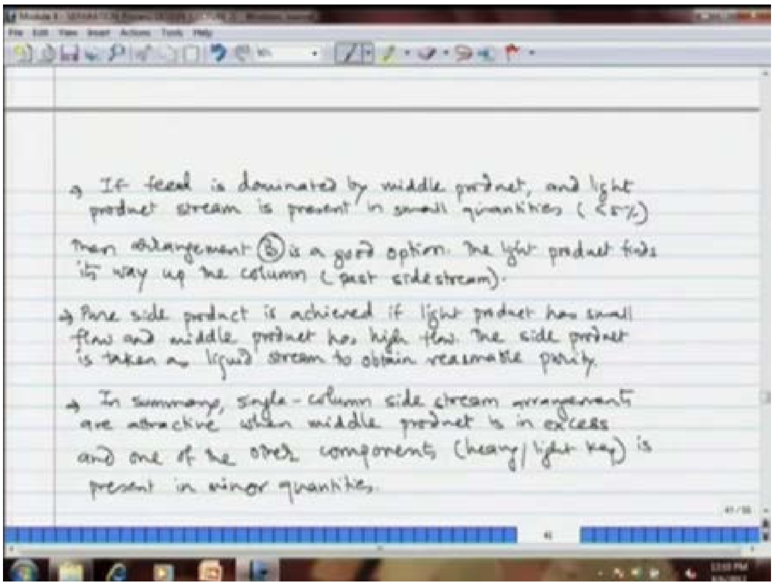

→ If feed is dominated by middle product, and light product stream is present in small quantities (< 5%) then arrangement Ⓑ is a good option. The light product finds its way up the column (past sidestream).

→ Pure side product is achieved if light product has small flow and middle product has high flow. The side product is taken as liquid stream to obtain reasonable purity.

→ In summary, single-column side stream arrangements are attractive when middle product is in excess and one of the other components (heavy/light key) is present in minor quantities.

Then, in the top most plates you may have sufficiently high purity or sufficiently high composition of B so that a side stream can be taken and then again there will be 3 products from the same column. So, a pure side product is achieved if light product has small flow rate and a middle product has high flow rate. The side product is taken off as a liquid stream to obtain reasonable purity. If you take that top most plates, then B being heavy component it will be mostly in the liquid phase.

So, vapours rising will have most of A, the liquid that is there will have sufficiently large quantity or mole fraction of B so as to obtain a side stream. So, in summary single column side stream arrangements are attractive when middle product is in excess and one of the other components either light or heavy component is present in minor quantities. So, in this way you can reduce the operating cost. Remember again, that a side stream may not have very high purity, but in many cases the side stream is recycled to the reactor. So, in that case the purity is not a very big constraint.

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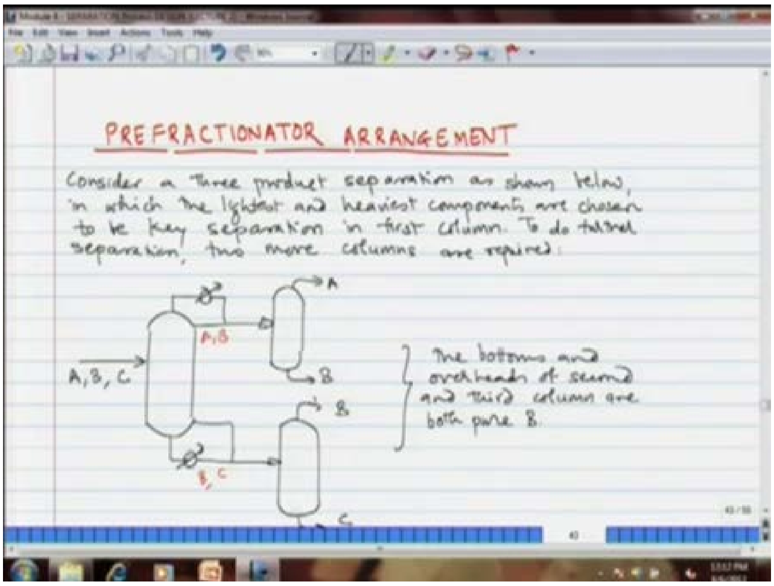

PREFRACTIONATOR ARRANGEMENT

Consider a three product separation as shown below, in which the lightest and heaviest components are chosen to be key separation in first column. To do total separation, two more columns are required.

The bottoms and overheads of second and third column are both pure B.

Then, let us consider another arrangement called pre fractionators. Consider 3 product separation as shown below, in which the light and heaviest components are chosen to be the key separation in the first column. So, the first column splits the A B C mixture not very sharply, but A and some B and C and some B like this. The A and C mostly end up in top and bottom, but B gets distributed and then the mixtures A B are spit in another column. B C are split in another column.

So, totally you require 3 columns. The first column may not have very large number of plates because it is not going for a sharp separation. So, few plates just to separate the components the 3 components A B and BC, B getting distributed between the two streams and then you have individual splits. So, you have basically 3 columns here.

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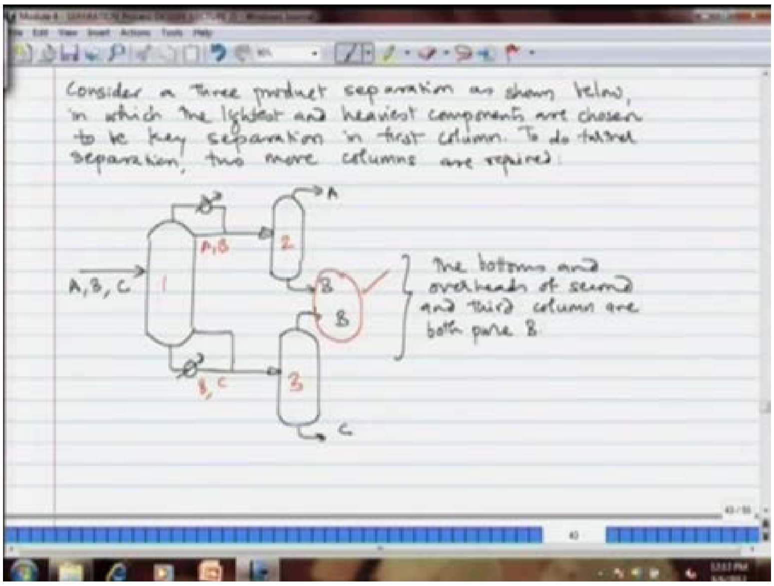

Consider a three product separation as shown below, in which the lightest and heaviest components are chosen to be key separation in first column. To do total separation, two more columns are required:

The bottoms and overheads of second and third column are both pure B.

Now, these columns can be coupled. Especially, the next 2 columns as you will see that the bottom and over head product of the second and third column is same, that is B and both are pure B. So, you can couple these 2 columns and that coupling gives what is known as the pre fractionators.

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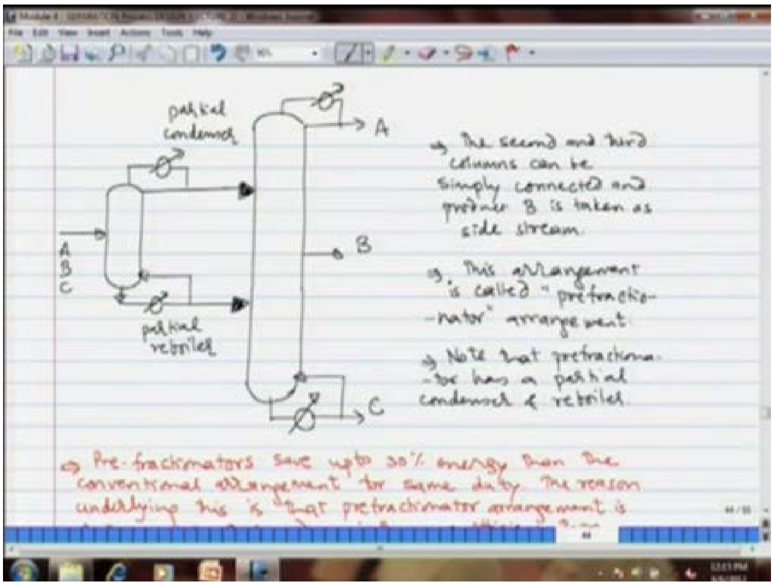

- The second and third columns can be simply connected and product B is taken as side stream.
- This arrangement is called "prefractionator" arrangement.
- Note that prefractionator has a partial condenser & reboiler.

- Pre-fractionators save upto 30% energy than the conventional arrangement for same duty. The reason underlying this is that prefractionator arrangement is

In pre fractionators, the ternary mixture A B C is split into 2 parts, a small column with a partial condenser and a partial re-boiler and then the tall column in which A is take off as the top product, B is the middle product and C is the bottom product. So, from the previous arrangement we are simply connecting the second and third column to obtain B as a side stream. This arrangement is called pre fractionators. So, remember that pre fractionators has a partial condenser and partial re-boiler.

These pre fractionators are reported to save about 30 percent of the energy than the conventional arrangement for the same duty. The reason underlying this is that the pre fractionators arrangement is fundamentally thermodynamically more efficient than the simple arrangement. As described earlier, now let us elaborate on this particular thing. How it is thermodynamically more efficient?

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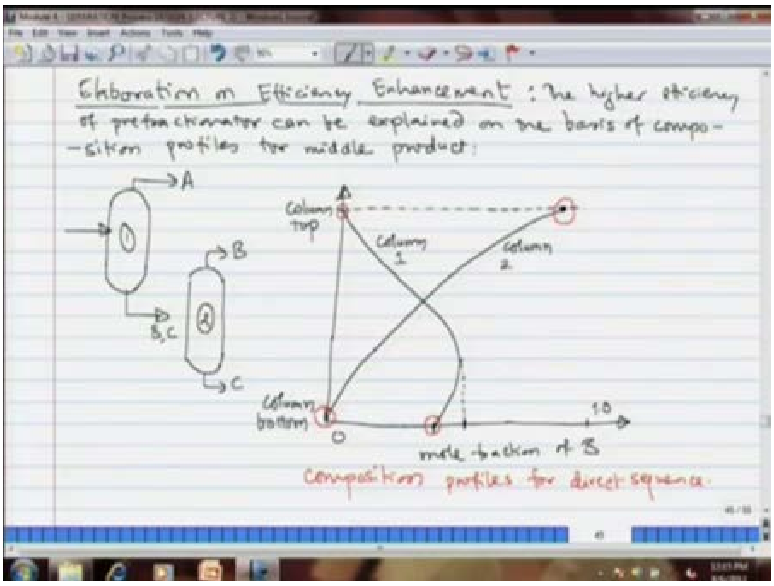

Elaboration on Efficiency Enhancement: The higher efficiency of prefractionator can be explained on the basis of composition profiles for middle product:

Composition profiles for direct sequence.

In the first sequence we were splitting, let us say A from B C and the mixture B C was being split into B and C. Now, this is the composition profile for the 2 columns. We have column 1. The we are plotting mole fraction of B against the column height, so in column 1, the mole frication B is almost 0. This is because A is being obtained as a pure product. However, B ends up in the bottom. So, the bottom of column 1 has sufficiently large concentration of B. Now, this becomes the feed to the next column and then again in the second column, B component is obtained as a top product with sufficiently high purity and C is obtained as the bottom product with high purity. So, the mole fraction of B in the bottom product of second column is close to 0.

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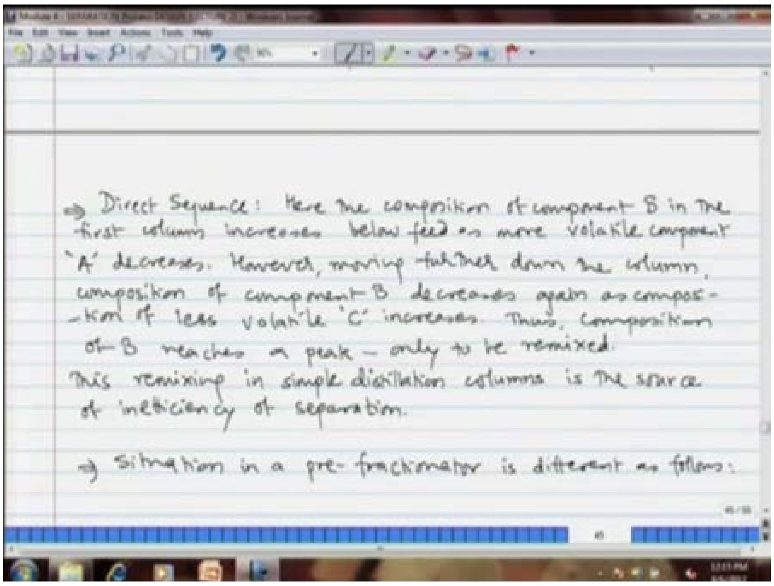

⇒ Direct Sequence: Here the composition of component B in the first column increases below feed as more volatile component 'A' decreases. However, moving further down the column, composition of component B decreases again as composition of less volatile 'C' increases. Thus, composition of B reaches a peak – only to be remixed.
This remixing in simple distillation columns is the source of inefficiency of separation.

→ Situation in a pre-fractionator is different as follows:

Now, in this sequence the composition of component B in the first column decreases below the feed, as more volatile component A decreases. However, moving further down the column the composition of component B decreases again as the composition of less volatile C increases.

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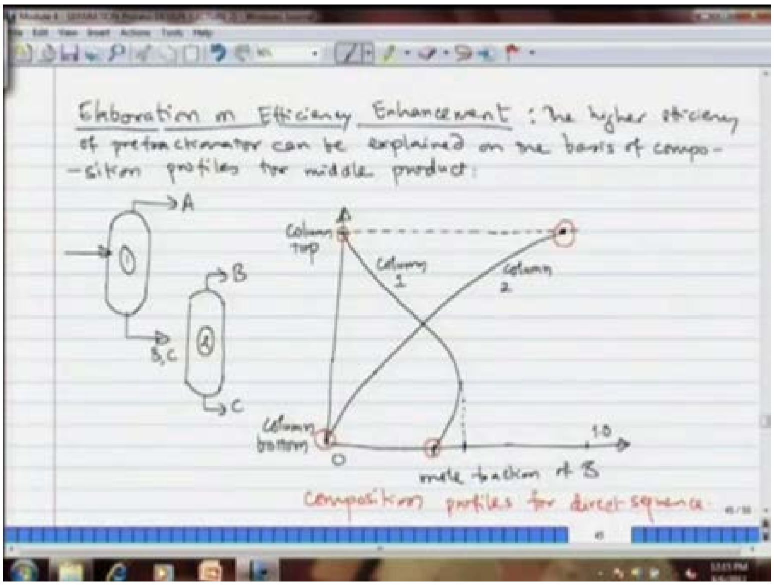

Elaboration on Efficiency Enhancement: The higher efficiency of prefractionator can be explained on the basis of composition profiles for middle product:

composition profiles for direct sequence

So, if you couple the columns and consider them as single entity, you obtain here a maxima for B and then again B is getting remixed into the process. The first column separates A from B C, so as B flows down its concentration increases. In the second column B flows up and then again the construction decreases. So, in between you are going to have a maxima for B. So, the composition of B reaches P only to be remixing and this remixing in simple distillation column is the source of inefficient separation. In pre fractionators, this particular deficiency is removed.

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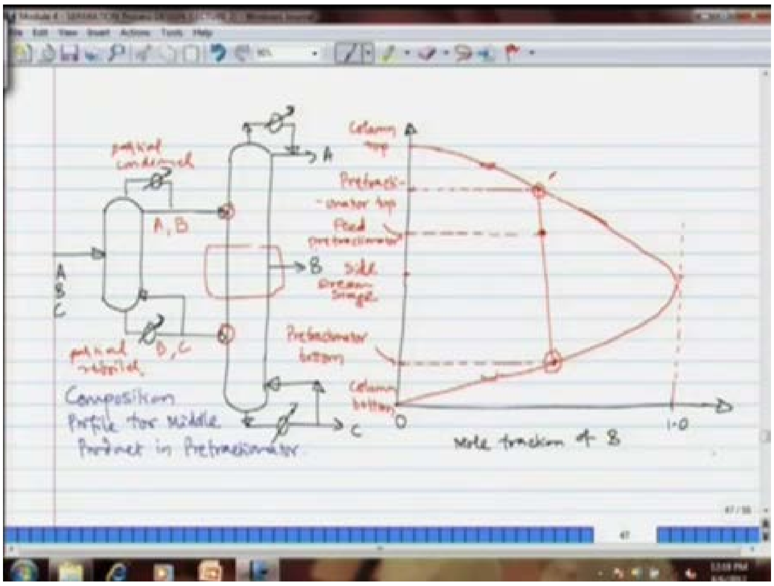

Now, let us see what happens in a pre fractionators. In a pre fractionators the A B C ixture is split into mixture of A B and B C. This mixture A B and B C is of course, as we have a partial condenser and partial re-boiler, fed at the 2 locations in the main column. In pre fractionator system, we are coupling the two columns. Now, what happens here if you see the concentration profile, the mole frication of B being plotted as the column height in the first column?

You get a distribution of B. B does not get sharply separated. B gets distributed between the top and bottom product. So, in both cases you have sufficiently large mole fraction of B column at the top as well as at the bottom. Then after being fed into the main column, as you go to the top of the column, so this is the feed pre fractionators top feed. Here you see that concentration of B decreases as you go to the top because A becomes more and more pure.

So, B flows down if you see bottom part. Then again concentration of B decreases because C flows down. As the purity of C increases and A flows up somewhere in the middle section of the main column, the concentration of B reaches very high. Let us say it is 0.92, close to 1. Then B is taken off as a side stream. So, in this particular case B is not remixed as the earlier case.

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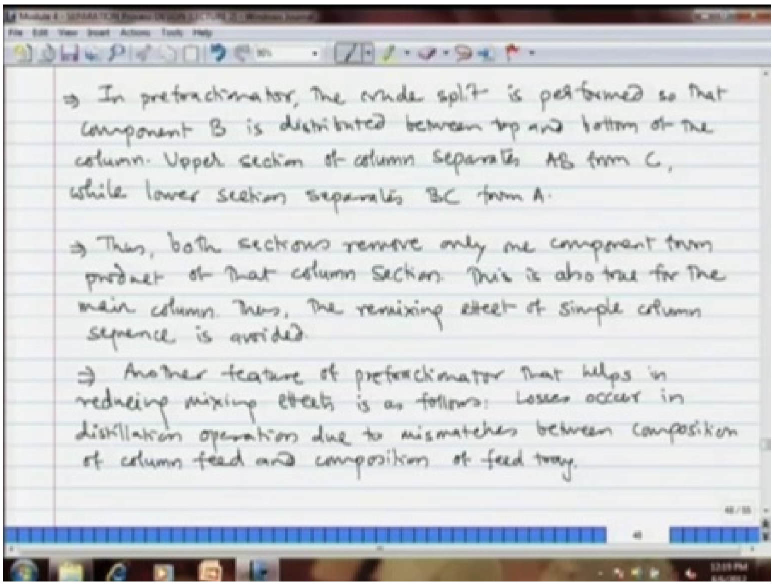

⇒ In prefractionator, the crude split is performed so that component B is distributed between top and bottom of the column. Upper section of column separates AB from C, while lower section separates BC from A.

⇒ Thus, both sections remove only one component from product of that column section. This is also true for the main column. Thus, the remixing effect of simple column sequence is avoided.

⇒ Another feature of prefractionator that helps in reducing mixing effects is as follows: Losses occur in distillation operation due to mismatches between composition of column feed and composition of feed tray.

In both sections of the main column, remove only 1 component from the product of that column section. This is also true for main column. Thus the remixing effect of simple column sequences of hydride helps in increase of the efficiency. Another feature of pre fractionators is that it helps in reducing the mixing effect losses occurring in the distillation operation due to mismatches between composition of the column feed and the composition of the feed tray.

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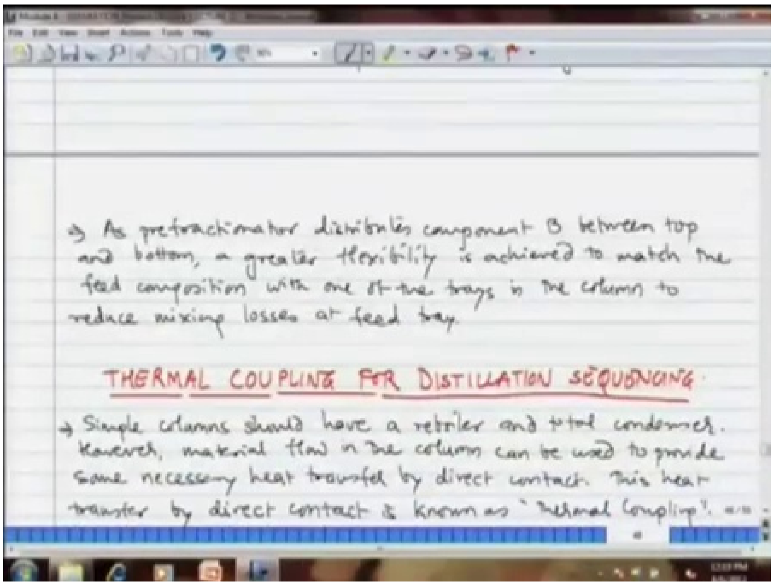

→ As prefractionator distributes component B between top and bottom, a greater flexibility is achieved to match the feed composition with one of the trays in the column to reduce mixing losses at feed tray.

THERMAL COUPLING FOR DISTILLATION SEQUENCING.

→ Simple columns should have a reboiler and total condenser. However, material flow in the column can be used to provide some necessary heat transfer by direct contact. This heat transfer by direct contact is known as "Thermal Coupling".

But here the feed is being split into 2 parts that is 1 part which is richer in A and 1 part which is richer in C. Then these are coupled to the main column. So, as pre fractionators distributes component B between top and bottom, greater flexibility is achieved to match the feed composition with 1 of the trays in the column to reduce the mixing losses. If the composition of the feed is different than the composition of liquid or vapour that is already existent in the feed tray, then you are going to disturb the operation of the column. So, that mixing loss is avoided in a pre fractionators system. Therefore, the total efficiency increases another design aspect.

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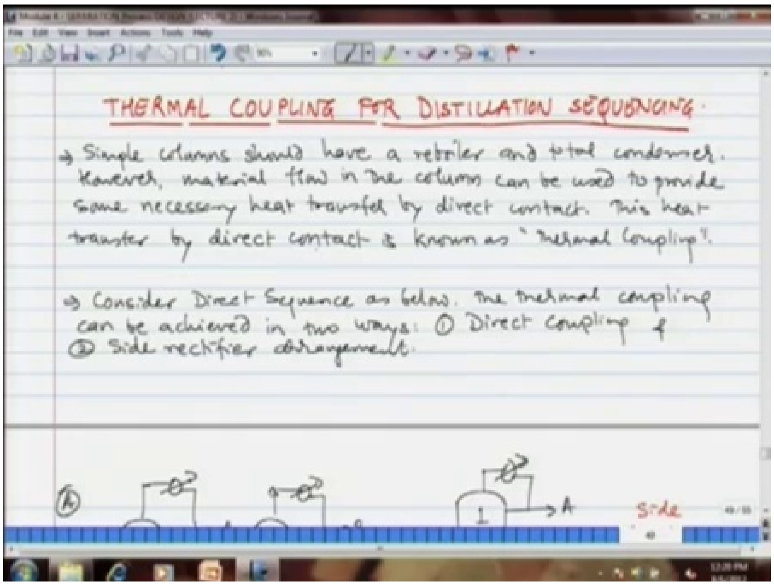

THERMAL COUPLING FOR DISTILLATION SEQUENCING.

→ Simple columns should have a reboiler and total condenser. However, material flow in the column can be used to provide some necessary heat transfer by direct contact. This heat transfer by direct contact is known as "Thermal Coupling".

→ Consider Direct Sequence as below. The thermal coupling can be achieved in two ways: ① Direct coupling & ② Side rectifier arrangement.

Another design variable of columns, is a direct thermal coupling. I told you that how columns can be coupled in the sequence that is vapour of one column condenses into re-boiler of another column, but that can occur when that heat exchange occurs in a heat exchanger, which has limited efficiency. So, there reduction in total thermal efficiency of heat integration, that particular aspect is avoided by direct thermal coupling of distillation columns.

Now, what does that mean is that the vapour from one column will condense directly into the re-boiler liquid of another column. There will be no any kind of a heat exchanger, as such direct thermal coupling. The vapour directly condenses into the liquid. Let us see how that feature occurs? A simple column should have a re-boiler and a total condenser. However, metal flow in the column can be used to provide some necessary heat transfer by direct contact and this heat transfer by direct contact is known as thermal coupling.

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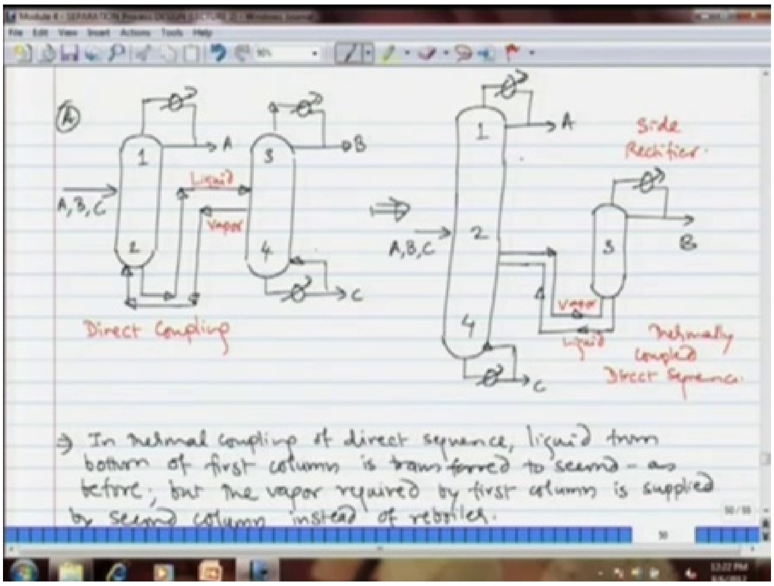

→ In thermal coupling of direct sequence, liquid from bottom of first column is transferred to second - as before, but the vapor required by first column is supplied by second column instead of reboiler.

Now, what I have shown here are by 2 possible sequences of thermal coupling, that is direct coupling which means that you have 2 columns and the vapour that is required by the first column is provided by the second column, while the reflex liquid that is required for the second column is provided by the first column. Direct coupling or side rectifier arrangement, that is called as the thermal coupling of a direct sequence. So, this is what you see on screen. Now, in that particular arrangement we have two columns and see how they are coupled?

We eliminate the re-boiler of the first column by condensing vapour of the second column in the liquid directly. The vapour is the vapour is directly fed into the column and then the liquid that is coming from the first column is directly fed into the second column. Now, these kinds of columns can be coupled as follows. Each column we divide in 2 parts. The first column 1, second column 2, 3, 4 and then you can put the fourth section that is the second section of the second column below 4.

So, below 2, that is below the bottom section of the first column and then you can have this kind of a sequence 1, 2, 4 and 3. Column three is a small column that takes vapour from the main column and returns liquid to the main column. So, that is thermally coupled direct sequence. This particular arrangement takes off B, the middle product as the top product or the distillate product. So, this column 3 is known as a side rectifier.

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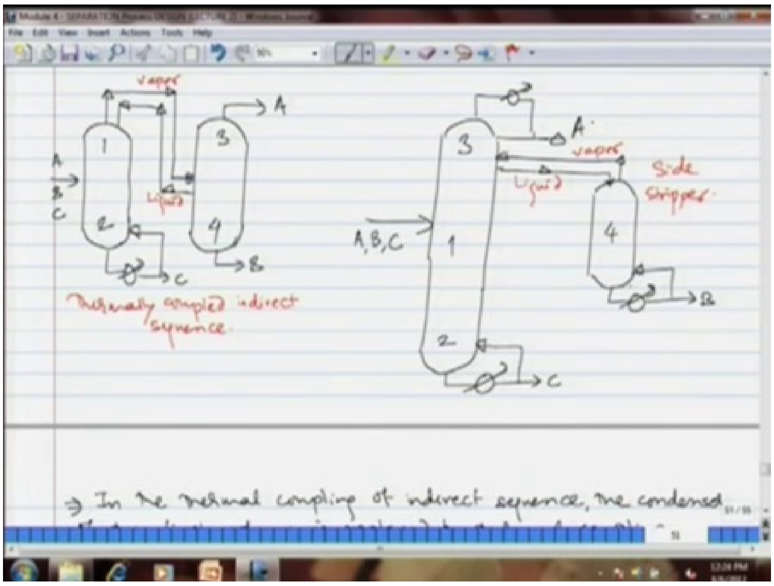

⇒ In the thermal coupling of indirect sequence, the condensed

You can also have a thermal coupling of indirect sequence. Now, that is being shown on here screen column 1 and column 2. Again, column 1 is divided in 2 parts, 1 and 2. Column 2 divided in 2 parts, 3 and 4. Here, you see that the reflex liquid required for the first column is given by the second column while the vapour from the first column goes into the second column. Now, these columns can also be connected. The section 3, that is the top section of the second column, can be put above the top section of the first column.

So, 3 1 2 is the coupling and then you can see a short column which is known as a side stripper besides the main column. Now, the side stripper takes reflex liquid from the main column and then returns vapour to the main column. Here, the middle product V is taken off as a bottom product. So, this particular arrangement is called as a side stripper because the middle product is taken off as a bottom product. In the previous case, the side rectifier, the middle product was taken up as a top product.

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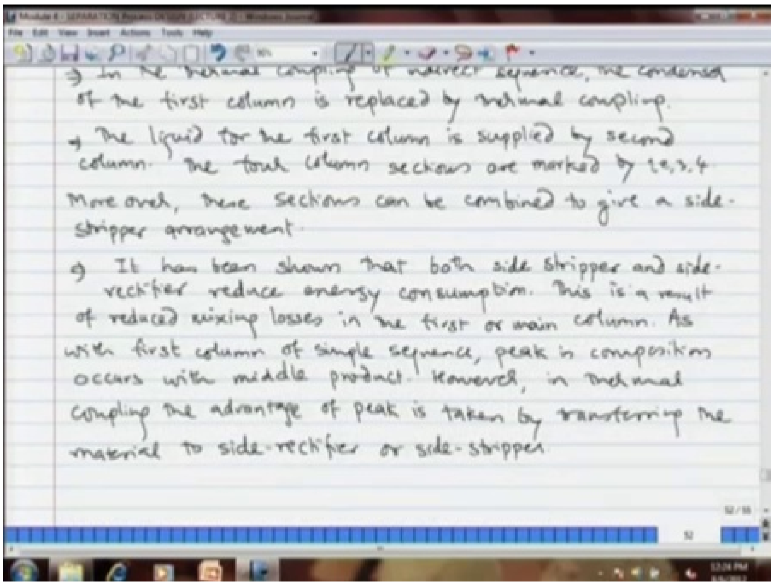

⇒ In the thermal coupling of indirect sequence, the condenser of the first column is replaced by thermal coupling.

→ The liquid for the first column is supplied by second column. The total column sections are marked by 1,2,3,4
Moreover, these sections can be combined to give a side-stripper arrangement.

⇒ It has been shown that both side stripper and side-rectifier reduce energy consumption. This is a result of reduced mixing losses in the first or main column. As with first column of simple sequence, peak in composition occurs with middle product. However, in thermal coupling the advantage of peak is taken by transferring the material to side-rectifier or side-stripper.

It has been shown that both side stripper and side rectifier reduce the energy consumption. This is the result of the reduce mixing loss as we have seen earlier in the first and main column. So, with the first column of simple sequence, the peak end composition occurs with the middle product. However, in a thermal coupling the advantage of the peak is taken by transferring the material to side rectifier or side stripper.

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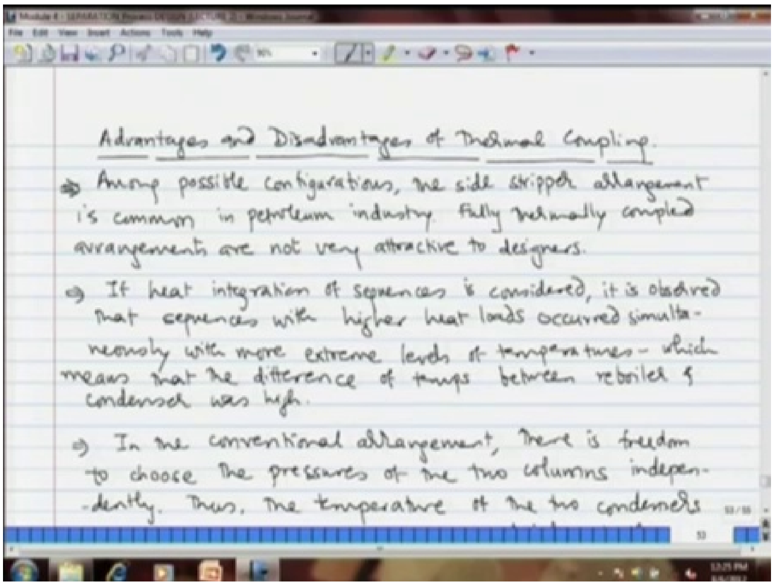

Advantages and Disadvantages of Thermal Coupling.

⇒ Among possible configurations, the side stripper arrangement is common in petroleum industry. Fully thermally coupled arrangements are not very attractive to designers.

⇒ If heat integration of sequences is considered, it is observed that sequences with higher heat loads occurred simultaneously with more extreme levels of temperatures - which means that the difference of temps between reboiler & condenser was high.

⇒ In the conventional arrangement, there is freedom to choose the pressures of the two columns independently. Thus, the temperature of the two condensers

Now, the question comes as if these columns have so much of advantages, should they be always used? But, there are certain limitations. So, let us see the advantages and disadvantages of thermally coupled columns. Among possible configuration, the side stripper arrangement is common in petroleum industry. However, fully thermally coupled arrangements are not very attractive to designers now, why? There are reasons. If the heat integration of sequence is considered it is observed that sequence with higher total heat load occurred simultaneously with more extreme levels of temperatures.

Let us say, you take up the mixture of hydro carbons. If you see the total heat which is supplied at the re-boiler, more or less same heat is recovered at the condenser. However, the temperature of the, that stream goes down. So, although the total amount of heat recovered is same, it is degraded in temperature. We are going to have a quantitative treatment of this in one of the tutorials. We shall determine how we can determine the temperature difference between the distillate bottoms by using the feed conditions and relative volatility. Now, if you have higher heat load and more extreme levels of temperature, then the sequence is not suitable for heat integration.

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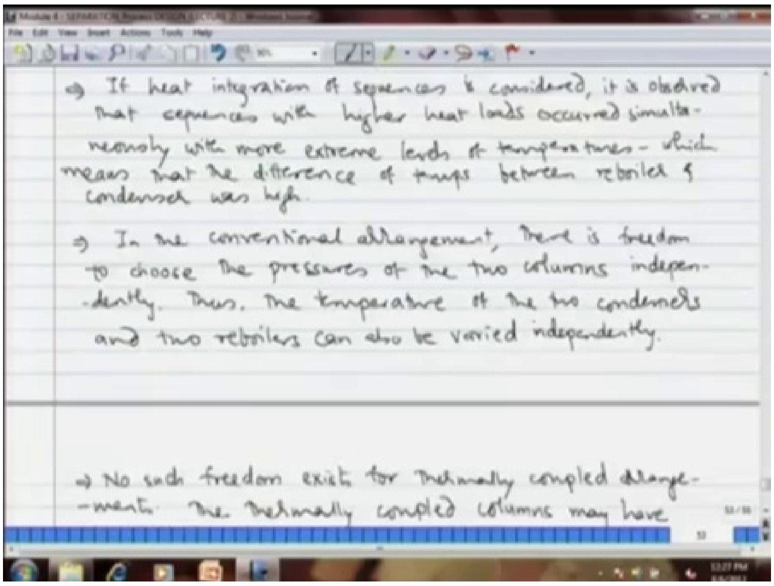

⇒ If heat integration of sequences is considered, it is observed that sequences with higher heat loads occurred simultaneously with more extreme levels of temperatures - which means that the difference of temps between reboiler & condenser was high.

⇒ In the conventional arrangement, there is freedom to choose the pressures of the two columns independently. Thus, the temperature of the two condensers and two reboilers can also be varied independently.

⇒ No such freedom exist for thermally coupled arrangement. The thermally coupled columns may have

So, in the conventional arrangement there is freedom to choose the pressure of the 2 columns independently. Thus the temperature of the 2 condensers and re-boilers can be also varied independently. Suppose, you have to couple 2 columns, then as I said when you vary the pressure, it increase the vapour condensing temperature in one case and reduces the re-boiler temperature. Let the vapour condense into re-boiler of another column and then you heat integrate, but when you have a thermally coupled sequence that particular freedom is gone.

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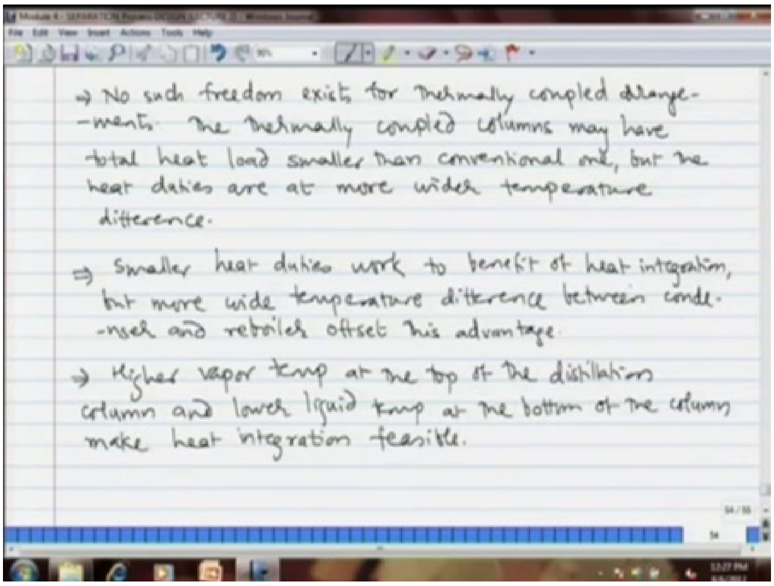

⇒ No such freedom exist for thermally coupled arrangement. The thermally coupled columns may have total heat load smaller than conventional one, but the heat duties are at more wider temperature difference.

⇒ Smaller heat duties work to benefit of heat integration, but more wide temperature difference between condenser and reboiler offset this advantage.

⇒ Higher vapor temp at the top of the distillation column and lower liquid temp at the bottom of the column make heat integration feasible.

So, you cannot have temperatures of the 2 condensers and re-boiler varied independently. So, that is the major discrepancy. Then smaller heat duties work to the benefit of heat integration, but more wide temperature difference condenser and temperature upsets this advantage. The higher vapour temperature at the top of the distillation column and lower liquid temperature at the bottom of the column makes heat integration feasible. So, that is that feature we have to see rather than thermal coupling.

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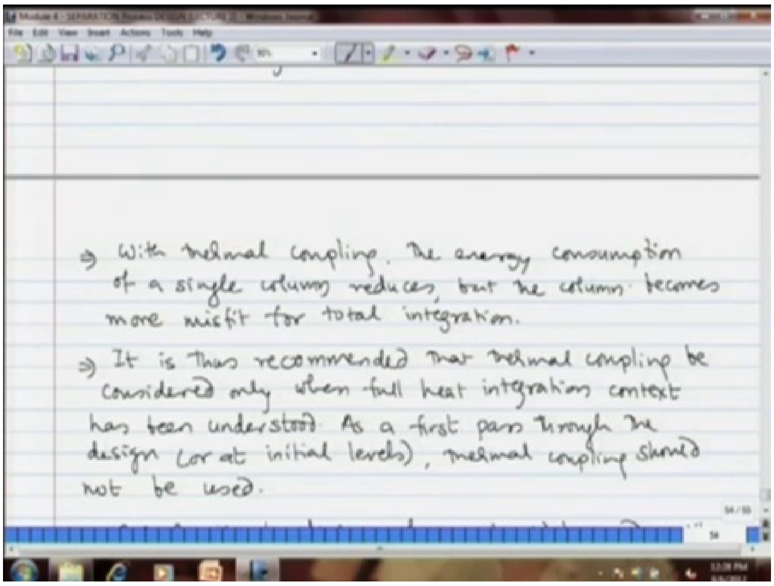

⇒ With thermal coupling, the energy consumption of a single column reduces, but the column becomes more misfit for total integration.

⇒ It is thus recommended that thermal coupling be considered only when full heat integration context has been understood. As a first pass through the design (or at initial levels), thermal coupling should not be used.

With thermal coupling, the energy consumption in a single column reduces, but the column becomes more misfit for total integration. Because to do all these thermal coupling, we have temperatures fixed. So, you cannot vary the pressures independently. So, let us say you have another process stream with surplus heat which is at slightly higher temperature. So, let us say you want to reduce the pressure of your column so that your re-boiler can be coupled with that stream. Now, that freedom is gone when you have a thermally coupled column.

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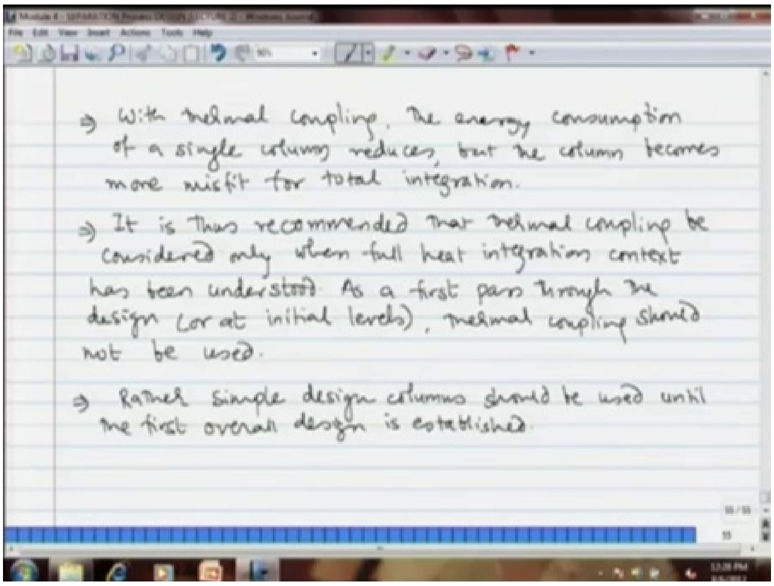

⇒ With thermal coupling, the energy consumption of a single column reduces, but the column becomes more misfit for total integration.

⇒ It is thus recommended that thermal coupling be considered only when full heat integration context has been understood. As a first pass through the design (or at initial levels), thermal coupling should not be used.

⇒ Rather simple design columns should be used until the first overall design is established.

Therefore, it is often recommended that the thermal coupling be considered only when full heat integration context has been understood. So, consider thermal coupling only when you have the complete data and you have complete heat integration. As a first pass through the design or at initial levels, thermal coupling should not be considered because it is going to severely cut down your degrees of freedom in the design. Rather, simple design columns should be used until the first word, that is the overall design is established. So, this factor we need to note before designing the distillation columns. In the next lecture, we shall see some quantitative treatment. We shall see how to determine the height of the column? How to determine the diameter of the column? And what are the different types of distillation columns that are available?