Mass Transfer Operations I
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Module - 5
Distillation
Lecture - 13
Multicomponent Distillation

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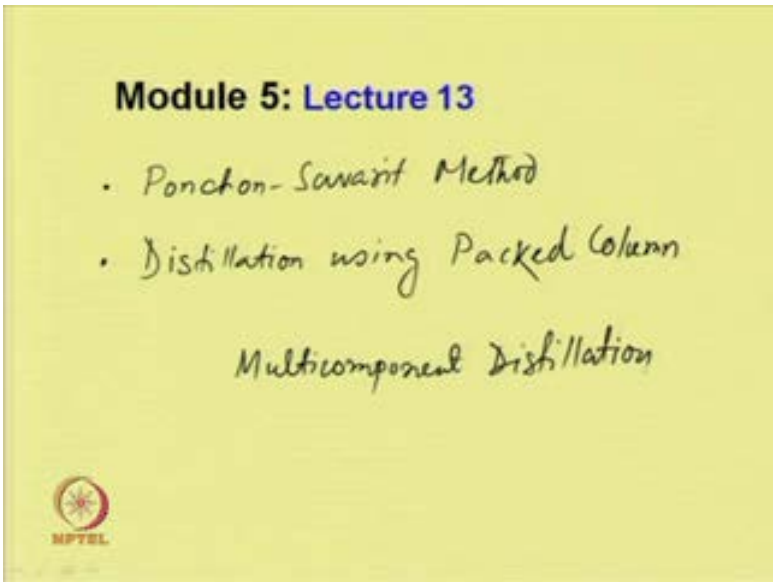

Welcome to the 13 lecture of distillation which is module 5 before we go to the discussion on lecture 13 we just have a recap of our previous lecture. In our previous lecture, we considered the design method of distillation using ponchon-savarit method, ponchon-savarit method and we discussed with their example how to calculate the number of plates required for a particular separation or specific separation, and secondly we have discussed the distillation, distillation using packed column. Today, we will discuss on multicomponent distillation this is basically a preliminary introductions to multicomponent system.

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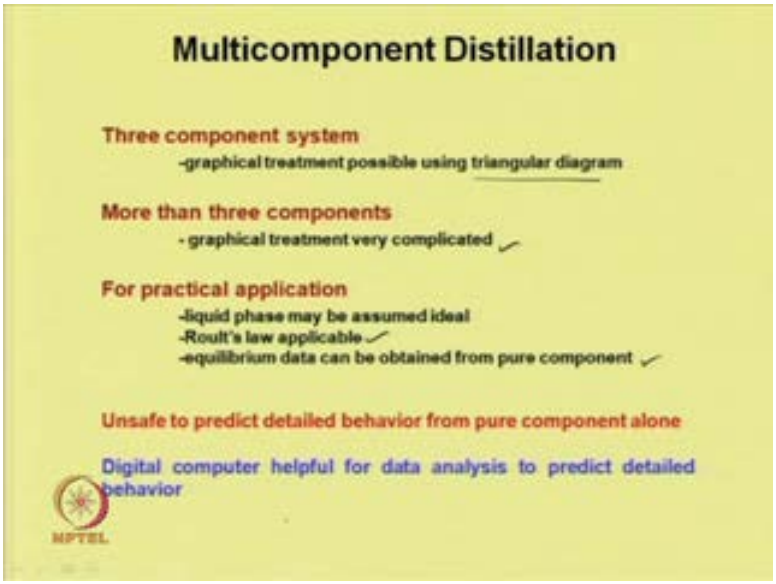

So, we will discuss multi-component distillation, for multi-component distillation if three component system then the graphical treatment can be possible if we use the triangular diagram. So, using triangular diagram we can do the graphical treatment, but more then three component systems the graphical methods becomes very complicated so graphical treatment method not desirable.

Most of the practical applications, we assume liquid phase is ideal where the roult's law can be applicable and equilibrium data can be obtained from the pure component data. This is in case of most practical applications we do that, but it is unsafe to predict detail behavior from the pure component alone or from the binary systems. In this case, for rigorous calculations digital computers are helpful for data analysis to predict the detail behavior.

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The general approach to solve multicomponent system is similar to the binary systems what we adopted over there that is one mass balance for each component and enthalpy balance are similar to those for binary systems, equilibrium relations in this case is little bit complicated, equilibrium data are used to calculate multicomponent bubble and due points; and the two limiting cases as we observed in case of the binary systems that is the total reflux and minimum reflux similar to the binary system it also applies in this cases. Rigorous methods, which are available for multicomponent distillations that is using computers, but there are some approximates or shortcut methods, which are more common for preliminary design.

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Today, we will discuss some of the shortcut method how to calculate the number of plates required to get a desired separation. In this case, we will considered how many towers for multicomponent systems are required as we have seen for binary system one tower is used to separate two components into relatively pure components, but for multicomponent systems n minus 1 fractionators required for the separation of n components that means if we have a three component system then n would be 3 n minus 1 is equal to 2 so 2 towers are required for the given separation.

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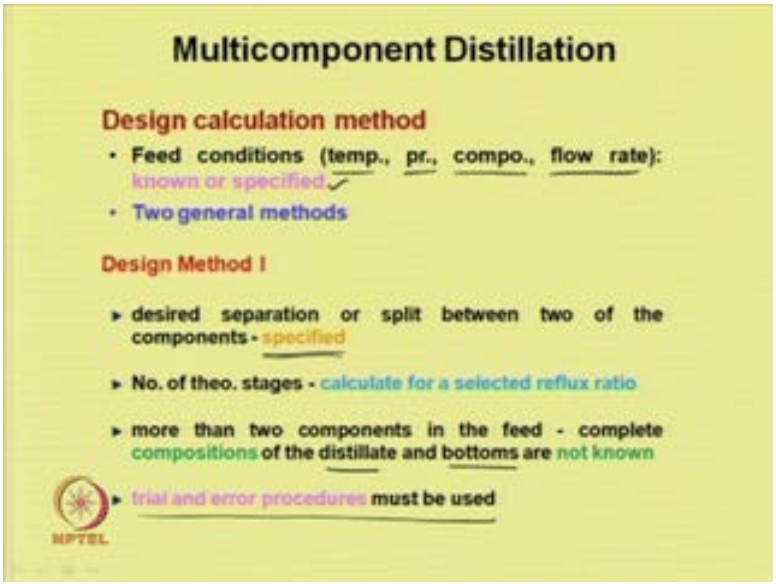

So this is the number of distillation tower required for a given separation. Now, design calculation method feed conditions temperature, pressure, composition, flow rate these are either known or specified. Then there are two general methods one is method one where desired separation or split between the two components between two of the components are specified. Now, number of theoretical stages this can be calculated from a selected reflux ratio number of theoretical stages which we required this can be calculated from a selected reflux ratio more than two components in the feed complete compositions of the distillation bottoms are not known. In this case, since the complete compositions of the distillate and the bottoms are not known for multi component systems, so trial and error procedures must be use to often the compositions.

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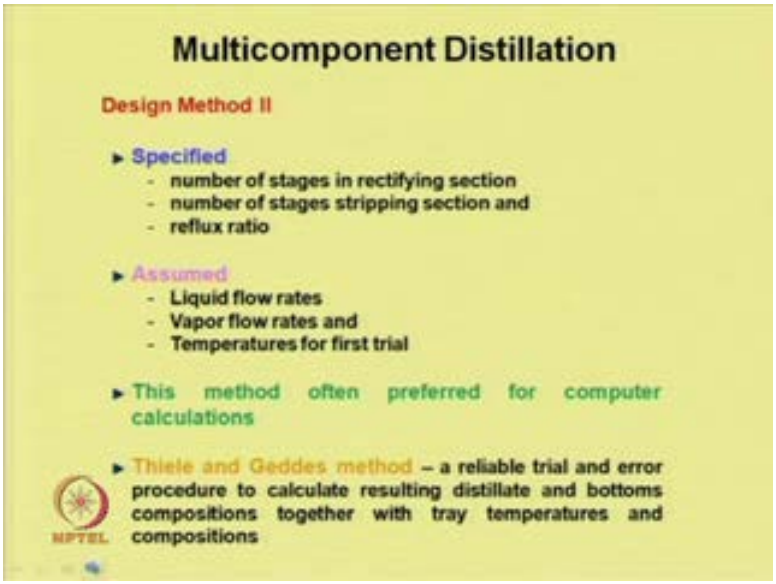

How to do that, we will discuss that in next few slides so design method to where what are the thing specified the number of stages in rectifying section, number of stages in stripping section, and the reflux ratio these are specified and assumed is liquid flow rate, vapor flow rate, and temperatures for first trial these are the assumed and then this method often preferred for computer calculations. Now, Thiele and Geddes method reliable trial and error procedure to calculate resulting distillate and bottom compositions together with the try temperatures and compositions. Thiele and Geddes methods are very reliable to do the trial and error procedure.

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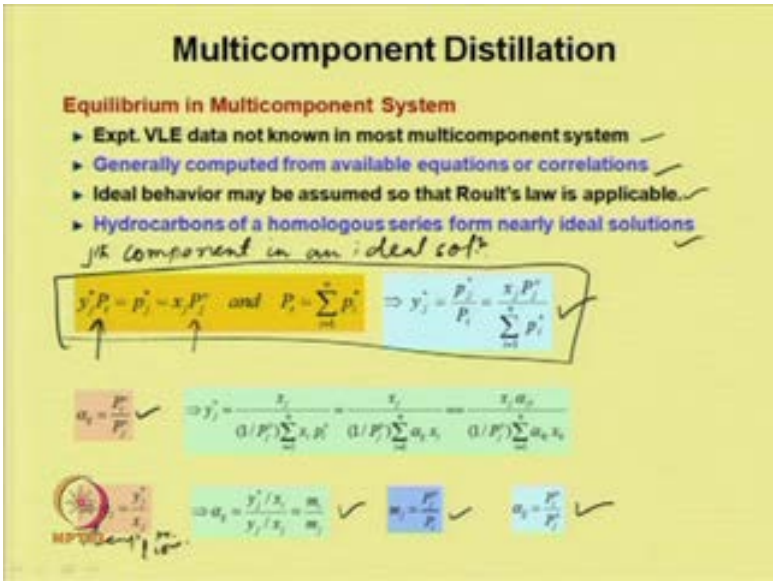

Now, in multicomponent systems how to obtain the equilibrium data. So, equilibrium in multicomponent systems experimental VLE data vapor liquid equilibrium data which are not known in most multicomponent system. Generally, these are computed from available equations or correlations. So, it is not known and generally it is computed ideal behaviour may be assumed so that Roult's law is applicable and as we know for hydrocarbons of a homologous series for nearly ideal solutions. Now, for jth component in an ideal solutions we can write y j star P t is equal to P j star is equal to x j P j v where x j is the mole fractions in the liquid phase, P j v is the vapor pressure of component j at a given temperature, and P t is the total pressure.

So then, P t for n component number of component if n it will be summation over i is equal to one to n P i star that is a total pressure the vapor pressure of the components in the mixture are known at a given temperature. Therefore, for a particular liquid compositions say x one to x n the vapor compositions can be calculated from this equations y j star is equal to P j star by P t is equal to x j P j v divided by summation over i is equal to 1 to n P i star. We know that, relative volatility between the component i and j is alpha i j which is equal to P i v divided by P j v and if we substitute this relations in this equations we can obtain y j star is equal to x j divided by 1 by P j v summation over i is equal to 1 to n x i P i v which is equal to x j divided by 1 by P j v summation over I equal to one to n alpha i j x i. We can also write x j alpha j i divided by 1 by P j v summation over i is equal to 1 to n alpha k i x k.

So, once the equilibrium vapor mole fractions are known the partial pressure, and the total pressure can be calculated from this relations. For multicomponent systems, generally the equilibrium data is defined in terms of the distribution coefficients for component j m j is the distribution coefficient which is equal to y j star divided by x j and this m j also depends on temperature, pressure and compositions of the mixtures and the relative volatility we can write, alpha i j would be equal to x j star by x i divided by y j star by x j which would be equal to m i by m j. For ideal solutions, at moderate pressure m is independent of composition and only depend upon the temperature, and the total pressure. So, m j is equal to P j v by P t, and, than alpha i j would be equal to P i v by P j v. Now, we will look how to do the bubble point and dew point calculations.

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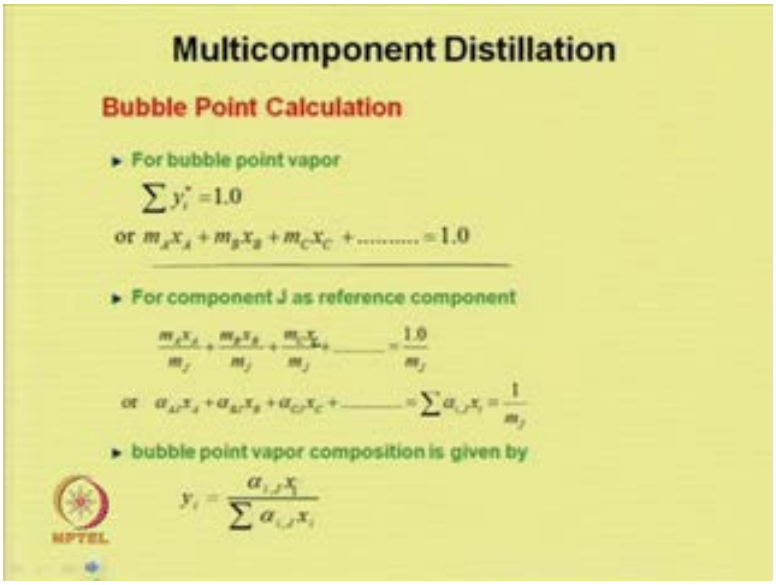

For bubble point calculations, if it is bubble point vapor summation over y i star would be equal to 1.0. So, we can write m A x A plus m B x B plus m C x C and so on would be 1.0. Now, if we considered J as the reference component we can write m A x A divided by m j plus m B x B divided by m j plus m C x C divided by m j and so on would be equal to 1 by m j or we can write alpha A j x A plus alpha B j x B plus C j x C and so on would be equal to summation over alpha i j x i would be equal to 1 by m j bubble point vapor composition which can be calculated y i would be equal to alpha i j x i divided by summation over alpha i j x i. If the liquid composition and total pressure is fixed the calculation of temperature can be made by trial and error satisfying this

equations, and its convergence is very rapid since change of alpha with temperature is very slow.

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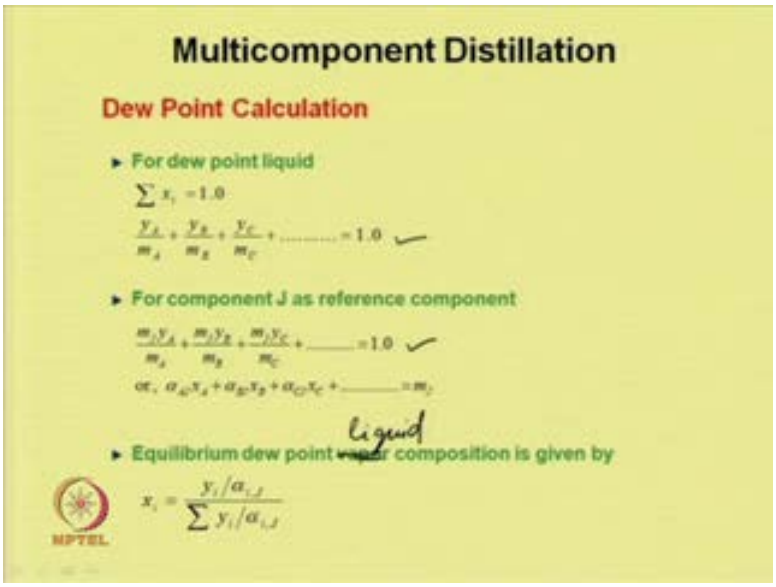

We will discuss this with an example, the dew point calculations which is similar to the bubble point calculations for dew point summation over x i would be equal to 1.0. So, we can write y A by m A plus y B by m B plus y C by m C and so on equal to 1.0. Now, if we considered j as reference component so m j y A by m A plus m j y B by y m B plus m j y C by m C and so on would be equal to . So, we can write alpha A j x A plus alpha B j x B plus alpha C j x C and so on would be m j and the equilibrium dew point liquid compositions can be written as x i is equal to y i divided by alpha i j divided by summation over y i by alpha i j.

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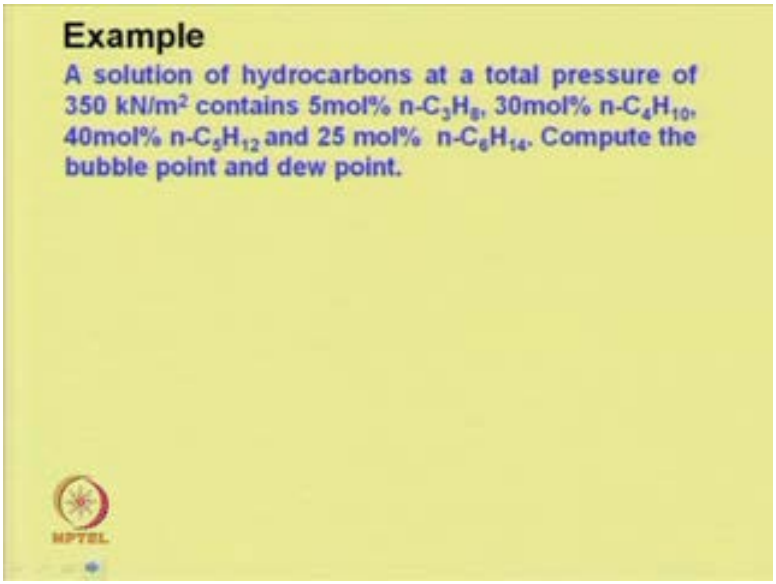

Let us take a very simple example or solution are hydrocarbons at a total pressure of 350 kilo newton per meter square, which contains 5 mole percent n propane normal propane 30 mole percent butane normal butane 40 mole percent normal pentane and 25 mole percent normal hexane compute the bubble point and due point.

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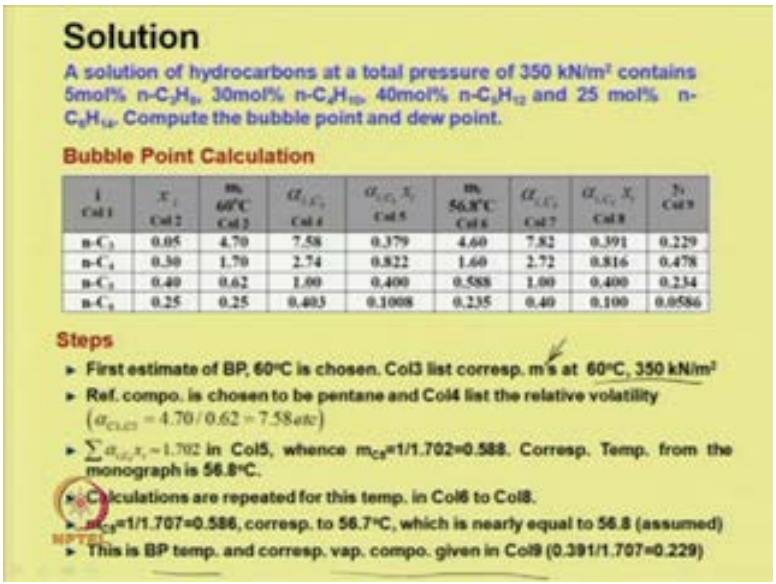

For bubble point calculations, the following steps can be followed first, we have to estimate the bubble point and to estimate that we have considered 60 degree centigrade is chosen. At, 60 degree centigrade and 350 kilo newton pressure we have to get the

corresponding distribution co efficient m which is given in column 3 for different component. So distribution coefficients is given reference component is chosen to be pentane in this case pentane is the reference component, which relative volatility we can see alpha i is 1, which is given in column 4 column 4 least the relative volatility here.

So we can see alpha c three c five the relative volatility between these two is 4.70 divided by 0.62, which is around 7.53 and so on, between this if we know the distribution coefficient and we know the relations between the distribution coefficients and alpha, and we can obtain the relative volatility for each components. And then, we can adapt the some of alpha i c 5 x i which is given in column 5 if we take the sum of all these which is 0.5 88 which is the reported in column 6 m i values is very close to the temperature which can be obtain from the monograph is around 56.8 degree centigrade calculations are repeated for this temperature in column 6 to column 8.

If we see column 6 to column 8 t so this calculations are repeated and we can see m c 5 is 1by 1.707 is equal to 0.586 corresponding to 56.7 degree centigrade which is nearly equal to 56.8 which is the assumed, and then this temperature it is matching the assumed temperature then this temperature is known as the bubble point temperature, and corresponding vapor compositions is given in column number 9 so the last column which corresponds to the vapor composition.

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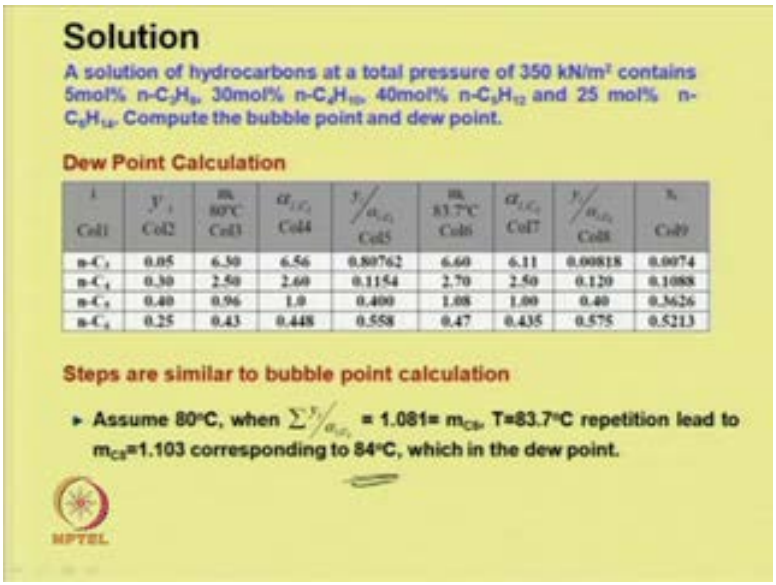

Similarly, for dew point calculations similar steps as we did for the bubble point calculations are followed, And in this case assume the temperature say 80 degree centigrade and when summation over y i by alpha i c five would be equal to 1.081 which is m c five and then we can get the corresponding temperature t is equal to 83.7 degree centigrade, and then we can repeat the calculations, which will give around m c five which is around 1.103 which correspond to the temperature of 84 degree centigrade and which is nearly to the assume temperature 83.7 degree centigrade and hence, the dew point is 84 degree centigrade.

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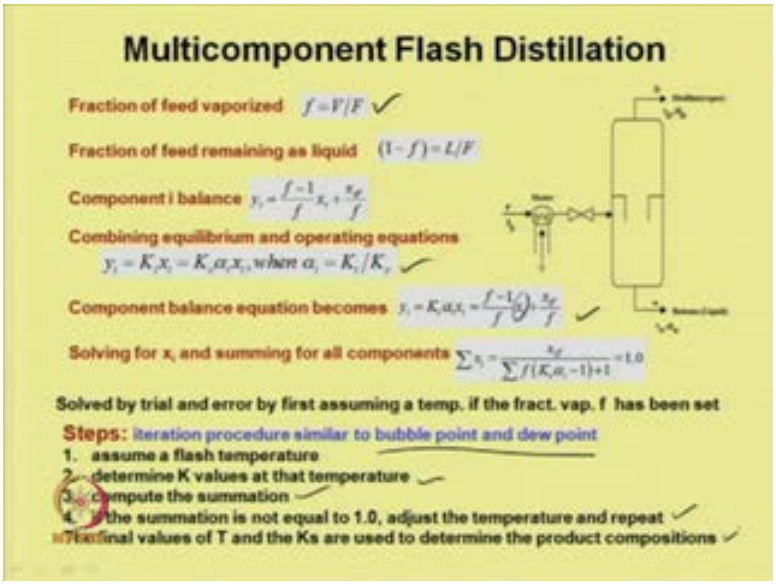

Now, we will discuss about the multicomponent flash distillation this is the typical flash distillation column we have discussed before we have a heater, and then the feed is heated in flux inside a distillation column, and then we have a distillate vapor bottom liquid if we define the fraction, which is vaporized is f a which V by F, then the fraction of the feed which is remaining as liquid is 1minus f which is L by F and if we do the component balance y i would be equal to f minus one by f x i plus x i f divided by f if we combined equilibrium an operating equations for multi component systems as we have seen y i would be equal to K i x i would be equal to K c alpha i x i when alpha i is K i by K c.

So component balance equations in this case if we apply this this will become y i would be equal to K c alpha i x i would be equal to f minus 1 by a x i plus x i f by f and if we

solve for x i and sum for all components the summation over the x i would be equal to x i f divided by summation over the f K c x i minus 1 plus 1 would be equal to one this is solved by trial and error by first assuming the temperature if the fraction of vaporize is set for a particular value the iteration proceeds similar to the bubble point, and dew point calculations what to do assume flash temperature determine k values at the temperature, and then compute the summation if the summation is not the equal to one adjust the temperature and repeat, By trail and error method we could obtain the flash temperature. The final values of t and k are use determine the product composition.

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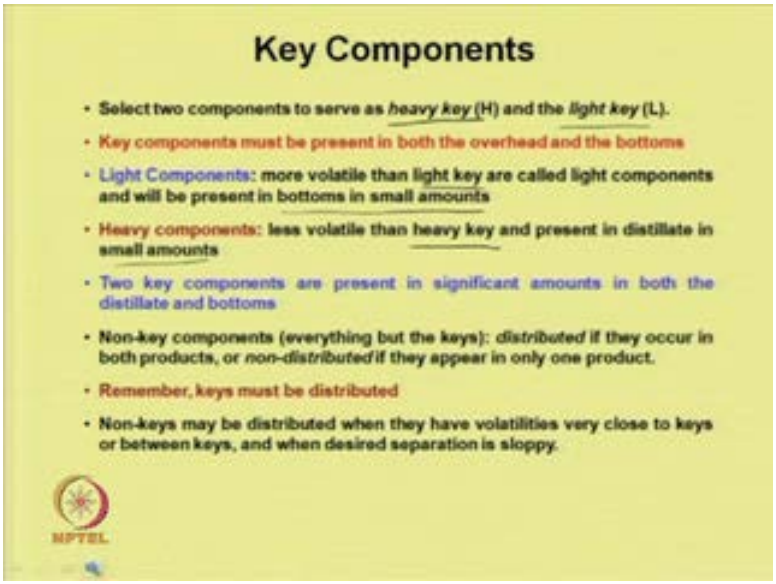

Now, in multicomponent distillation another important parameter is the key component. Generally, two key component one is selected is known as the heavy component h and another component is light component, which is the designated as l key components must be present in both the overhead and the bottoms. Light components the mole volatile component with respect to the light key components are called the light components, and that will be present in bottoms in small amount, and heavy component which is less volatile compare to the heavy key components and that will be present in distillate in very small amount. The two key components as we have selected heavy key or light key they are present in significant amounts in both the distillate and bottoms.

Now non-key components every thing, but the keys they may be distributed if they occur in both products are non distributed, if they appear in only one product remember keys

must be distributed. But, non keys may be distributed when they have volatilities very close to keys or between the keys or when the desired separation is very sloppy. So, two key components are very important to select for getting a particular distillation calculations for multicomponent systems.

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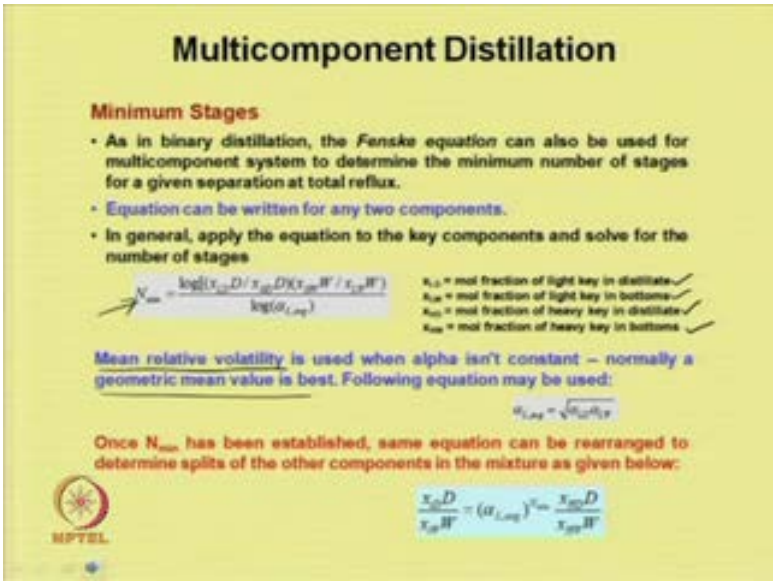

Now, for multicomponent systems how to obtain the minimum number of stages as in binary distillation the Fenske equations can be used for multicomponent systems to determine the minimum number of stages for a given separation at a total reflux equations can be written for any two components. In general, apply the equations to their key component and solve for the number of stages.

If we apply for the key components n mean would be equal to log of x l D into D divided by h x D into D multiplied by x is W into W divided by x l W by W all divided by log of alpha l average now x l d is mole fractions of the light key component in distillate x l W is mole fractions of the light key in the bottoms x s D is mole fractions of the heavy key in the distillate an x s W is mole fractions of the heavy key in the bottoms.

Now h alpha l average is the mean relate volatility this is used when alpha is not constant normally a geometric mean is the based so for geometric mean alpha l average we can write between the heavy key and the light key these root over bar alpha l D into alpha l W once the minimum n mean has been established same equations can be rearrange to determine the splits of the other component in the mixture as given bellow so x i d into D

divided by x i w into W is equal to alpha l average to the power n mean into x s d into D divided by x s W into W by this way we can determine the split of the other components as soon as the n mean is obtained.

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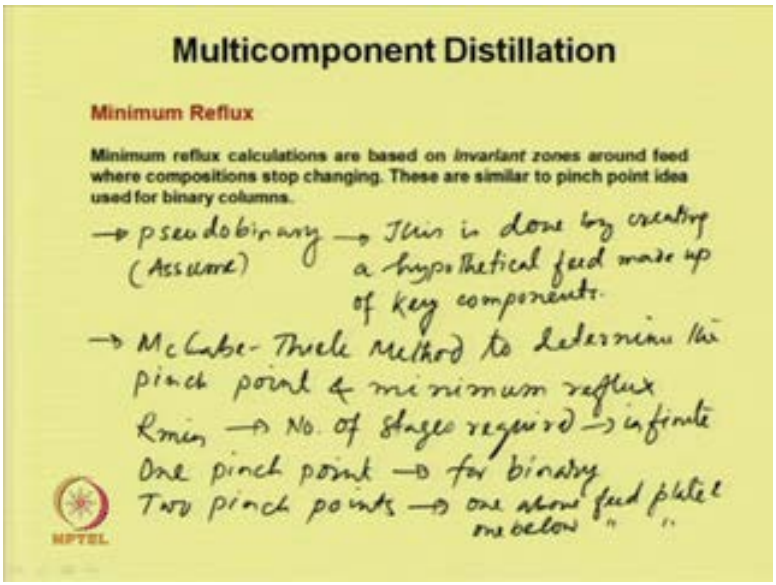

Now, minimum reflux. The minimum reflux calculations are based on invariant zones around feet were compositions stop changing these are similar to pinch point idea used for binary columns. One way, to determine the minimum reflux ratio for binary system is to assume a pseudo binary system this is done, by creating a hypothetical feed made up of key components . First, we have to assume pseudo binary system, and then we can use the Mccabe-Thiele method, to determine the pinch point and minimum reflux.

We know that, at minimum reflux R minimum the number of stages required is infinite, number of stages required infinite for a given separations of key components, but in this case for binary systems we know that there is only one pinch point one pinch point for binary, but in this case there will be two pinch points two pinch points one is above the feed plate one above feed plate and another one below feed plate, the rigorous procedure can be applied to calculate r m by trial and error calculations but, that is very tedious for n calculations.

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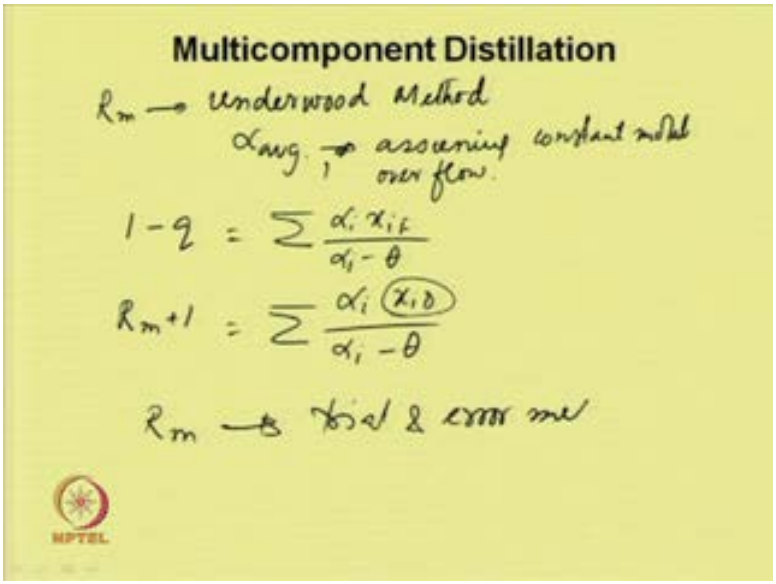

The minimum reflux R min can be determine by underwood short cut method this method also assumes equimolar overflow and it defines the relative volatilities of each component relative to some reference components, and they are usually the heavy components. Using, the average alpha values and assuming constant molal over flow these are the following equations one minus q is equal to summation over alpha i x i F divided by alpha i minus theta and, than R m plus one would be equal to summation over alpha i x i D divided by alpha i minus theta. So, these to equations should be simultaneously solved to obtain the minimum reflux ratio R m, so x i D are suppose to be the values at the minimum reflux alpha i may vary which can be assumed or the average values can be taken, which we have discussed before, and alpha values for heavy key which is considered as one. So, from this we can calculate R m by trial and error method.

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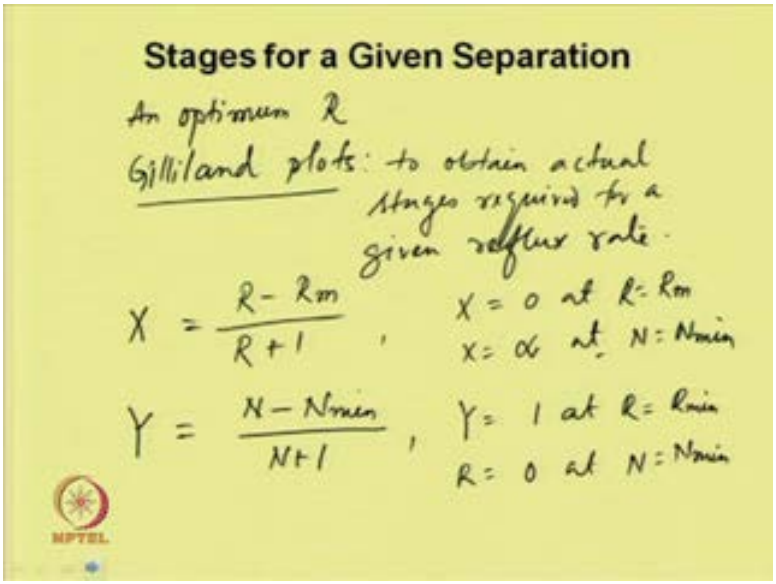

Now, how to obtain number of stages for a given separation the short cut method requires and optimum are reflux ratio, which can be obtain from the empirical correlations then we can use the Gilliland plots to find the actual stages required for a given rate for a given reflux rate the plots relate two variables one is X, which is equal to R minus R min divided by R plus 1 this X ranges from 0 X is equal to 0 at R is equal to R min and X is equal to infinity at N equal to N min. So, y is equal to N minus N min divided by N plus 1 this is ranges Y is equal to 1 at R is equal to R min and this equal to 0 at N is equal to N min.

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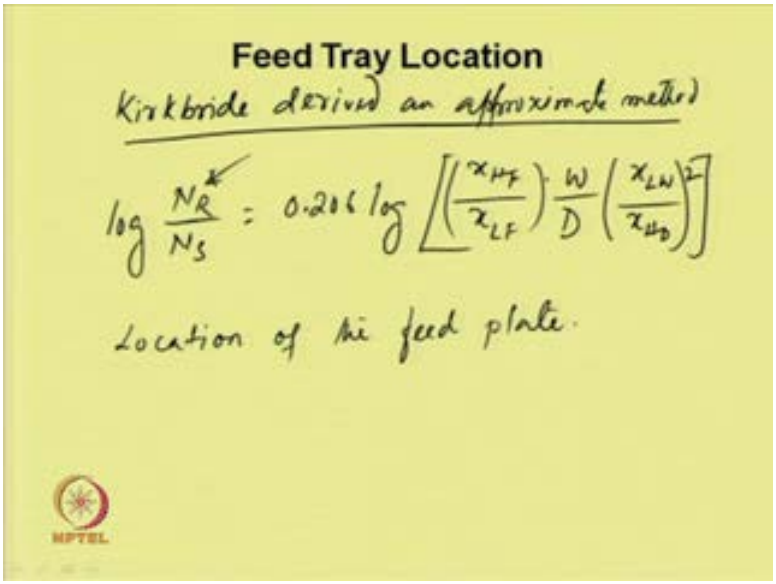

This way we can obtain the number of stages required for a given separations. Now, how to locate the feed tray Kirkbride derived an approximate method to calculate the number of theoretical trays above or below the feed, which can be used to determine the feed tray locations this is an empirical relations which is log of N r by N s would be equal to 0.206 log x H F by x L F into W by D into x L W by x H D this is square. So, the x H F x L F W D x L W and x S D which are defined before it has similar significance N R is the number of theoretical trays in rectifying section and N S is the number of theoretical plates in the stripping section, then from this we can obtain the location of the feed plate.

Thank you.