Plant wide Control of Chemical Processes
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Lecture - 17
Homogenous extractive distillation

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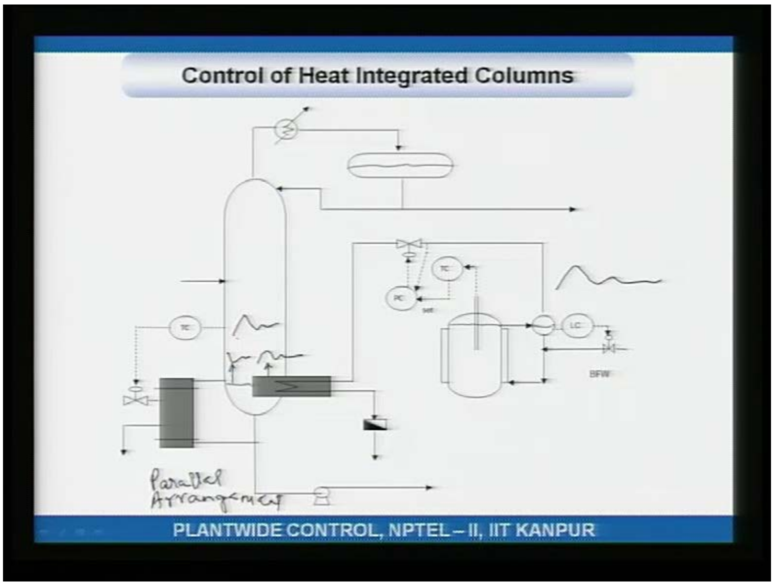

Control of Heat Integrated Columns

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Good morning, and welcome again to this next lecture on plant wide control. We have been looking at control of heat integrated distillation columns, and the heat integration is in different scenarios. One column heat integrated with another column or you could also have a column heat integrated with a reactor. So, we were last time looking at a highly exothermic reaction in a in the reaction section, and that exothermic heat of reaction is removed as steam. And this steam is used to give some amount of reboil in a distillation column, and you also have an auxiliary reboiler.

So, let us just say if the total heat load is X, 50, 60, 70 percent comes from the steam from the reaction section. And the remaining 30, 40, 50 percent comes from this auxiliary reboiler. Notice that the auxiliary reboiler gives its own boil up, and this reboiler which is taking steam from the reaction section gives its own boil up. So, these are arranged, the two reboilers are arranged in a parallel fashion.

So, this is a parallel arrangement, and what we discussed parallel arrangement? In fact, it has been pathetic. So, last time what we saw was that if you do temperature control the way it is shown that is not the best way of doing it, because fluctuations in the steam from the reaction section cause fluctuations here in the steam. And therefore, since the boil up is fluctuating the temperature fluctuates, because the temperature fluctuates this temperature controller then makes the boil up here fluctuate in some way. And what that essentially results in is large variation in the tray temperature that you are trying to control and the way around it.

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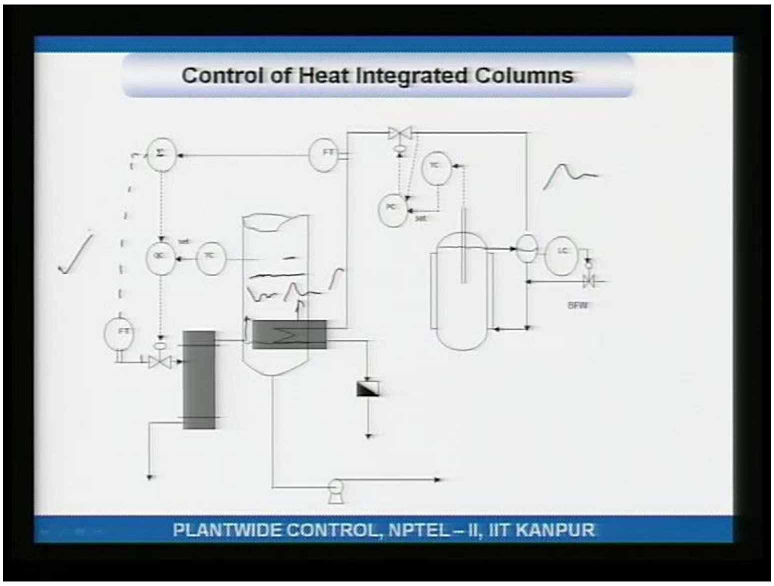

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That we discussed last time was that you instead of controlling the temperature using the steam. Using the auxiliary steam what one should be doing is actually, let us see this summation had to have another signal, where is this signal? Let us see, steam from the reactor, and steam from the; this signal you sum it up. So, instead of manipulating the steam flow to the auxiliary reboiler if you manipulate the total steam flowing. So, this sum is giving the total steam which is the steam from the reaction section as well as steam to the auxiliary reboiler. And in this case what happens is if this fluctuates if the steam from the.

So, if the boil up due to this, you know this fluctuates then the total steam will fluctuate, because the total steam is fluctuating; this Q C the total steam controller will pinch or will adjust this valve. So, that the total flow does not fluctuate. So, there is fluctuation in the steam from the reaction section, the boil up due to steam from the reaction section. And this is compensated for by opposite fluctuation in steam from the auxiliary reboiler.

And, when you sum it up that would be relatively constant. And therefore, the temperature as far as the temperature controller is concerned or as far as the tray is concerned it does not see large fluctuations in the boil up and since, it does not see large fluctuations in the in the boil up, the temperature remains relatively constant.

So, this is in parallel arrangement when you have the auxiliary reboiler and the; I would I do not know what to call this reboiler. The reboiler that takes steam from the reaction section in a parallel arrangement; this is a better of controlling tray temperature. It will give you much tighter temperature control and correspondingly tighter correspondingly tighter quality control.

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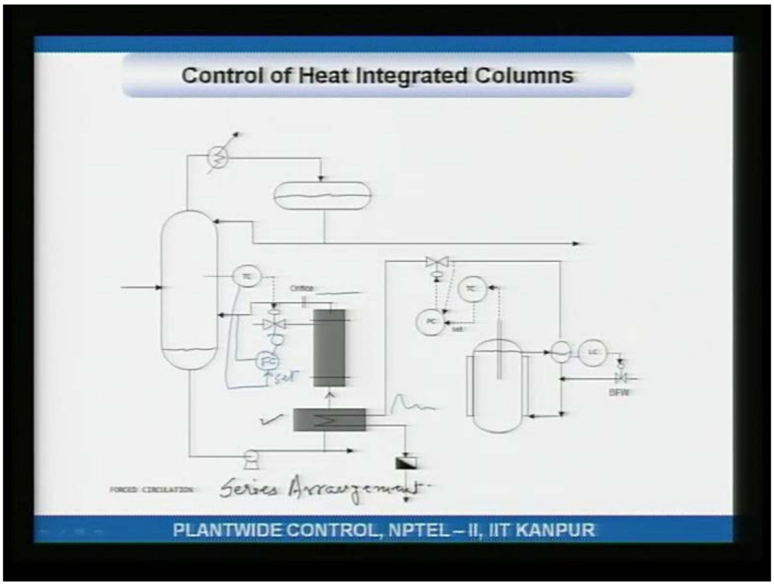

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A designed solution the series arrangement in this case notice what happens the way the 2 reboiler’s are arranged they are in series. And in this series arrangement; this reboiler takes steam from the reaction section. And there is some boil up that is created because of that which is fed to the auxiliary boiler which is taking its own steam. And that creates further boil up and the totalizer here is you know the steam that is going into the column or the boil up that is going into the column. Because of the way it is designed it you know it is the total steam. So, one way of controlling you know here the totalization happens naturally. And I think should be shown I mean it is not very well shown in the presentation.

So, what I would say is what should be done is if this is the valve this is the total boil up that is going into the column. This total boil up is controlled by adjusting the auxiliary steam, and the temperature controller adjusts this steam set point. So, notice, because you are controlling the total steam in or the total boil up into the column again naturally if this guy is varying, if the steam from the reaction section is varying, that would be compensated by this total flow controller in such a way such that this flow remains constant.

So, now, because the total boil up is remaining constant, even though the steam from the reaction section is fluctuating as far as the tray is concerned or as far as the column is concerned, it sees constant boil up or nearly constant boil up. So, this is in some way a designed solution if you had you reboilers arranged in series, you do not have to actually use a totalizer I mean it naturally, it is naturally amenable to tight temperature control.

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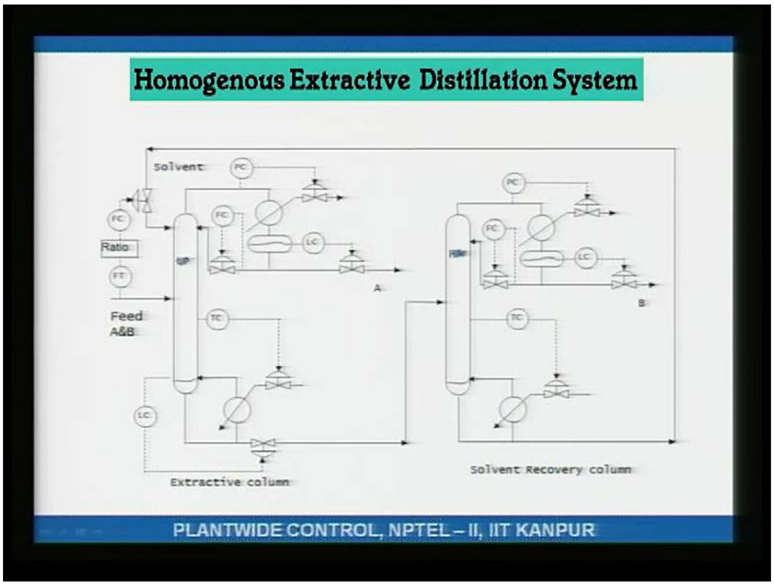

Homogenous Extractive Distillation System

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Now, we will look at what is heterogeneous extractive distillation? By the way this guy is not there L P H P is not correct. So, these are 2 columns, extractive distillation is used maybe I should explain this before explaining the flow sheet maybe I should do a little bit of you know theory.

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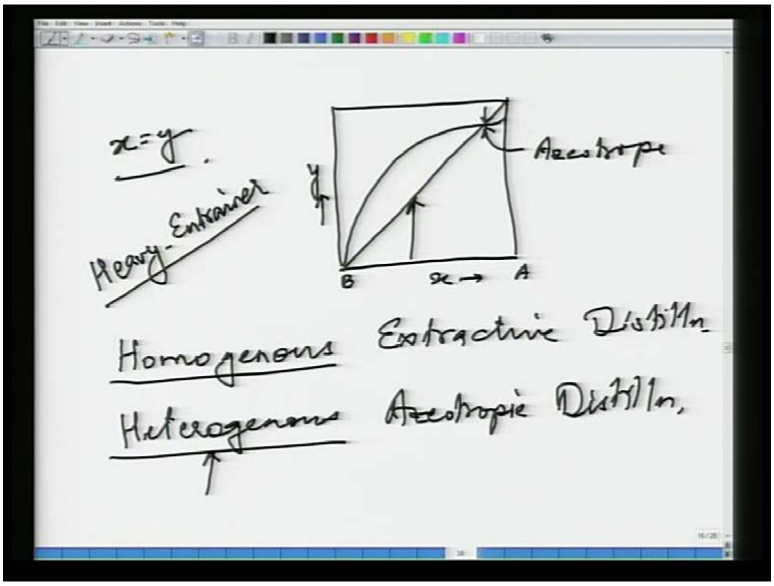

Let us say, you take ethanol water system all of you would know that it forms an azeotrope and what is an azeotrope? An azeotrope is, if this is x liquid phase composition in equilibrium with y which is vapor phase composition. This is an azeotrope. Now for example, my system could be water ethanol. So, it has an azeotrope at, let at atmospheric pressure, let us say at 95 96 97 percent mol percent. Now, the azeotrope sets a limit. So, for example, if I have a feed that is here, let us say this is my feed composition. No matter how tall my tower, no matter how much reflux I use even if I operate the column at total reflux.

The best that I can do is I can get your, what is this? I can get a distillate that is close to the azeotropic composition and I can get a bottoms that is, let us say this is component a. So, this will be component b. So, I will get an azeotrope, an A B azeotrope which is let us say 95 percent pure, let us say this is 95 percent. And I will get a bottoms which is pure B or nearly pure B with small amount of A. I simply cannot produce using distillation because of this azeotrope, and at azeotrope x is equal to y.

So, no matter how much I boil the vapor is not any richer in the light component. Therefore, no further separation is possible, no matter how tall the column. This composition cannot be bypassed or this is what you can reach, you cannot reach pure A. So, there are various techniques you know processing situations you require, let us say the processing situation is such that, you require pure A and pure B. Let us say it is pure you want pure A because it is you want to sell pure ethanol. So, how do we alter the vapor liquid equilibrium, alter the system such that, you know pure A and pure B can be obtained.

One of the ways is extractive distillation, homogenous it is called homogenous, because well there are there are two very common ways; one is called homogenous extractive distillation that we will take a look at here, and the other is called heterogeneous. Homogenous means no phase separation, heterogeneous means you know the mixture or the mixture separates into a typically an aqueous phase and an organic phase. The aqueous phase being rich in water, and water being heavier than organics would be the heavy phase and on top of it will be the organic layer.

So, in heterogeneous azeotropie distillation by adding and an trainer or a solvent, what you are essentially doing is? You are essentially causing a phase split the liquid separates into two phases vapor rich, water rich and organic rich. And because of this phase separation, you actually cross the azeotropic composition that is the idea behind heterogeneous azeotropic distillation. The idea behind homogenous extractive distillation is to add an entrainer.

And this entrainer is typically heavy in you know it is a heavy you add a heavy entrainer. And what that heavy entrainer does is? It actually preferentially soaks up either component A or component B. One of the two components it preferentially soaks up. So, what that does is it actually alters the vapor liquid equilibrium in such a way that it soaks up one of the components. And therefore, you can get a pure A and pure B. To explain it a little more I think we need to look at a residue curve map.

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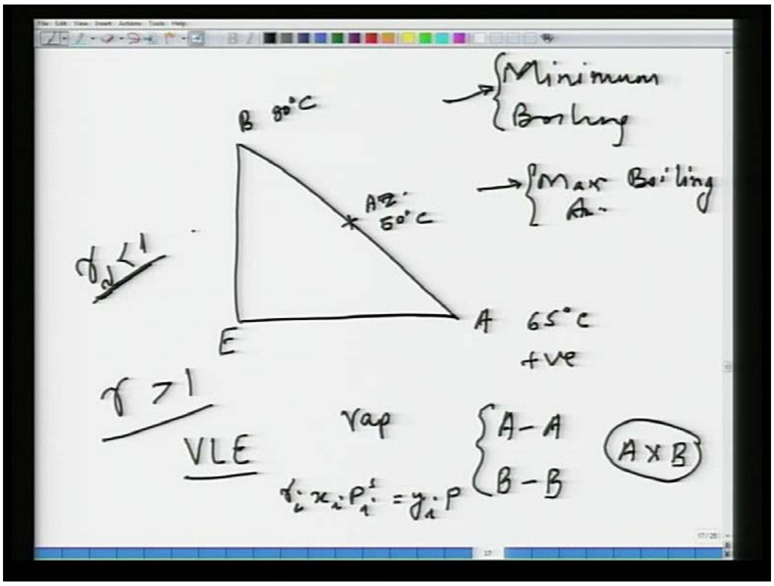

So, let us say A B, and I add a heavy entrainers, let me call it E. And it since, its heavy I am I am I am drawing it here A B have an azeotrope, let us say this is the azeotropic composition. And typically azeotropes are minimum boiling, what is that suppose to mean? Most azeotropes are minimum boiling. So, let us see maybe I should explain that also, what does minimum boiling mean? If the boiling point of A is, let us say I do not know 65 degree Celsius, let us take whatever. And, let us say boiling point B being slightly heavier than that lets say that boiling point of B is I do not know may be 90 degree Celsius or 80 degree Celsius. The boiling point of this minimum boiling azeotrope will be less than 80 and 65.

So, let us say this azeotrope boils at what does it boil at? Less than 65. So, let us say 60 degree Celsius. So, that is a minimum boiling azeotrope, where the azeotrope; this is a binary azeotrope. The azeotrope boils at a temperature that is lower than both the pure components which take to mean that binary azeotrope. There is also what is called a maximum boiling azeotrope? These are much more rarer, you see these are much more common, very common. Maximum boiling azeotropes are you know rarer far and few. And I will just briefly explain the reason for that, in a maximum boiling azeotrope what will happen is the boiling temperature of the azeotrope is more than both the components. So, if it is maximum boiling; this boiling temperature may be for example, 85 degree Celsius.

Now, why is it that most azeotropes are minimum boiling that is because you see when I am talking vapor liquid equilibrium I mean let us just explain it very without getting into equations. Basically, what happening is? I have got 2 components. A, a molecule of A in the liquid phase would like to be with the molecule of A, a molecule of B would like to be with the molecule of B. And typically A would like to avoid B, and B would like to avoid A, why is that true for a liquid phase, because liquid phase density is very high. So, there is lots of molecules that are close by.

So, because they are trying to avoid each other, when you bring A and B together in the liquid phase, what will happen is B would like to both A and B would like to get into the vapor phase. Because that is where A molecule of A does not see you know vapor phase is very rare, it is not very dense. So, the molecules you know the chance of an A molecule seeing a B molecule is very is smaller in the in the vapor phase. So, what that essentially means is for most typical mixtures because A and B like dissolves like.

So, A and B do not like each other, and therefore, A and B would like prefer to stay in the vapor phase what that essentially means is vapor pressure the expressed. So, if you look at the vapor liquid equilibrium equation, what you have is Raoult's law is x i p i sat is equal to partial pressure of that component where p is the pressure of the system. And then there is a gamma activity coefficient that corrects for non-idealities. Now, from most typical systems the gammas would be greater than 1, what that essentially means is that the because of non-ideality the pressure exerted on the left hand side the term on the left hand side gammas will be more.

So, you have you have got positive deviations from ideality. If there was an ideal solution it would exert without this guy it will exert so much pressure. If it is a non-ideal solution it actually exerts more pressure, more vapor pressure gets exerted by the liquid and that is this guy, because gamma is i is greater than 1. So, you have got positive deviations from ideality. Positive deviations from ideality are much more common than negative deviations. Negative deviations will have a will happen when you know, let us say some sort of hydrogen bonding happens between A and B. And therefore, A would be like to be with B therefore, it does not want to go into the vapor into the vapor phase then you will have the gammas will be less than 1.

So, most typical solution situation is that these gammas are greater than 1. The activity coefficient for most mixtures unless you have get, got you have got something special going on greater than 1. Now, if you have got an azeotrope what that means is, because the deviations from ideality are positive you are exerting more pressure in the vapor phase therefore, you will be boiling at a lower temperature right. So, therefore, minimum boiling azeotropes are most common. Now, if I if you do not know about residue curve it does not matter let me just explain what is going on if I take a sum A E mixture.

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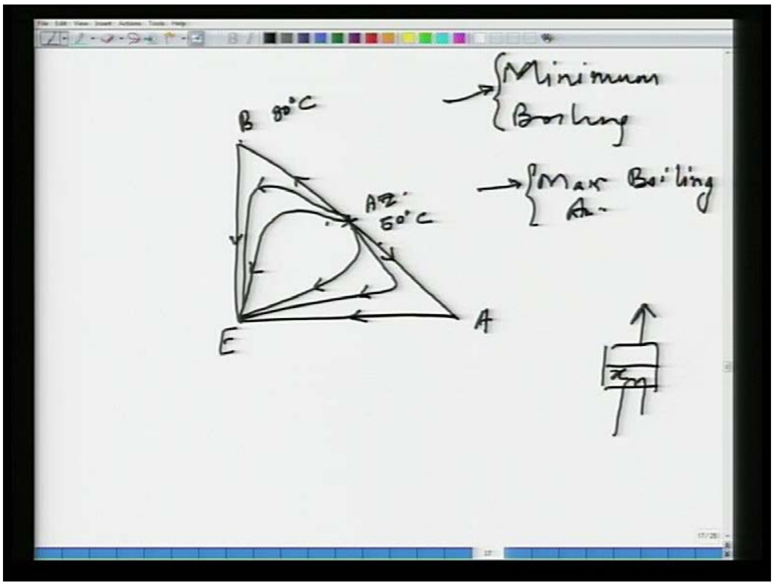

Let us say its initial composition is, and if I have a still here is a still, and I am heating it vapor is being drawn because it is being heated. Then the composition in the still will follow a trajectory with time; this composition will change with time. So, if I have an A E mixture, the still will become richer and richer in E, because E is the heavy component. Now, if I have a composition that is let us say any anywhere on this side you know somewhere here, let us say I have a compo initial composition in the still which is here. Now, because the azeotrope is lighter than pure A as I do this simple boiling exercise.

The composition of the residue in the still will move this way on this side, because B is heavier than the azeotrope, the composition would move this way. And on this edge the composition would move this way, because E is the E is heavier than both B and A.

And what is the composition is here well ultimately you cannot have an intermediate boiler you cannot end up here, you cannot end up here you have got to end up at E. So, what you essentially have are residue curves that actually you know something like this. And there is a result in literature which says that you know the residue curves are approximately the same as a rectifying or stripping profile that you would get at total reflux; that means you are not drawing out any product. So, these residue curves are similar to the shape of the rectifying and stripping profiles. Now, if you look at why I am doing this? Just take it on faith, do not ask me for explanations, because explanations will require a lot of theory.

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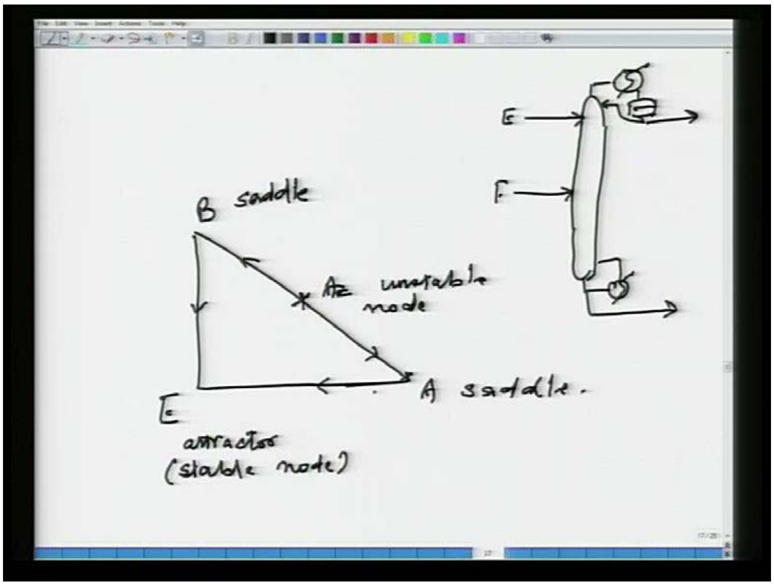

So, I have got a column which is my azeotropic heterogeneous azeotropic, homogenous extractive column. I have got a feed which let us say is close to the azeotropic (()), what I do is I add an entrainer somewhere near the top section of the column, but not at the top this is the entrainer; this is the feed. And if I look at this well reflux is going top, what happens in this situation is given that I have given you the shape of the residue curves A B E. Notice that all the residue curves were ending up at E, but some of the residue curves end at A, some of the residue curves emanate from A some of the. So, A let us just if you look at these vertices E is an attracter, it attracts all residue curves towards itself, B well it attracts depending on whether you are on the A B edge or whether you are on the B E edge. If the composition is on the B E edge it is actually what should, what is the opposite of attracter may be anti-attracters.

So, attracters are also sometimes referred to as stable nodes, you see everything ends here, everything ends up, no matter where you start from ultimately you are going to end up at a. So, it is a stable node that is just some jargon. If you look at the azeotropic composition it being the lightest of all the, you know A B E, and this is the azeotrope. All residue curves you know it emanates from here it does not attract any residue curves, all residue curves emanate from it this is called an unstable node, opposite of an attracter, unstable node.

Now, A and B are neither attracters nor unstable nodes. So, these are called saddles depending on what the initial condition is. So, depending on what the initial condition is the A and B you know you can have residue curves that end up at B or you could have residue curves that emanate from B similarly, for A. So, these are called saddles which are neither unstable nor stable depending on which direction depending on which direction you are coming from it could be stable, and depending on the other direction it could be unstable. And that sort of the ways that tests the saddle is you know if you look at the saddle on a horse if you are going this way, the saddle point is a minima. If you are going that way the saddle point is a maxima.

So, that is just by the way, let us say I choose a composition when I am designing this column I choose a composition that is nearly pure A. So, this is my pure A, let us say my feed composition is feed composition is some place here I am adding some entrainer to it. And therefore, the composition because of entrainer will you know move into the triangle.

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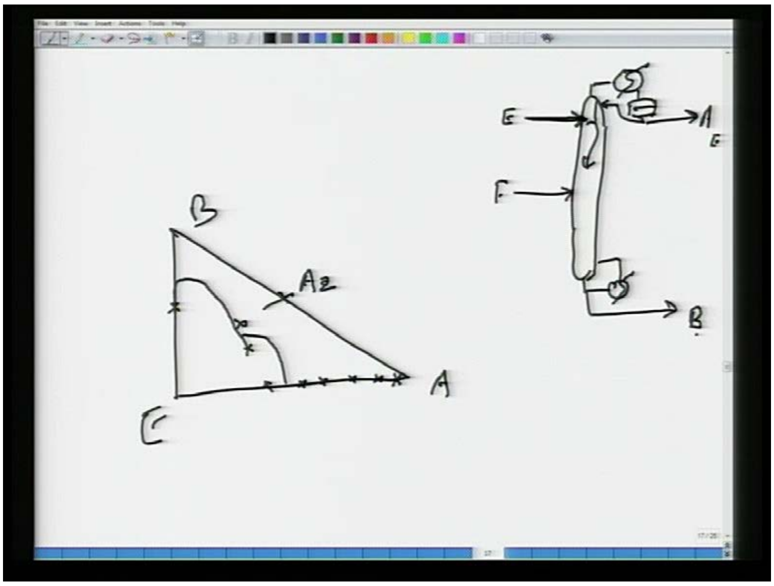

Now, if I look at I choose a composition when I am designing this column; this is A; this is B; this is E, and this is that minimum boiling azeotrope which is on the base. Note that I am not choosing it, and there is a reason for this, because it is on the base as I move down. So, this composition here is nearly pure A with some entrainer very little or no B. The primary impurity here is the entrainer, as I move down from here what you will see is? How do the, how are the residue curves shaped? The residue curves are you know going towards E. So, what you will find is that the next ray composition will be, let us say some place here, the next ray composition will be some place here, next ray you know, and I can keep drawing it until it you know.

There is some amount of entrainer. So, this is my distillate, my feed is near the azeotrope I add some entrainer to it. So, this is my let us say over all feed composition, and then you know the bottoms has to be in a straight line with this. So, bottoms would be let us say this. If I look at the stripping profile, the stripping profile actually will go like this, and end up in a pinch where the composition does not change anymore. So, this is called a feed pinch. So, what is a feed pinch? I can keep integrating the, or I can keep doing the material balance on the stripping trays, what will happen is this composition after sufficient number of trays will not change. Now, by definition this pinch will never be at the base.

It will be some were in the composition space. So, what that essentially means is you need a middle section to join the two. So, what basically what we are what I am saying is I mean there is a lot theory here, do not worry if you do not understand it. Basically, what we are saying is that for the split to be feasible where you are getting pure A at the top, you have to have this middle section. What that essentially means is you cannot mix E and f, and send it as a as single stream. And what that means is that the E which is altering your vapor liquid equilibrium has to be being heavy it will essentially flow down. It has to be available in sufficient quantity on most of the trays inside the column to alter your vapor liquid equilibrium sufficiently. And in this example the entrainer preferentially is soaking B.

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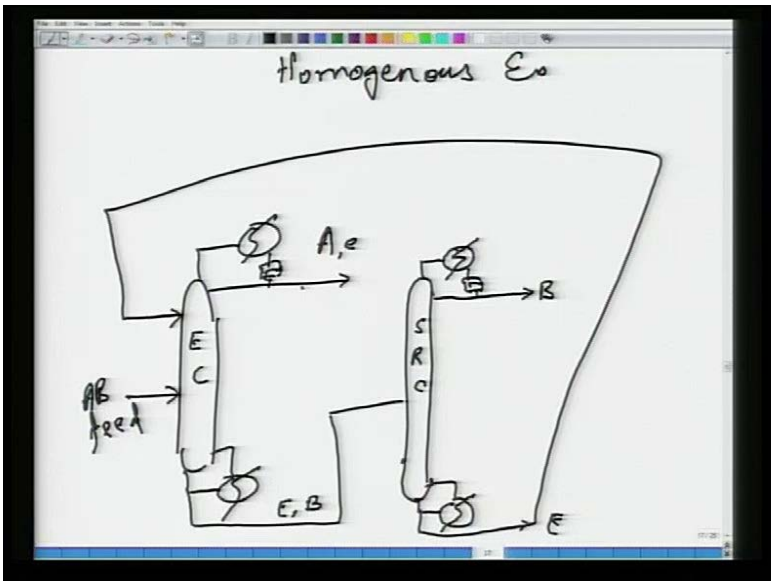

So, the bottom stream is B plus E, and this actually gives us the sequence that we want. You have got the first column where you are having a feed and then you are having an entrainer, you have got. So, this will be pure A with some amount of very small amount of entrainer almost negligible. And then this goes, then you go to A this is my extractive column, and this is my solvent recovery column. So, the bottoms is E, and my entrainer is such that it is preferentially soaking up B. So, it is a mixture of E and B.

This E B mixture is sent to a solvent recovery column, solvent being heavier goes down the bottoms, B being lighter goes up the top. The solvent being heavier goes down the bottoms this is the solvent or rather the entrainer. And, what we then do is you know this entrainer is what is sent back. So, this is my homogenous extractive distillation sequence. The point that I was trying to explain was, you see why do I have the entrainer at the top, and not mixed with the feed. This is the A B feed, well the reason for that is, if you mix it with the feed; this split becomes infeasible. And that is what I was trying to explain with that those residue curves I do not think I did a good job may be I will try again.

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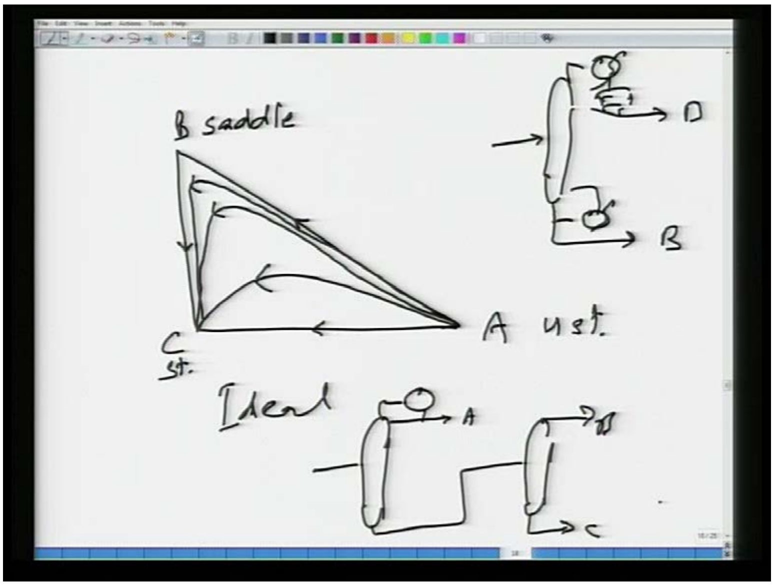

If you take an ideal mixture, ideal, let us say it is an ideal mixture, light component, intermediate component, C component. And, what you what you will then have is if you have an initial composition in the still which is on the A B edge, B being heavier than A, the residue will move that way. If you have a initial composition on this B C edge, you know the residue composition will move this way. If you have an initial composition on the A C edge, C being heavier.

Now, if you have a residue composition that is got A B and C what you will find is residue this is called residue curve map. For an ideal system it will looks something like this. Depending on different initial compositions, and here you can see A is an unstable node, C is a stable node, stable, unstable and B is a saddle. Some residue curves reach it, it is an attracter for some residue curves, it is a some residue curves emanate from it. So, B is a saddle.

Now, intuitively if you have a simple distillation column; this is essentially saying that look your unstable node is something that can be your distillate composition, and your stable node something that can be your bottoms composition. So, you can have A split, an A B C split where you can have pure C. And then an A B mixture or you can have pure A, and A B C mixture if you got an A B C mixture. So, you can have first column taking out pure A, first column taking out pure A. And the second column taking out B and C, alternatively I could have the first column take out pure C, and the next column take out A and B.

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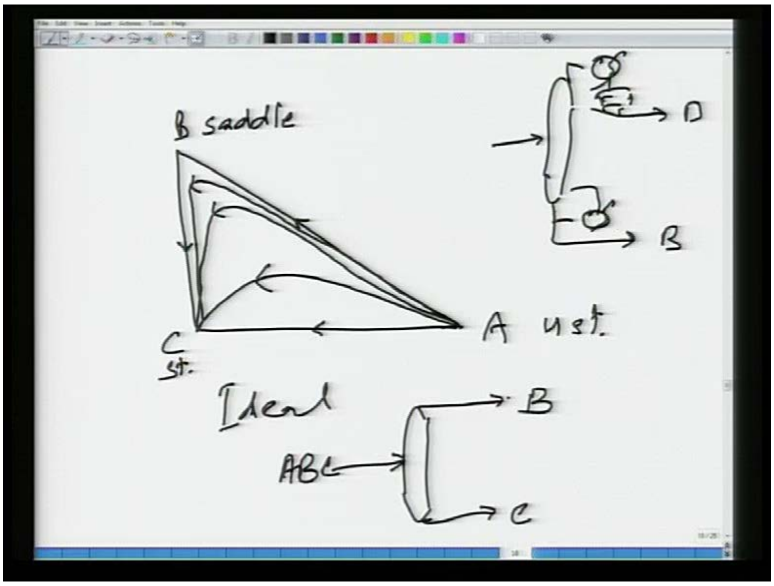

That if you are designing the first distillation column, you can design it, so that your distillate is this vertex pure A or you can design it such that. So, a simple distillation column from this residue curve map, you know we this residue curve map is saying that pure A product stream is possible or pure C bottom stream is possible. You will intuitively appreciate no matter what you do from this column if you are having an A B C mixture, no matter what you do you cannot take out pure B up the top or the bottoms you cannot take out pure B as a product stream. So, what that is saying is, if you would look at the residue curve map saddles cannot be products. Now, your product has to be limited to volt you know stable or unstable nodes.

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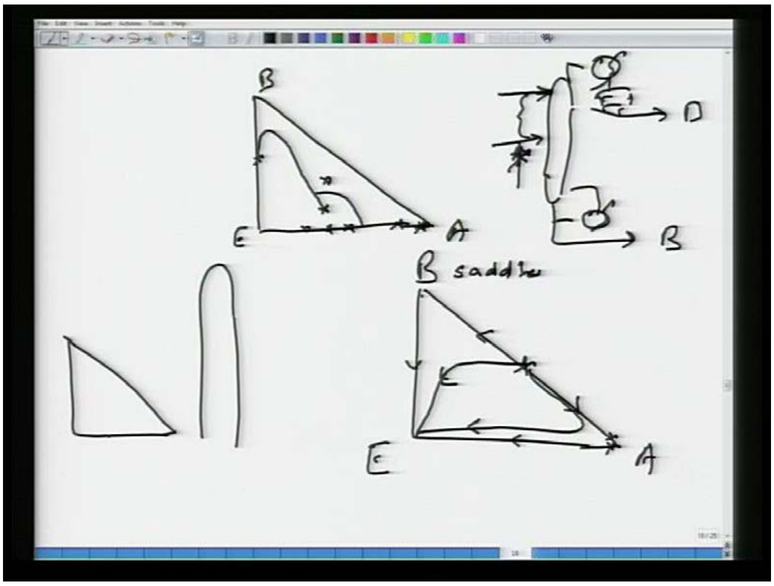

Now in the extractive distillation business if you look at your extractive, if you look at your residue curve A and B form an azeotrope, E is an entrainer which is heavy which does not form an azeotrope with either A or B. Therefore, the residue curve map looks like this. Since, both B and A vertices are saddles in a simple configuration where you got a single feed you cannot reach A, you cannot reach B. If you want to reach A as a vertex what that essentially is saying is you will have to add the entrainer, not with this stream, this should not be done, but somewhere up the top.

And that will give you know that is that will give you the kind of profile that I drew just a little bit earlier. This is my bottoms with the entrainer I get a total feed composition that is some place here. This is my bottoms, which is A B E mixture, and this will come down. And you know pinch some place what do I mean by pinch? What I mean by pinch is well look up the definition of a pinch. This goes this way, it is this section which is the middle section that bridges that acts as a bridge between the stripping profile, and the rectifying profile. If you did not put the entrainer up the top which is one way of saying that in order to sufficiently, in order to break the azeotrope which was there, you need to have the heavy entrainer on almost all the trays which requires that the heavy solvent B fed some place near the top of the column above the feed. If you mix it with the feed, the separation becomes infeasible.

Why did I choose my product composition to be here and not here? Why on the A E edge and not on the A B edge? That is because if you look at the fact that residue curves are similar to rectifying and or stripping profiles. Then what that means is if I have chosen, let me just blow this up.

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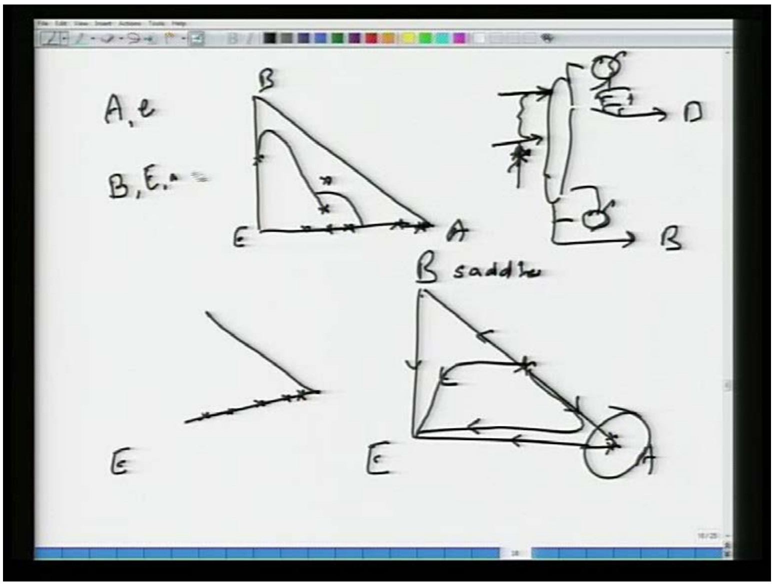

If I blow this up, if my profile vertex composition is this, then the way the rectifying profile will move is this similar to you know the residue curve. This will require extra trays that will give me a taller than necessary column. Therefore, I am better off on the other hand if I blow it up if I chose my composition to be here where the principle impurity is E and not D. Then my rectifying profile moves along the base, similar to the residue curve, and the residue curve I have already drawn it goes like this. Therefore, the top is essentially A with a little bit of E, the bottoms is all of the B, all of the entrainer may be a little bit of A. Now, we are going to look at, how do we control?

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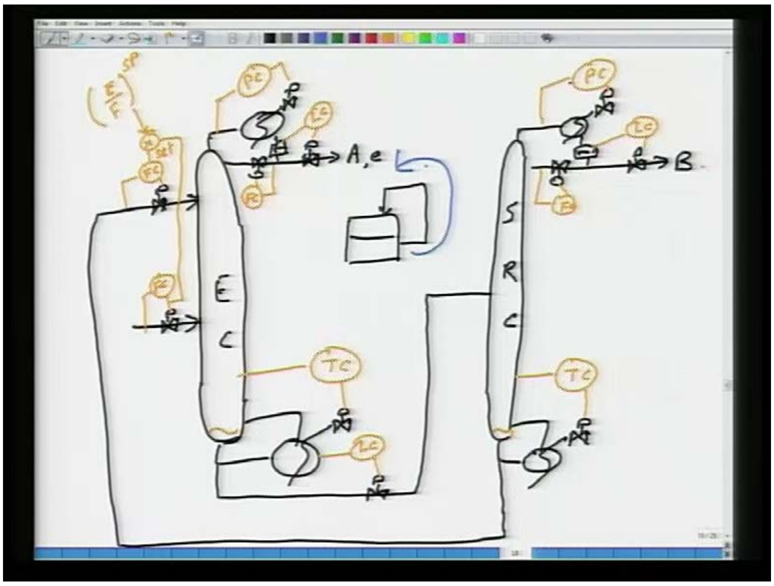

So, we are looking at the homogeneous extractive distillation sequence. The sequence looks like this I have got the extractive column which takes in the feed. And the solvent some place up there or the entrainer some place up there, because it is got a condenser reflux drum and reflux. The top stream is essentially, let us say pure A, and some amount of E bottoms is essentially B this is called the solvent recovery column.

From the solvent recovery column you get pure B up the top. The well, maybe I should draw it the other way, solvent down the bottoms which is recycled just drawing I have drawn it twice sorry, valve is already drawn here. So, these are the independent valves, let us draw a control systems on it. Pressure control; this is obvious, pressure control; this is also obvious, level control level control level control what I would do is, let us say I am holding a reflux rate fixed sufficient reflux. So, that sufficient reflux here so, that entrainer does not go up the top.

This is under flow control; this is the feed what do I do with this guy I use this to control a tray temperature. So, that, the A does not drop out of the bottom to ensure that, the A does not drop out the bottom I use a temperature controller here. So, that the B does not drop out the bottom. And what I do is I maintain I take this feed, the feed flow if the feed flow increases for the same separation I would like the solvent rate that is going to the extractor into the extractive column. So, if the feed goes up by 10 percent, the solvent or the entrainer flow rate should also go up by 10 percent alright.

So, to do that, I maintain the solvent flow rate. So, there is a flow controller here this is what sets it, and the operator sets this ratio set point, which is entrainer to feed ratio; this is the set point. Notice that when you may say that this does not sound right, because level here should be controlled well the level here is not controlled. And in fact, it should not be controlled, and what is the reason for that? Well if you look at the flow sheet other than small amount of entrainer loss may be here, may be here.

Other than that small amount of entrainer loss, you are essentially not putting any entrainer that is fresh. So, what you are essentially doing is charging the system with an amount of entrainer and that entrainer is recirculating in the system. So, what the flow sheet is under ideal conditions, none of that entrainer will get lost. So, this is like saying that I have got I am just for explain this is like saying I have got a tank, forget the in and out, and I have got an internal recirculating stream. If this is the situation do I need to control the level of the tank, given that none of the material is leaking out I do not. That is because I can set this flow rate that is going round, and round at whatever value I want, and the level will still remain the same right.

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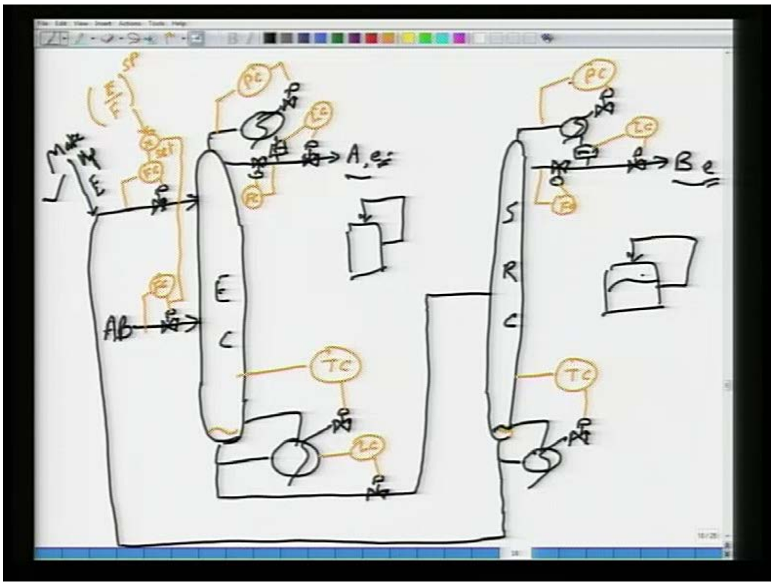

Similarly, if you look at this process like a tank, then I am putting in an A B feed I am taking out A I am taking out B, the entrainer is simply circulating round and round. So, that is that is like this recirculation stream

This entrainer recirculation rate can be set at whatever I want, and be wherever the entrainer accumulates that level need not be controlled. Where does the entrainer accumulate in this system? It accumulates at the bottom in this column. So, this bottom level is not controlled. Of course, there is some amount of loss here, there is some amount of you know very small loss here, very small loss here. These losses need to be compensated by a makeup stream. This is not something that that we will use for continuous operation; this is a makeup entrainer.

So, it is like your air conditioner you know you charge your air conditioner with refrigerant. Then you run your air conditioner for one season, two season, three seasons you see the refrigerant is going in a close circuit of course, some amount of leak is there and. So, progressively from one season to the next season you are losing a losing out some of the refrigerant, may be after three seasons you have lost enough refrigerant that you need to recharge that refrigerant. That is what that service engineer comes and does, something similar is going on here. You have charged your system with the entrainer some amount of entrainer is getting lost may be here, may be there.

You are running your system continuously may be after 6 months, may be after 3 months, may be after an year, the level here which was let us say 80 percent goes down to 50 percent. That tells you I have lost sufficient entrainer to require a recharge and then I will recharge it using this make up stream. But as far as day to day operation is concerned this level should not be controlled. Why should this level not be controlled? Because it is the situation is similar to this. In this case no matter what is the flow rate of this circulating stream, the level will regulate itself, it need not be controlled. In fact, if I try to control it that will create problems I am controlling something that should not be controlled right. So, I hope it is clear to you why this level at the bottoms of the solvent recovery column is not controlled. So, this is about homogenous extractive distillation.

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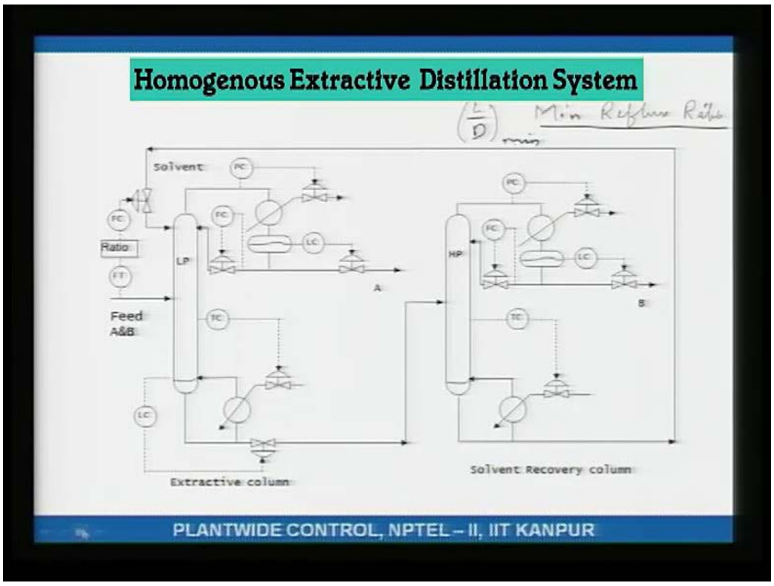

Homogenous Extractive Distillation System

$\left(\frac{L}{D}\right)_{min}$ Min Reflux Ratio

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And I think I would like to show this to you a words of caution, well one word of caution you know most distillation systems have got minimum reflux ratio. What does the minimum reflux ratio corresponds to well the minimum reflux ratio corresponds to you will get the desired separation or the desired purities or the desired impurity levels. But to get that impurity levels reflux must be at least this at such minimum at such when the reflux ratio is at this minimum value L by D min. When the reflux ratio is at this minimum value the tower has to be infinitely tall to give you the purities or the recoveries or the impurities that you desire to give you that separation the 2 the 2 degrees of freedom the 2 separation degrees of freedom that you desire. So, L by D minimum comes from there all distillation systems have a minimum reflux ratio. Well a heterogeneous extractive distillation system.

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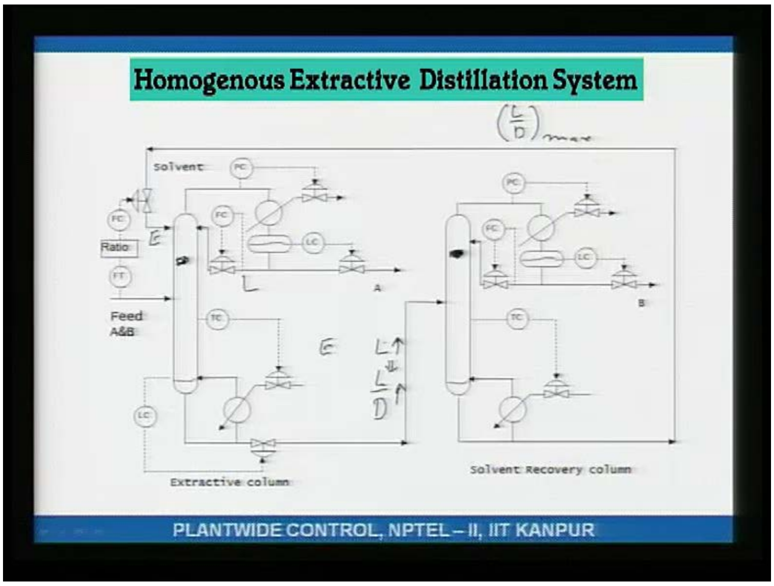

Homogenous Extractive Distillation System

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Also has what is what you may call L by D max. It also has it has the heterogeneous extractive distillation column not only does it have a minimum reflux ratio there is also a maximum reflux ratio beyond which the spilt becomes infeasible. Now, you can think why that happens? Let us say I forget the control structure, let us say I hold the extractor flow rate, extra entrainer flow rate constant if the entrainer flow rate is held constant. And let us say I keep on increasing the reflux flow rate. So, E is held constant L extractor is increased, as the L is increased or the as the reflux is increased the internal liquid that is flowing in goes up. Now in order to change the vapor liquid equilibrium because it is the entrainer, which is breaking the azeotrope?

Now, there is more amount of material that is flowing through the column in order to change its V L E or in order to break the azeotrope naturally, you require more amount of solvent. But if you hold the solvent constant and keep on increasing the reflux there will come a point where this entrainer flow becomes limiting. And if you increase the reflux any further, the split then becomes infeasible you see. So, to break azeotrope there is so much amount of liquid that is flowing inside the column to break that azeotrope you require sufficient amount of solvent. Now, as you are increasing the L that is equivalent to increasing the L by D, because the distillate is set by how much A is coming in the feed.

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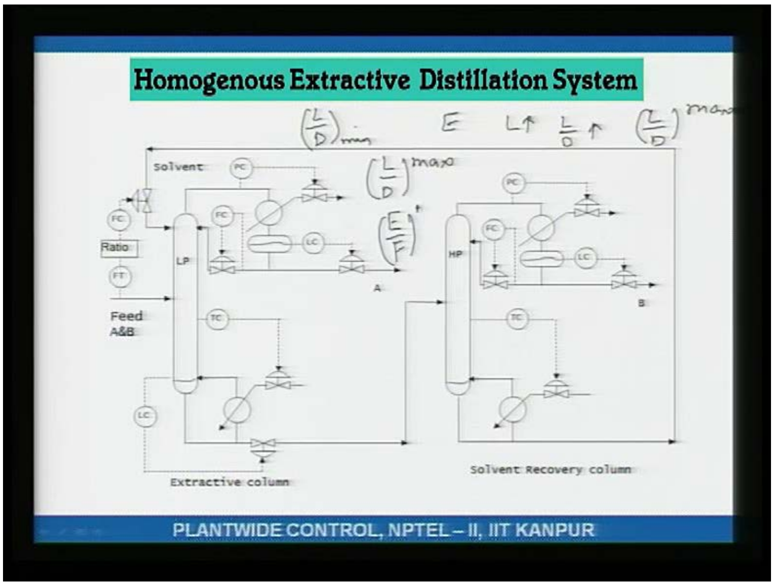

Homogenous Extractive Distillation System

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So, L by D increases, and if you keep on increasing the L, because entrainer is now becoming limiting, your split becomes infeasible keep on E is held constant, L is increased if L is increased L by D increases if L by D increases there more there is more amount of liquid flowing down the column. To change the vapor liquid equilibrium of this extra liquid that is flowing down the column at a higher L by D you require more entrainer. There will come a point that if you keep on growing L by D the entrainer becomes limiting and the vapor liquid and the azeotrope now, is not getting broken Therefore, there is the idea of L by D max, there is also the id. So, so there is L by D mean there is L by D max, and there is also entrainer to feed ratio min right.

And I hope you understand all of these. What are the implications of having an L by D max, you see typically in an ordinary distillation column if you increase the L by D reflux ratio. The product purity or the distillate purity actually goes up, here the reverse can happen there will be an operating range over which if you are increasing L by D purity of the of the top stream is increasing. And then if you keep on increasing L by D the purity of the top stream or the distillate stream will actually start to go down. As an operator you need to be aware of that when do you cross that hump.

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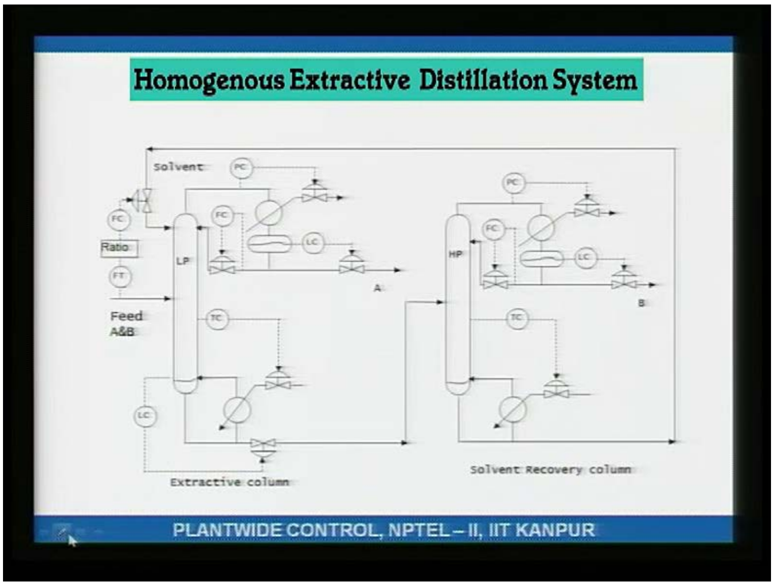

Homogenous Extractive Distillation System

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And that when the purity starts to decrease even though L by D is being increased you must become aware that the solvent to feed ratio needs to be increased in this control structure that is about it. So, we have talked about heterogeneous extractive distillation system. Next class, which will be the last class on distillation systems, we will look at some complex column configurations and their control and after that we will end, then will go onto control of reactors.

Thank you.