Plantwide Control of Chemical Processes
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Lecture - 14
Considerations in temperature inferential control

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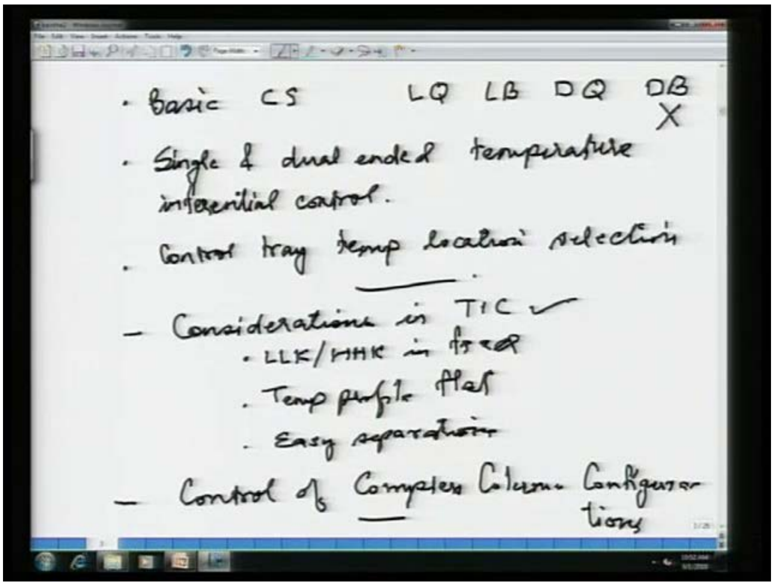

Welcome to this next lecture. We are looking at control of distillation columns and we have looked at till now, the basic control structures; basic control structures them being LQ, LB, DQ, DB, DB being cell amused except for super fractionators. We have also looked at single and dual ended temperature inferential control, single and dual ended temperature inferential control of distillation columns. Then we have looked at techniques for selecting which tray temperature to control.

So, control tray temperature location selection, all this we have done. Today, we shall look at considerations or problems that you may face that are that are quiet common in TIC, temperature inferential control of columns. Basically what we will look at, we will be looking at three things; first one being lighter than light key or heavier than heavy key in the feed. What problems this can create, how to overcome them? Then we will look at columns where the temperature profile is very flat, that means temperature profile flat means the key components are close boiling. The boiling point difference between the key components is not very large, let us say about 10 or 10 degree Celsius of that order.

Finally, we will also look at distillation columns that do very easy separations. So, not very tall easy separations means, the key components their boiling points are very different. What kind of problems this can create in temperature inferential control and how do we overcome these these these problems? Then we will also get into control of complex column configurations column configurations. There are many complex column configurations and we will talk about about them a little bit. So, main column with a side stripper, a main a main column with a side draw, a side stripper or a side rectifier.

Then we have column which have a pre fractionators and then the main column section and so on so forth. All kind of complex configurations are there.

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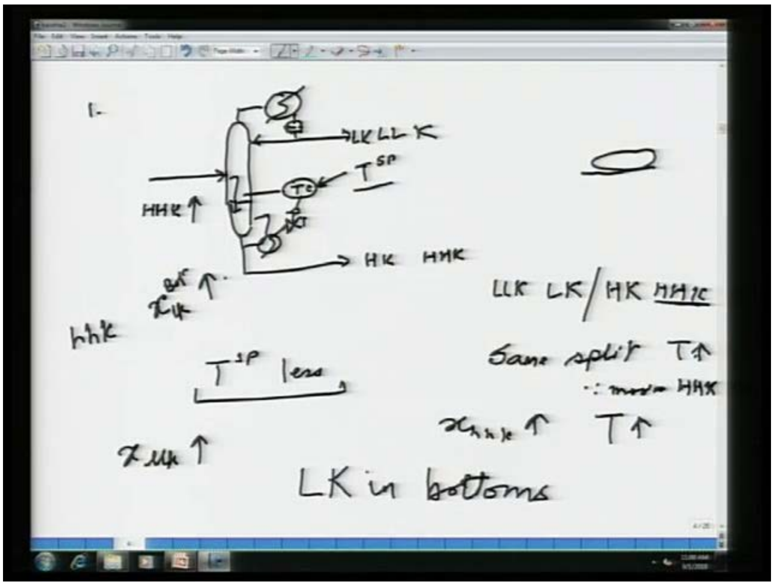

So let us get on with it. Considerations or problems that one may face, problem number one; you have got a column, in this column anything that is lighter than the light key, that means all lighter than light key go up. Essentially light key and everything that is lighter than light key goes to the top, heavy key and anything that is heavier than heavy key goes to the bottom. That is by definition of the keys, of the key components.

So, light key and lighter than light key go to the top, heavy key and heavier than the heavy key go to the bottom. Now, let us say we are controlling, I am not showing all the other valves etcetera, etcetera. Let us just say, we are controlling a tray temperature using reboiler duty. Let us say we are doing this. Now, consider the fact that the feed has got light key, heavy key, lighter than light key as well as heavier than heavy key components. Now let us say HHK goes up, HHK or rather or the heavier than the heavy key in the feed goes up. Now, if heavier than heavy key in the feed goes up, notice that all of these heavier than heavy keys will accumulate towards the bottom of the column or in the stripping section.

Heavier than heavy key will flow down that is because it is heavier than heavy key. Therefore, if if this is my tray temperature that is being controlled most of the heavier than heavy key would have accumulated here, the composition of well let us say. So, all of the the heavy this, the heavier than heavy key will accumulate toward the bottom of the column, that is by definition or that is what happens in distillation. Now, because of the presence of heavier than heavy key for the same split, see the split is between light key and heavy key. Anything that is heavier than heavy key goes down, anything that is lighter than light key goes up for the same split because the heavier than heavy key is accumulating in the bottom section. For the same split that means this light key heavy key split is the same, for the same split because now you have got more heavier than the heavy key coming in the feed, which is accumulating on those trays.

For the same split, split always refers to the key components, for the same split temperature of the tray will go down, will go up because you have got more. So, temperature of the tray must go up because now you have got more heavier than heavy key which is on that tray. I hope that makes sense, for the same split temperature is more because more HHK in feed. That heavier than heavy key accumulates in the stripping section more towards the bottom.

Therefore, if I am controlling a tray let us say that is towards you know, let us say 5, 10 trays below the feed. The heavier than heavy key composition on that tray for the same light key heavy key split would be more and because x h h k is more on the tray. Therefore, for the same split tray temperature should be more. Let us say I am operating at the, I do not change this tray temperature set point is kept constant. So, tray temperature set point is kept constant, if the tray temperature set point is kept constant then this because heavier than heavy key is more in the feed, this tray temperature set point should be more.

I am however operating at the same temperature set point, when the heavier than heavy key in the feed was less. So, what happens then? Now, my tray temperature set point is less than what it should be it it should be because the tray temperature set point is less than what it should be, what would happen is; lighter than light key to get this lower tray temperature set point I will have to have some lighter than light key. Because lighter than light key will give me a decrease in temperature set point, a decrease in temperature, heavier than heavy key causes the temperature to increase.

So, because the heavier than heavy key is accumulated on this tray, and I am trying to maintain it at the same tray temperature set point. What that would ultimately end up doing is, x l l k will go up because x l l k will go up what that means is, now the lighter now lighter than light keys are coming down. So, what will happen is you will start getting l l k in the bottoms. Just to repeat it once again, more heavier than heavy key in the feed that heavier than heavy key accumulates on the trays in the stripping section. Now, because the control tray temperature is the same heavier than heavy key tends to increase the temperature of the tray. In order to bring that increased tray temperature back to set point, what will happen is the re boiler duty will be adjusted, so that enough lighter than light key accumulates on that tray, so that the tray temperature set point is the same as so that the tray temperature is as its set point.

So, we have essentially ended changing the split in such a way that now lighter than light key is actually coming down. Now, because the lighter than light key is coming down you will get contamination of light key and lighter than light keys components in the bottom. So, not light key sorry this will be actually l k in the bottoms, I am sorry. This would be light key in the bottoms. So, if I am operating this column without adjusting the tray temperature set point what I will find is; that if HHK goes up, x light key in the bottoms goes up, right.

Notice that if my control tray, how do I mitigate this? The way to mitigate this is this phenomena would be more and more extreme as I move from the feed stage.

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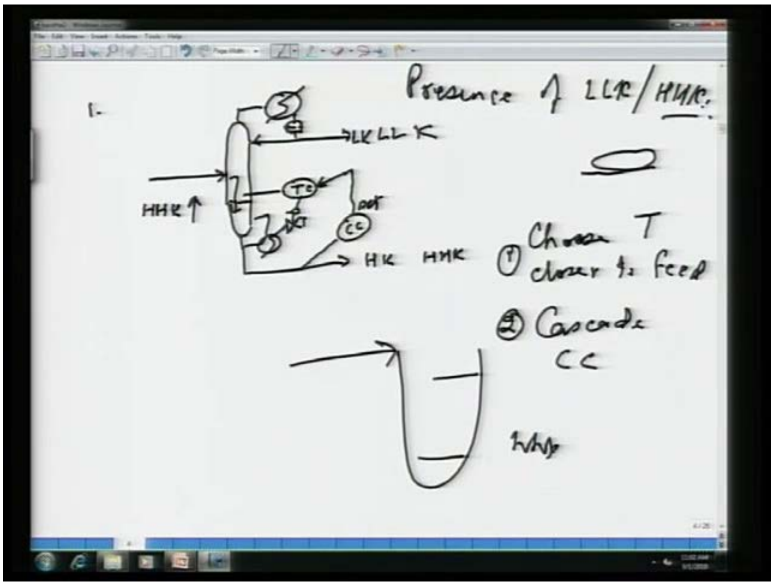

If I am towards the bottom of the column the change in temperature because of heavier than heavy key will be much more than I am say towards the feed, closer to the feed. So, one of the ways of mitigating this effect is to choose control trays, choose temperatures that are to be controlled closer to feed. That is possibility number one, possibility number two is that you measure light key impurity in the bottoms and if this light key impurity is going up you make an adjustment to the temperature set point.

So, these are the two ways of addressing this problem, cascade control, cascade composition control. So, this is problem number one presence of LLK or HHK. If I can have the same logic which I applied to HHK also I can apply to LLK.

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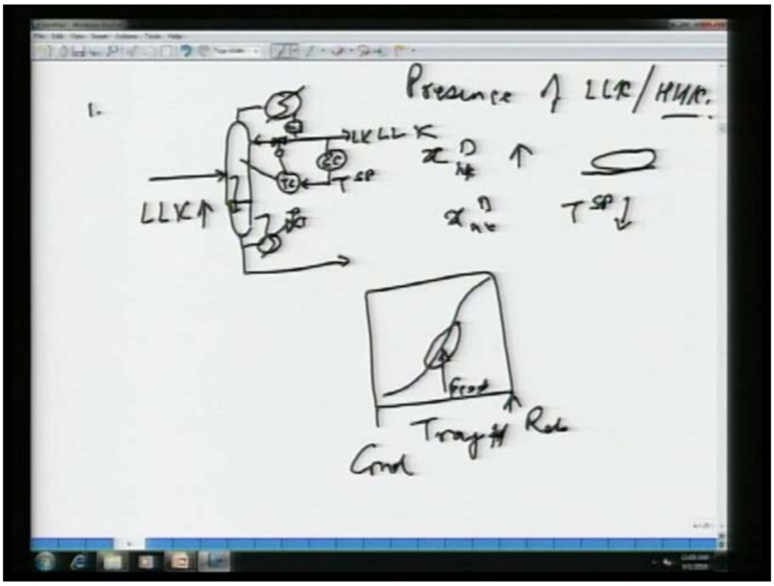

If LLK goes up then this lighter then light key tends to accumulate towards the top of the column. If I am controlling a tray temperature let us say by reflux, if I am controlling a tray temperature like this. Now, because lighter than light key is accumulating on those trays for the same split, my temperature has actually reduced. However I have not changed the temperature set point.

Therefore, to maintain the tray at its temperature set point my reflux would be adjusted, so that some amount of heavy key is there, some amount of extra heavy key is there on that tray, and because to compensate for the presence of light lighter than light keys in the top section I am allowing heavy key to come into my rectifying section. I will get ultimately contamination of heavy key in the distillate. This will go up. Again mitigation of this effect, the closer the control tray temperature is to is to the feed the less severe is this effect. That is point number one and the other way of course, is I do a composition control here that adjusts the temperature set point, which composition I am looking at? Heavy key composition in the distillate, if the heavy key composition in the distillate is going up, I should T set point should be reduced, right.

So, this is how you, this is what the presence of, this is what the presence of lighter than light key or heavier than heavy key can screw up my split. So, that my split does not get affected and I operate the column at the desired split that I want, I either do composition control which adjusts the temperature set point or and or I choose the tray temperature location to be close to the feed stage.

Hopefully and if you look at the temperature profiles of well designed columns, you will find that if this is tray number, this being the condenser, this being the reboiler. You will find that the tray temperature is typically of this type and feed may be somewhere in the middle. This is the feed stage and you will find close to the feed stage the slope of the temperature profile is pretty steep. Therefore, close to the feed tray but not the feed tray controlling a tray temperature close to the feed tray, actually is sensitive and it also naturally mitigates the deterioration in quality control due to the presence of lighter than light key or heavier than heavy key in the feed. So, I hope this has this is clear enough.

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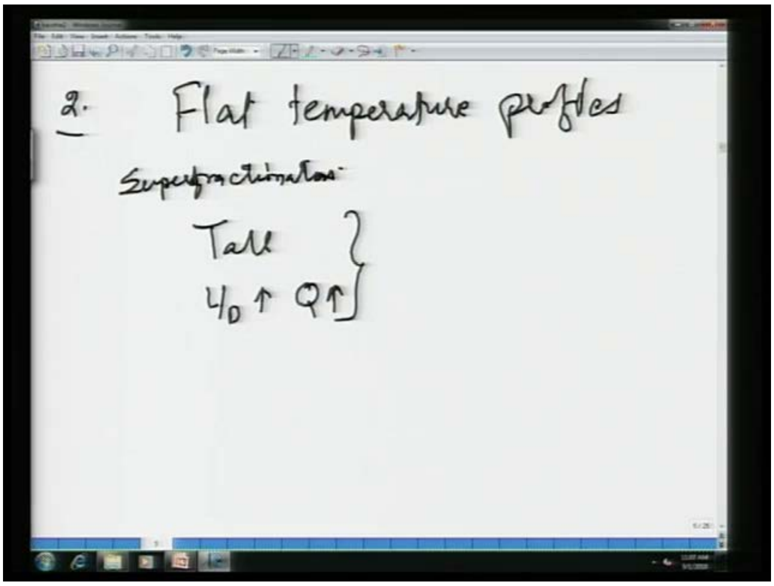

Point number two, flat temperature profiles. Flat temperature profiles, this will happen for situations where the light key and heavy key component boiling point difference is small, not very not very large say between 5 to 10 degree Celsius. So, the relative volatility of the key components is close to 1, it is a difficult separation and therefore, what you will find is a, this is typically the case in super fractionators. So, super fractionators would be tall that is because because number of trays would be more that is because the separation is difficult. So, you require more number of trays and you would also have reflux ratio is large, reboil is also large. That is a typical super fractionators.

So, the vapour liquid traffic inside the column is large because the reboil is more reflux is also more. That is a consequence of the fact that the separation is difficult, alright.

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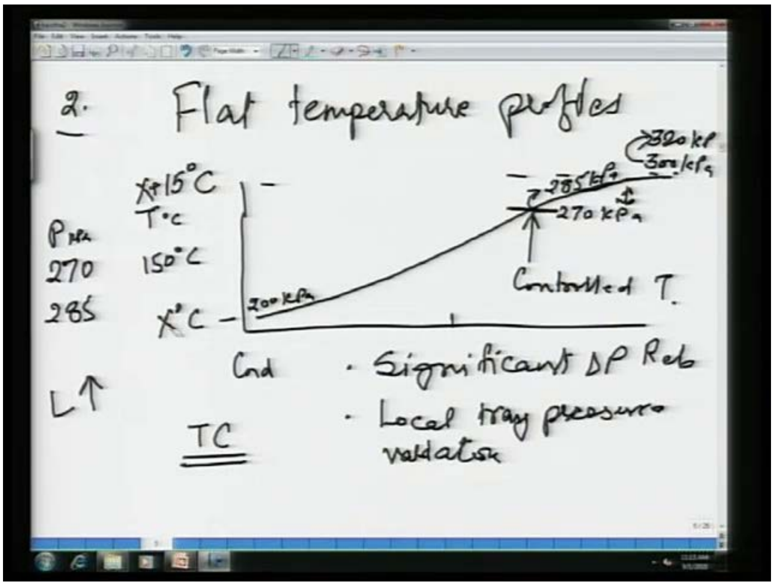

Given this, if I look at the temperature profile in a super fractionator its got a large number of trays. Well, let us say this is the feed stage, this is condenser, this is. So, because the separation is difficult and the boiling temperature difference between the key components is small you will find that the tray temperature changes only by, you know let us say, this is I do not know, X degree Celsius, well this may be, well this.

Probably like, this this may be X plus, I do not know may be 15 degree Celsius. So, the top is only 15 degrees cool colder than the bottom or the bottom is bottom is only 15, 10 to 15 degrees hotter than the top. You will see that the change in temperature as you move from one stage to the next is very small. That is because even though the composition may change by it is it is small, because the key components are close boiling also as you move from one tray to the next the change in composition is not is not very large, alright.

What happens in such a case is, if you try and do temperature control because the column is long there is significant pressure drop across the column, significant delta P, because it is got a large number of trays, alright. Also there are local significant well local fluctuations. I would not call it, local variation in tray pressure, local tray pressure variation. What I mean by that is; let us say at base case or at my design condition that top pressure is, I do not know 200 kilopascals, bottom pressure is let us say bottom would be, would have to be at higher pressure and let us say 2 kilopascals per tray. Let us say 60 trays, let us say about 300 kilopascals.

So, 2 atmosphere, bottom pressure is about 3 atmosphere that 1 atmosphere pressure drop is because the tower is very long. Let us say I am controlling this tray temperature, controlled. This tray temperature is being controlled. If I increase or decrease the reflux as the flow through internal flow through the column is changed, what will happen is; the level of the accumulated liquid on each of the trays, let us say I have increased the reflux. If the increase reflux has been increased then the level on each of the trays would have gone up a little bit. When you sum it up over 60 trays or let us say how much is this, may be 40 trays. When you sum up that slight increase in delta P across the trays over from the top to the bottom, what you will find is this is maintained at 200 kilopascal.

Now, the pressure here which was let us say, I do not know. Pressure here originally, let us say it was two thirds of that, let us say about 270 kilopascal. If I increase the reflux L is increased, if I increase the reflux the amount of liquid on each of the trays would be more. The vapour will have to displace more liquid in order to find its way up. Therefore, the pressure drop across each of the trays has gone up by a little bit. And now, what will happen is if I am controlling the condenser pressure well the bottom pressure would have gone up to let us say, 320 kilopascal. This goes to this, this is the top is the condenser is maintained at its designed pressure because this is gone up, this is also gone up and let us say, this goes up too I do not know may be 200 and well may be 285 kilopascals, right.

So, because the internal vapour liquid flow can change, the pressure on this tray the pressure that this tray sees, which whose temperature is being controlled changes. And it can it changes by, you see if a if a liquid at 270 kilopascals, if this is the pressure for the same composition. Let us say the pressure is in kilopascal, temperature is in degree Celsius, at the same at 270 kilopascals if the boiling temperature for the given composition on that tray is let us say, 150 degree Celsius at 285 kilopascals because the pressure has gone up of the tray locally.

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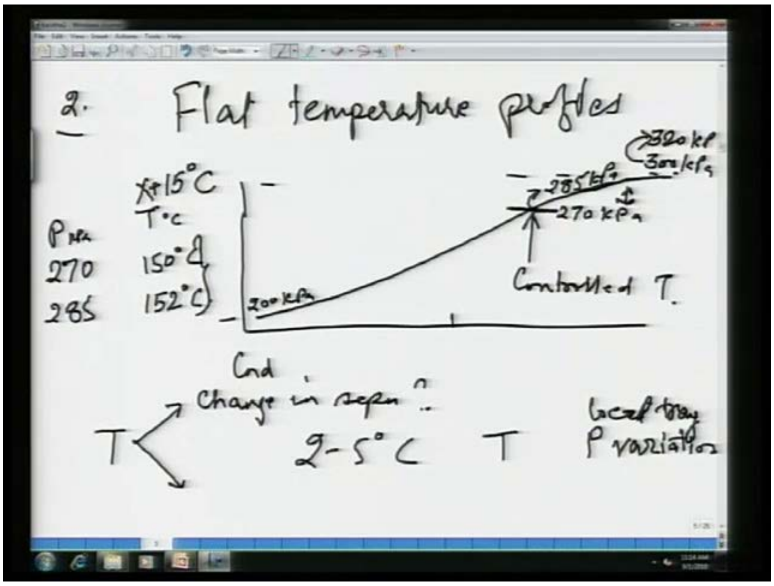

The boiling temperature may be would go up, higher pressure liquid same composition liquid will boil at a higher temperature. Therefore, this temperature may be, let us say 152 degree Celsius, alright just for example. You can get a 2 to 5 degree Celsius change in tray pressure, you can get a 2 to 5 degree Celsius change in tray temperature because of pressure variability, local tray pressure local tray pressure variation. Well you can see as you go from here to here the change in temperature is only 15 degree Celsius. Now, when the temperature of the tray is changing by 2, 1 or 2 degree Celsius, you cannot really tell whether the change in temperature.

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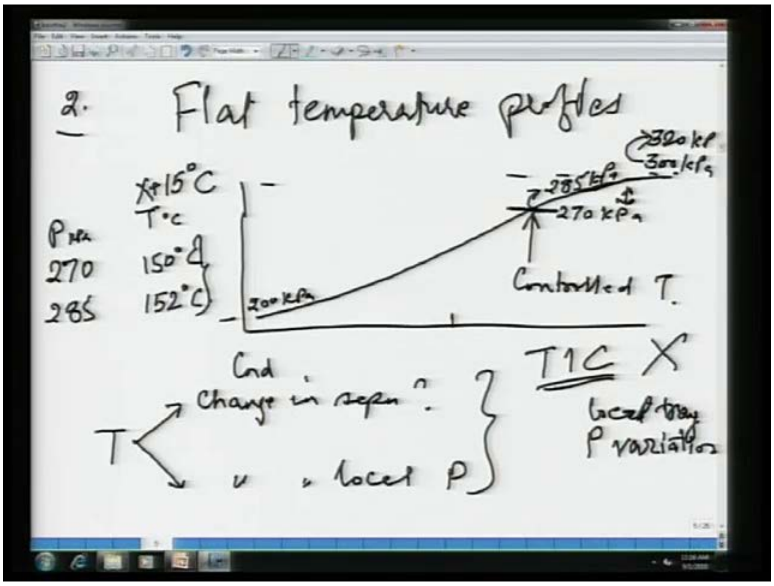

If a tray temperature changes what is it due to is due to change in separation or is the change in tray temperature due to change in local pressure. You see when the boiling point difference is large, a local pressure variability is small because the tower is small and internal flows are small, because reflux is small amount of boil up that unit is relatively smaller. Therefore, local pressure variability is small, also the amount of change in temperature as you go from top to the bottom is large, 30, 40, 50 degree Celsius. So, if a small amount of change in separation occurs that will create a change in temperature of 2, 3, 4 degree Celsius. Pressure fluctuations would be creating a change in temperature of only of the order of let us say, 0.1, 0.2, 0.3 degree Celsius. So, if the temperature in a small column changes by about 1 degree Celsius, you know that is due to a change in separation.

On the other hand in a tall tower if the temperature is changing by 1 or 2 degree Celsius, you really cannot tell whether it is because the local pressure in the column has changed or is it because the separation has changed, alright. So, temperature inferential control, if you try and control that tray temperature it would not work. You will find that the product purity is varying all over the place and that is because pressure fluctuations are masking change in separation. The pressure fluctuations overwhelm the temperature, so that variability in temperature is largely due to change in pressure, local pressure on the at local pressure on the local pressure on the tray that you are trying to control. How do you get around this problem? Again you see measuring composition is difficult, analysis are expensive, how do you get around this problem? Ultimately, I do have to run a super fractionators.

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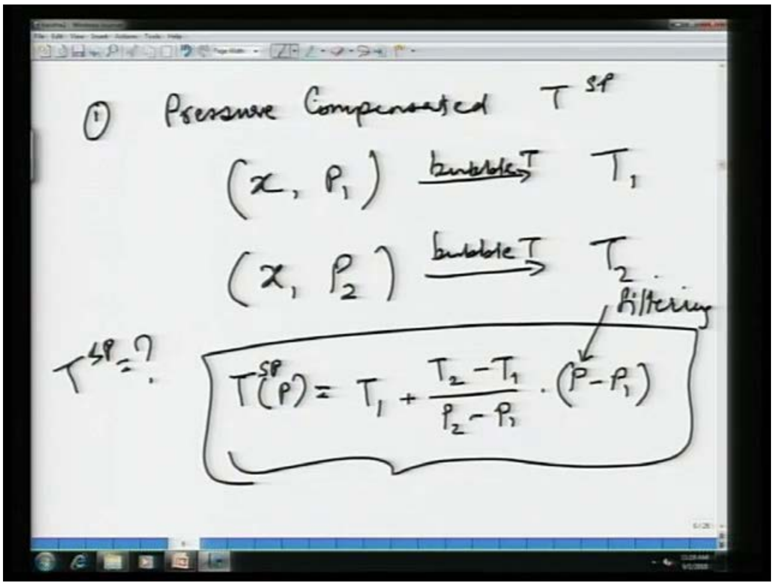

So, there are two ways of getting around this problem; one way is well, you have got a one way is you have got a temperature sensor on the tray, also put a pressure sensor on the tray. So, what you then do is pressure compensated temperature set point, pressure compensated temperature set point. So, you are measuring the temperature on the tray, you are also measuring the pressure on the tray. So, once you are measuring the pressure on the tray, how do you do pressure compensation? Well given a liquid x, you would like to hold the composition on the tray constant, so given x p 1, I know what is my mixture.

I can do a bubble point calculation so I will get this mixture. If I do a bubble temperature calculation it will it will tell me this mixture will boil at this temperature T 1. At the same composition a different pressure, I again do a bubble T calculation. This mixture will boil at a temperature T 2. Well then what I do is; my essentially say that if I have a pressure P, what should my pressure set point be? That comes from, you know you can just linearly interpolate, do not make me do it because well. So, T 2 minus T 1 divided by P 2 minus P 1 times P minus p 1 plus T 1.

So, temperature set point at a pressure P would be calculated from here and this is you know you can do your bubble point calculation of line. Then all you have to do is just implement the simple linear relation to get what your temperature set point should be based on the local pressure at the at the tray. Note that pressure can fluctuate a lot and so you will have to filter the pressure signal, this will require some sort of filtering, so that the noise in the pressure signal is filtered out and you are only compensating the temperature for long term trends, that are seen in the pressure. That is by the way, this is one one way of circumventing this problem.

A more popular way is you see super fractionators will have temperature sensors on a large number of trays. At many locations in the column you will have a temperature measurement.

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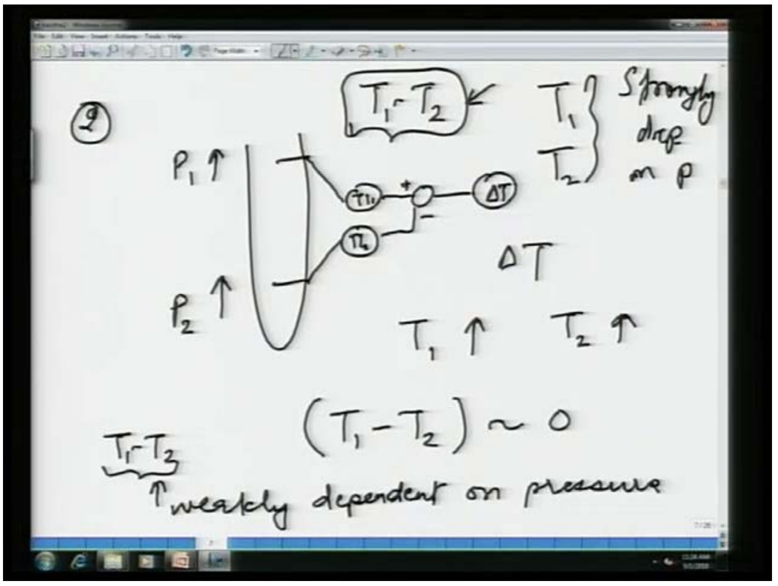

A more popular way is, you take the column, instead of controlling a tray temperature what you do is you take the difference. So, this is well so these are two temperature indicators, temperature indicator one, temperature indicator two. You take these two signals, substract them plus minus and then what you get is delta T. Instead of controlling a tray temperature you try and control a difference between the temperature of two trays, that are let us say separated by 5 or 10 trays, whether it should be 5 or whether it should be 10 that depends on what is the temperature difference across the whole column.

Why does this work? Well this works because if the pressure here goes up, local pressure here goes up. Let us say p 2 is going up well then p 1 will also go up, right. If the pressure in on on the bottom tray goes up, if the pressure on the tray, on the higher tray will also go up because both the pressures go up, T 1 will go up because it is at a higher pressure. T 2 will also go up because the pressure on that tray is more.

When I take T 1 minus T 2 this would be close to 0. It will be close to 0 because the pressure has gone up by about the same amount on this tray and the other tray, which was about which is about say 5 trays below. Therefore, the difference in the tray temperatures is of the order of 0 or very very small difference in the tray temperatures. So, T 1 minus T 2 as a signal does not or or depends on pressure very, its dependence on pressure is very weak. T 1 minus T 2 is weekly dependent on pressure weekly dependent on pressure. Now, because T 1 and T 2 are weakly dependent on pressure, on the other hand T 1 depends or T 2 by themselves they are strongly dependent on pressure, strongly depend on pressure local pressure on the tray, right. T 1 minus 2 is weekly dependent, its almost independent of the local pressure on the tray.

Now, when I was looking at T 1 or T 2 by itself I could not tell whether the change in temperature is due to pressure or due to a change in separation. When I am looking at T 1 minus T 2, since it is weekly dependent on pressure if T 1 minus T 2 is changing that is because the heavy key or the light key depending on where this this T 1 and T 2 are located in the column towards the top or towards the bottom. That is because the separation is changing. Now, delta T, a change in delta T indicates a change in separation. So, instead of controlling a tray temperature you control the difference between two tray temperatures in towers that are long, that have large pressure drops and are doing difficult separations. So, that the change in temperature from the top to the bottom is not very large.

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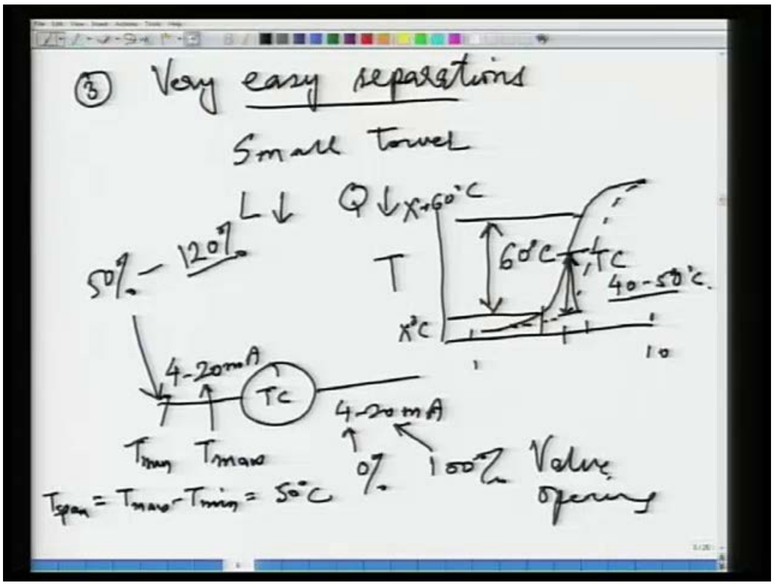

Third problem, very easy separations. Let us just columns that do very easy separations. What that means is that, the light key, heavy key relative volatility is very large relative volatility, being large means that these two components have a very large difference in their pure boiling temperatures. So, let us say of the order of 50, 60, 70 degrees Celsius. That being the case what would what you would see is, since the separation is easy tower is small since the separation is easy this implies a small tower. It also implies reflex is small Q is small; you do not require a large amount of steam to separate components that are easy to separate.

Since, the separation is easy if you look at the tray temperature profile, the temperature profile may be of you know, let us let us say it just got say 1 to 10 trays, that is not a long tower. What you would find is that the tray temperature is very sharp. You see, this change in temperature let us see over or let us just say, this is the tray temperature profile. What you will find is that the change in temperature, this is over 3 trays, the temperature changes from let us say, X degree Celsius to X plus 60 degree Celsius. The change from here to here, this change is a very large one; 60 degree Celsius that is because the separation is easy you move from one tray to the next, to the next and the temperature has changes by 60 degree Celsius.

What are the implications of this? Well, its caught some pretty significant implication in the sense. That you see when you have a controller it takes in a signal that is between 4 to 20 mille amps. Its output is a signal that is between 4 to 20 mille amps. This 4 mille amp will correspond on to T min, which is the span of the sensor. This 20 mille amp will correspond to T max which is again the span of the temperature sensor. Typical span of temperature sensors is anywhere from 50 to 100 degree Celsius. So, let us say T min minus or T max minus T min, which is the span, temperature span which is equal to this is equal to this is equal to about 50 degree Celsius.

By the way this 4 mille amp corresponds to let us say, 0 percent valve opening. This 20 mille amp corresponds to let us say, a fully open valve, valve opening. If I try to control a tray temperature, which is let us say this guy. Let us, I am trying to control this tray temperature, alright. So, if I am trying to control this tray temperature what happens is, if the separation moves a little bit up or down you know the this separation zone if it moves a little bit up or down the column.

Let us say it moves down the column, what I will get is; I will get. So, this the small change in the separation which is causing the separation zone to move slightly below the you know down the column. So, what happens now is the tray temperature that I am trying to control has changes from where ever it was, to a much lower value. Let us say this value is about 40, 50 degree Celsius, if the difference between this and this is about 40, of the order of 40 degree Celsius. Now, you can see what the problem with this is, my separation profile moves down a little bit and my temperature sensor reading, which is here this sends reading goes from 50 percent to 100, I do not know 20 percent may be. You see my temperature reading is actually going off the charts.

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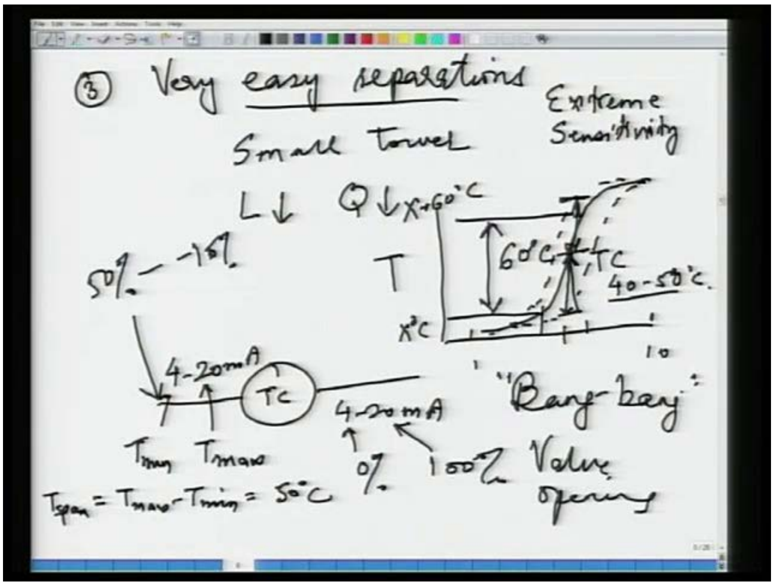

Well here the temperature is decreasing its going from 50 percent to minus 10 percent. My temperature on the tray is below the span, you know the below the minimum temperature that the sensor can read. So, what happens is my temperature has gone down, my read my separation profile has moved down a little bit, my temperature sensor has gone to 0 percent or below what I then do is I crank up the heat.

When I crank up the heat the separation profile moves up and now it moves up a little more than it should have. Now, you see my control tray temperature is here, there is the problem of what I am referring to is extreme sensitivity because the separation is easy. My temperature sensor is moving from 0 percent to 100 percent, I reduce the re boiler duty, it goes down to 0 percent. I increase the re boiler duty it goes up to 100 percent, I get what is called bang bang control. That is because my temperature is extremely sensitive to the change in the re boiler duty. My separation profile moves down a little bit, temperature sensor shoots off the chart, my set, my separation profile moves up a little bit again my temperature reading shoots off the chart.

So, this results in what is called bang bang control, bang bang. So, my re boiler duty is open, is closed, is open, is closed temperature sensor is off the chart, off the chart, off the chart, off the chart. How do you circumvent this problem of extreme sensitivity?

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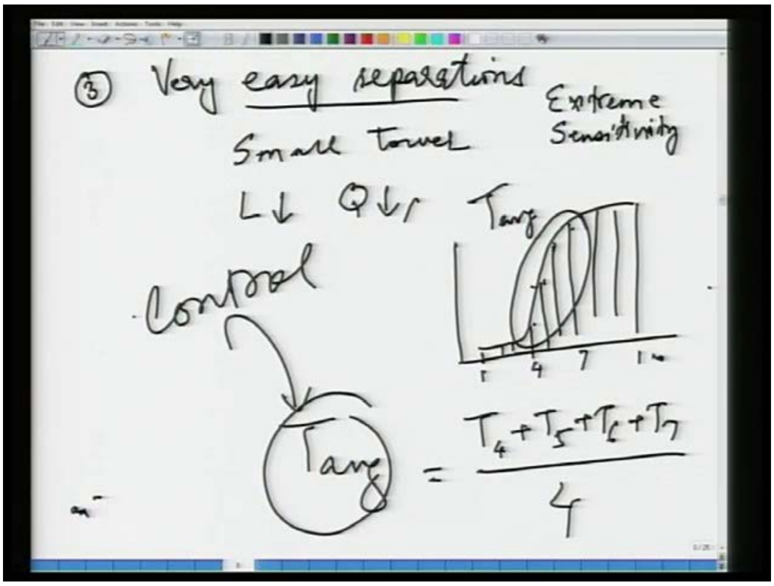

Well in this case instead of trying to control a tray temperature, what should be done is you try and control an average tray temperature. So, if my tray temperature profile is very sharp, I instead of controlling a tray temperature I control the average of 3 or 4 tray temperatures. I take these tray temperatures, average them out, let us say these are tray 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10. So, there are 10 trays, 1 to 10. I am controlling 1, 2, 3, 4 so 1 2, 3, 4, 5, 6, 7. So, this is 4 this is 7. So, I am going to say instead of controlling one tray temperature, I control T 4 plus T 5 plus T 6 plus T 7, T average is what is controlled. From, in difference distillations scenarios that are pretty common. So I thought it is good to describe them, explain them and suggest where is around the problems.

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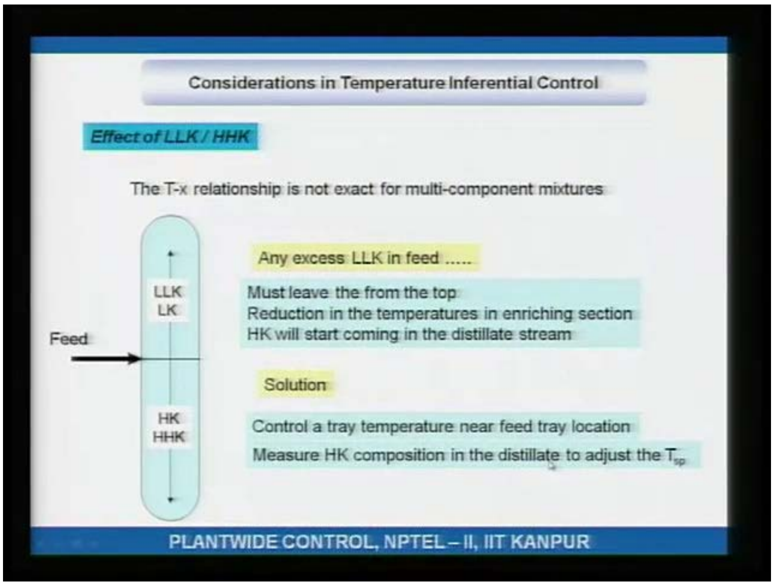

Considerations and temperature inferential control. We have looked at effect of lighter than light key or heavier than heavy key. If there is excess lighter than light key in the feed, the lighter than light key must leave from the top. It accumulates towards the top of the column, this cause is a reduction in the temperatures in the enriching section. If I try and control a tray temperature its set point should be reduced because of the presence of lighter than light key on that tray.

However, if I do not reduce the temperature set point in order to bring the temperature back up some of the heavier than heavy key will end up being on that tray, and ultimately you may find in extreme cases that the heavier, that the heavy key is actually contaminating the your distillate. So, the heavy key will start coming in the distillate stream. Similarly, so the solution here is you control a tray temperature near the feed tray location, where this effect will not be as severe or you major the heavy key composition in the distillate and adjust the temperature set point.

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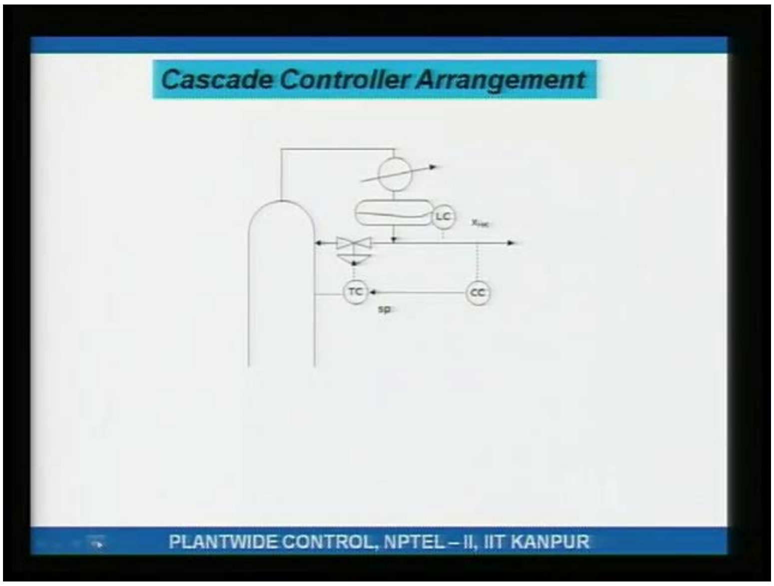

This is what is shown here and you can have a corresponding argument for the striping section for the bottom stream.

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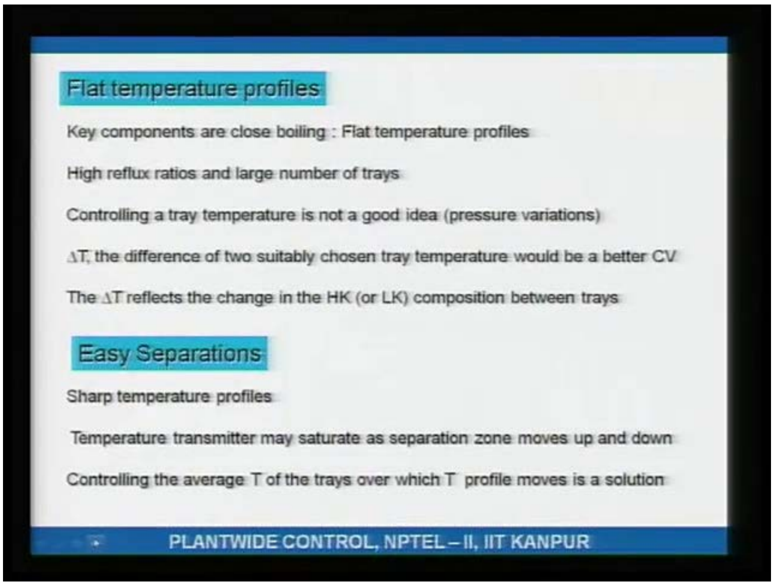

Flat temperature profiles, well this occurs when key components are closed boiling, you get flat temperature profiles. Such columns will have high reflux ratios and large number of trays, tall towers. Controlling a tray temperature is not a good idea, because the tray temperatures is strongly influenced by local pressure variations. Instead, what is recommended is you control delta T, which is the difference of two suitability chosen tray temperatures. Delta T is a better control variable because delta T is does not depend very strongly on on on pressure fluctuations, because when you subtract two tray temperatures the the pressure variability or the effect of pressure also cancels out.

In this case the delta T reflects a change in the heavy key or light key composition between the trays depending on whether it is located here or there. Easy separations, well in easy separations you get sharp temperature profiles. The temperature transmitter may saturate if you are trying to control a tray temperature in the separation zone. Because of this extreme sensitivity you get bang bang control, in order to mitigate this extreme sensitivity you are better of controlling the average of trays over which the temperature profile moves. This averaging actually mitigates the sensitivity and therefore, would give you a better control.

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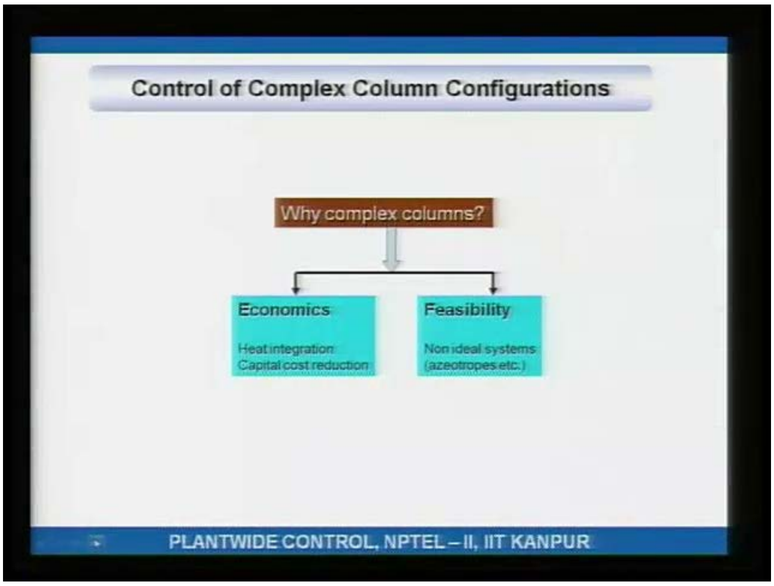

I think that is that for today. Control of complex column configuration, that is a new topic, will leave that for the next lecture. So, next time control of complex column configurations.

Thank you.