Chemical Process Control
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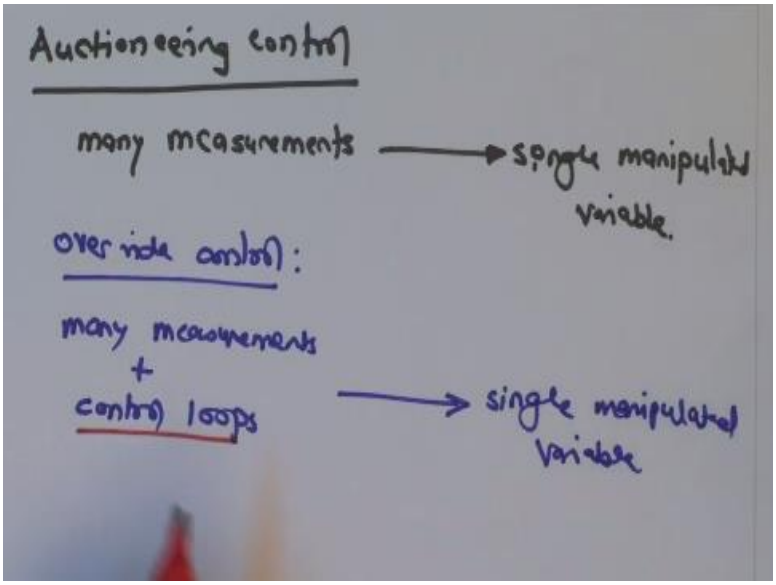
Lecture – 40
Auctioneering, Ratio and Inferential Control

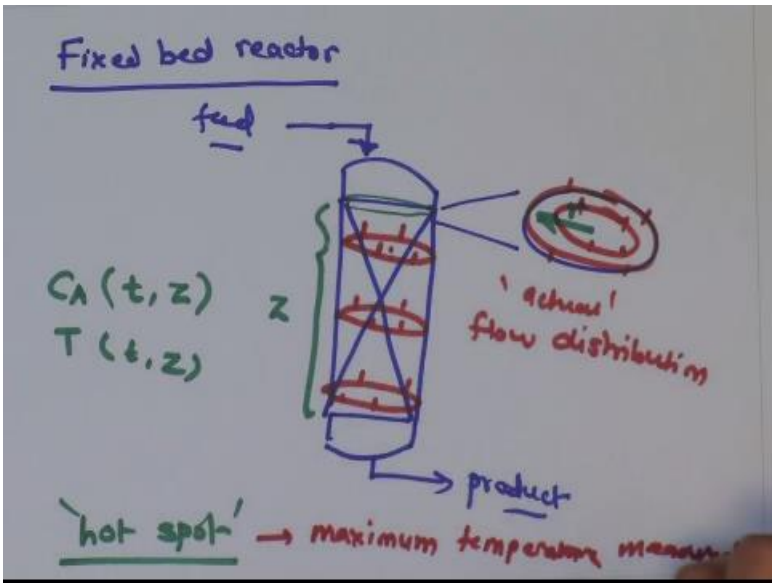
Welcome back, students. Before the break, we have been looking at traditional advanced controllers and we had looked at cascade control, split range control and within selective control, we looked at override control. There is another type of control which also forms which is also a part of selective control, so that is known as an auctioneering control.



This is also part of a selective control in such a way that there are many measurements which are used but eventually, there is only a single manipulated variable. If I want to contrast this with override control, in override control also we had so this is auctioneering. In override, we also had many measurements, but along with that we also had their own control loops as well and one of those control loops was active at any time which was used to move the manipulated variable.

If you want to see the difference between the 2, we will see that in auctioneering control we have many measurements, but we do not have that many control loops. Let us see how does an auctioneering control look like or what is the case where auctioneering control will really be useful.

The very commonly used place where auctioneering control finds its use is a distributed system, for example, a PFR or a plug flow reactor or a fixed bed reactor.



Let us say we have a fix bed reactor where a gas phase reaction is taking place. You have all the catalyst packing here and the raw material enters here. The reaction takes place over the length of the reactor and finally, you get the product stream out. Now typically from your reaction engineering course, you would realize that when you have a distributed system like a fixed bed reactor, then you will see that the concentration will show variation.

The concentration and temperature, so these are all the variables of the system. They will show variation as a function of time as well as location. So throughout the location, this concentration and temperatures will be different. If I look at the cross section of this, if I zoom in terms of the cross section let us say a circular cross-section, then even within this cross section as a function of radial distance you may see that the concentrations and temperatures are different.

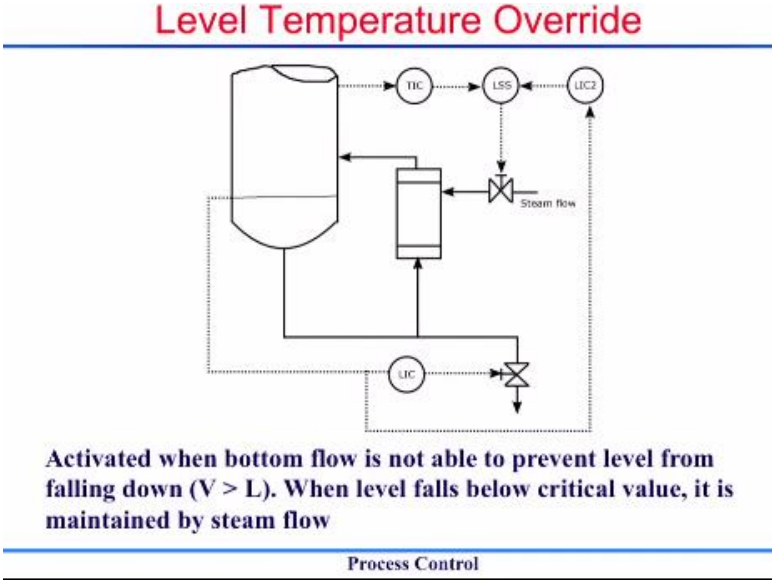
Even though when we design, we assume that radially the entire section is uniform and we make a plug flow type assumption, but in the reality, you can see that or you can expect that these concentrations and temperatures would also vary as a function of radial distance as well. All that is dependent on how well the flow is distributed. It all depends on flow distribution or I would say actual flow distribution not a theoretical or ideal flow distribution which we used to design this kind of a system.

So what happens is in a real fixed bed reactor, you would expect a variation of concentration and temperature along the length as well as in the radial direction. Because of that, if the reaction is exothermic you may have, you may develop what is known as a hotspot. So at a certain location inside the bed, the temperature may shoot up to a very high value this may be because of some sort of a dead zone where a certain runaway reaction can take place or there is a lot of maldistribution related issues which give rise to such kind of hot spots in a reactor. So such hot spots typically can be detrimental for this process. Because at a certain location, the temperature may shoot up to a very high value which may result in catalyst melting or giving rise to some runaway reactions. It is very essential that you monitor these hotspots and try to control these temperatures below a certain safe value.

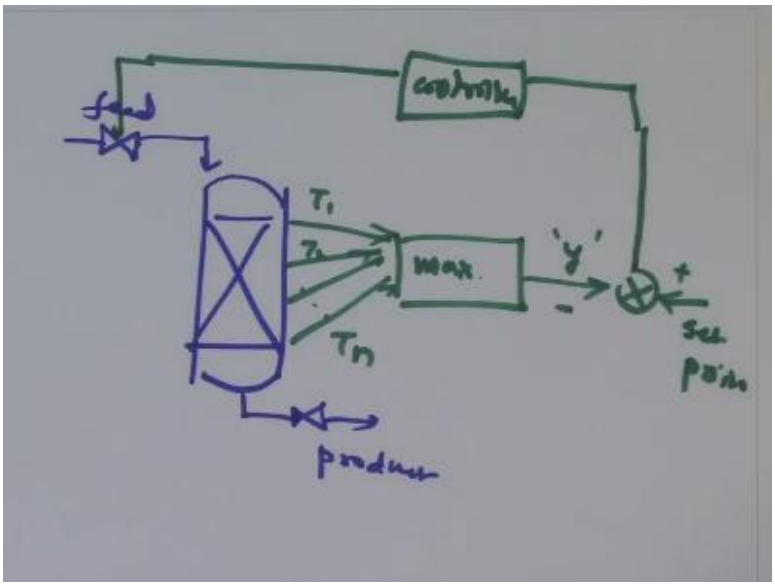
The problem comes because you do not know where exactly such a hot spot would develop because this is not a theoretical aspect. It has more to do with the practical flow behavior which is typically not those flow measurements and distribution measurements are not available. So, in that case, this becomes a real practical problem in terms of locating such a hotspot and trying to control it below a certain safe value.

So what is typically done in such a case is that along the length of the reactor you would have multiple temperature sensors. Let us say you will have a temperature band of temperature sensors in this location. You will have a band of temperature sensors in this location and depending on how much is the length of the reactor, a certain number of such rings will be placed and even on those ring, there will be multiple temperature sensors placed at different angular direction. Within that as well you can have, so if I want to show even at different radial distances you may have a band of temperature sensors. The idea is that you want to put in as many eyes into the process in terms of temperature measurement so that you want to capture that if there is such hot spot which is getting developed. Having all these 15 or 20 temperature sensors, you have so many measurements.

From that, the idea is that you want to identify where is the hot spot and hot spot would be the maximum temperature inside this reactor. Given that these are all the measurements, we would be interested in getting the maximum temperature which is measured out of all the sensors which we have and that temperature will be used to control the hot spot.



So if I want to show how this strategy would look like.

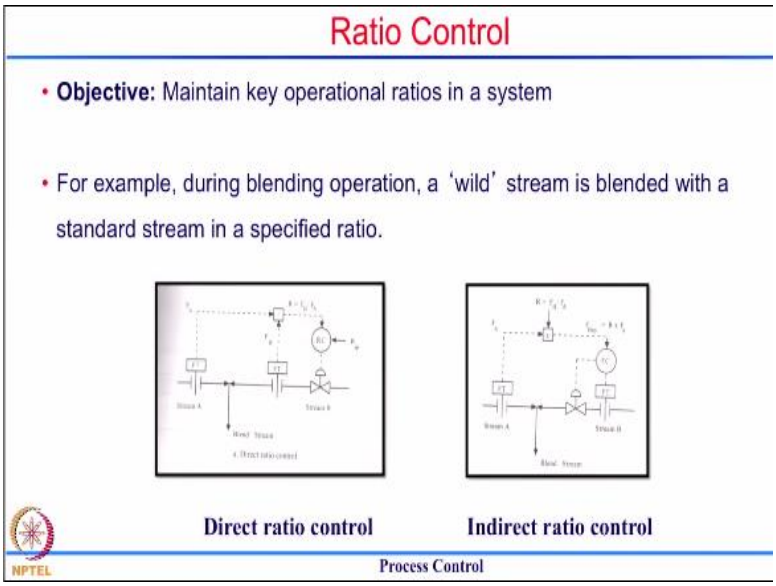


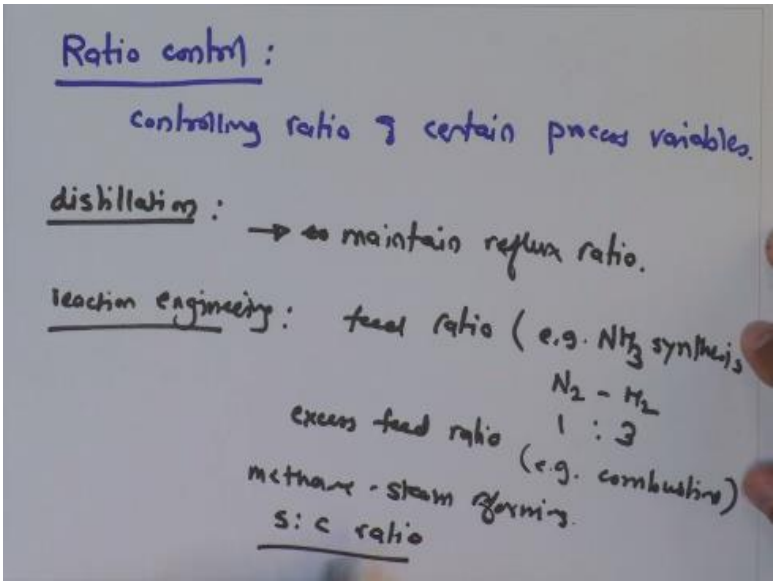
Let us say this is our packed bed reactor, this is your feed, this is your product and from this reactor we will have multiple temperature measurements, which will be taken at different location, different radial distance, different angles and all these would go to an auctioneering control, which in this case would be the find the maximum out of all these measurements. Let us say this is T_1, T_2, all the way up to T_n. You have n measurements, out of that it will find out whatever is the maximum measurement that gives you an idea about the hotspot and that will be used as a controlled variable or measurement of that control variable and eventually

you will have a control strategy around that. So this will be the set point and that would be used to control the feed valve.

You can distinguish this is an example of an auctioneering control. You can see that we are using multiple measurements, but for each of those measurements, we do not have a control loop. We select whichever is the critical measurement rather than a control loop and then take the control action according to that. That is the main difference between override control and auctioneering control. But both of these controls strategies fall under the case of selective control because we are selecting out of multiple possible control variables or measurements. This kind of strategy is very commonly used to control hotspot temperature in a fixed bed catalytic reactor.

Let us now move to another traditional advanced control strategy known as a ratio control strategy.

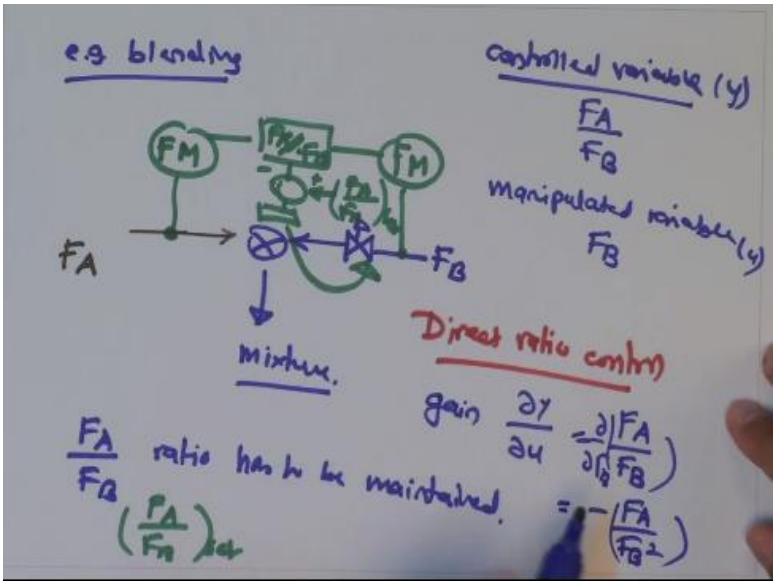




As the name suggests here we would be controlling a ratio of certain process variables. Now in your other chemical engineering courses, you might have seen that there are different ratios which are of importance. For example, if I am talking about distillation or separation, what ratio comes into your mind? You would say that you would want to control or maintain reflux ratio. If you are taking an example of reaction engineering, you might be interested in maintaining feed ratio that certain times you want to maintain that the feeds which are going into your system are at a particular ratio. If I want to take an example of ammonia synthesis, you would want that N_2 to H_2 ratio is 1:3. So that you get the desired maximum productivity out of that reactor or it can be an excess feed ratio.

A lot of times in combustion you want to make sure that complete combustion of the fuel occurs, so you would be supplying air in excess and that how much excess air should be used that ratio can also be one of the key operating parameters in your system. So this will be for example in combustion. Another place where you might want to have ratio control is, for example, methane steam reforming, where you want to maintain steam to carbon ratio.

There are a lot of places you can revisit your other chemical engineering courses and you will realize that a lot of times we are interested in maintain certain ratios because that essentially governs the productivity or economics of that particular system. Let us see how do we go about controlling or maintaining such kind of ratios in a system. Let me take a very simple example of blending.



Blending is an operation where you are going to mix two streams and you want to mix them in a particular ratio. Let us say you have a stream A, which is coming in from one particular source and you are going to mix it with another stream F_B, which you can control its flow rate. These two are mixed and what you get is the mixture and you want to blend this in such a way that I have a certain F_A over F_B ratio has to be maintained.

This can be done in two ways. The one way or the straightforward way is you can measure the instantaneous value of F_A, so that is the flow measurement. You can measure how much is the flow coming in. You can also measure whatever is the flow of F_B coming in and you have what is known as a division operator. If you divide F_A over F_B, it will give you the instantaneous ratio and you can have a controller around that which will have a set ratio.

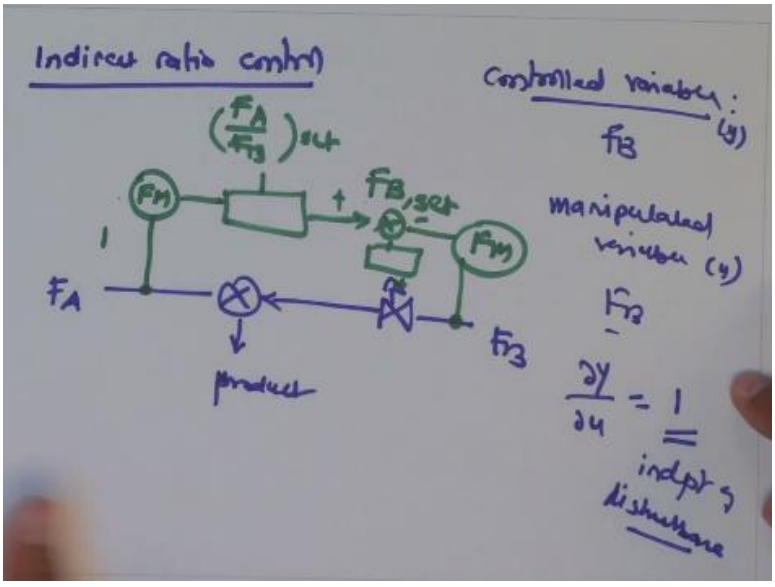
So let us say the set point here is $(F_A/F_B)_{set}$. You compare your current value with the set point and accordingly have a controller which will decide how this valve should move. As you can see that in this case, you are directly computing the ratio which you are trying to control and based on that ratio you are comparing its value with the desired value and taking a control action. Therefore, it is known as a direct ratio control. It is straightforward to visualize and therefore it is directly controlling ratio so that is why it is known as the direct ratio control.

However, it suffers from a drawback that this particular control strategy is a sort of nonlinear. What do I mean by that is? If you look at this particular controller, for this controller, the

controlled variable which we generally designate as y is F_A over F_B and manipulated variable u is F_B. If I look at how much is the gain between the controlled variable and manipulated variable what you will realize that, that particular gain is - $(F_A/F_B)^2$. You will see that the gain of this particular controller is dependent on the instantaneous value of F_A as well as F_B. The gain of this controller or the gain of this system is going to be changing as F_A and F_B change.

This is sort of a nonlinear system between the control variable and manipulated input and we have seen that the controllers which we have seen so far in terms of PID control, all those are linear controllers. In that case, as the process gain is going to change, the optimum controller settings are also going to change depending on the value of the disturbance. This control strategy may not give you the best performance throughout the disturbance or disturbance window in terms of how much disturbance it can tolerate. Depending on that value of F_A, changes in F_A the controller may perform as per expectation or may perform poorly. That is one of the major drawbacks of direct ratio control.

Let us now see how this can be avoided or how this error or this limitation can be rectified. So that is done by using what is known as an Indirect ratio control.

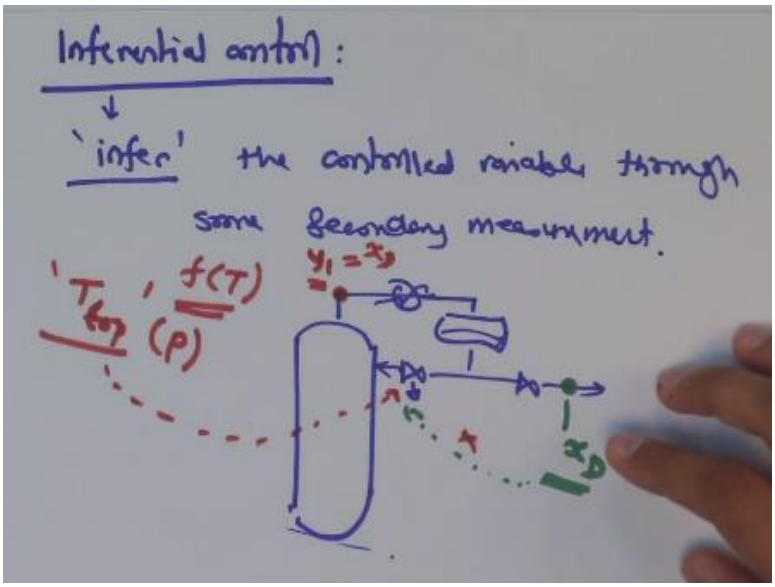


Let us take the same example, we have F_A as one of the streams and you are mixing it with another stream F_B and in this case in order to get the product or blend, so in this case, what you do is you measure your value of F_A. Your flow measurement, so it will give you the

value of F_A and it will take in whatever is your $(F_A/F_B)_{set}$. It takes in whatever is the set value of the ratio. It measures whatever is the current value of F_A and by using these two, it will compute whatever is the F_B needed in order to maintain this ratio. So you do not directly control the ratio or compute the ratio, you measure one of the disturbance variables, use the set value of the ratio to compute what is the ideal value of F_B for that corresponding value of F_A and then use this as a set point to control this particular flow. Now you will have this another flow measurement and depending on this error, you will have a controller which will set the flow rate. So you are indirectly controlling the ratio because as long as this F_B is maintained at $F_{B,set}$, my ratio of (F_A/F_B) will be equal to $(F_A/F_B)_{set}$.

The advantage of this strategy is that now if you look at the controlled variable, so am going to control flow rate F_B. The controlled variable y is F_B and your manipulated variable u is also F_B. So if you look at your gain of this particular controller, the system, this is going to be 1. It is going to be independent of disturbance. You can see that by simply rearranging the way we are computing or using the desired ratio, we are now able to make sure that the corresponding controller is linear, the system is linear so that any PID controller will give you a good result. That is why indirect ratio control is preferred over direct ratio control. So that was ratio control.

Let us now move to the next or the final traditional advanced control strategy which is known as inferential control.



Again as the name suggests what we are going to do here is that we are going to infer the controlled variable through some secondary measurement. Let me first give you the motivation for why we go about inferential control, what do we mean by inferencing and what is the secondary measurement? Let us again go back to our very commonly used separation processes it is a distillation.

You know that in distillation, we are interested in controlling the top purity, which would typically be done. Let us say this is your top of the distillation column I am not showing whatever is happening in the bottom of the column. What we are interested in is maintaining this final product purity and accordingly, we want to control the reflux rate.

Now what happens is in a distillation column or in general when you want to measure purity, these are not very straightforward measurement. They are highly dependent on what is the species which you are trying to measure sometimes it may be easy to measure it online, a lot of times you have to take out the sample, process it in the lab and after the chemist processes the sample, you would have a measurement of that particular controlled variable. Now you can see that this process may take anywhere from a few seconds to even sometimes minutes, few minutes or even a fraction of an hour.

If you are seeing that your controller is not able to see what is happening during that time, it cannot take any action. All the feedback control strategy requires measurement of the controlled variable. Here if the chemist does not give you whatever is the current purity, then you cannot take any control action till that time and it is very easy to show that in case of such measurement delays you have to go with a really slow controller in order to make sure the system is stable.

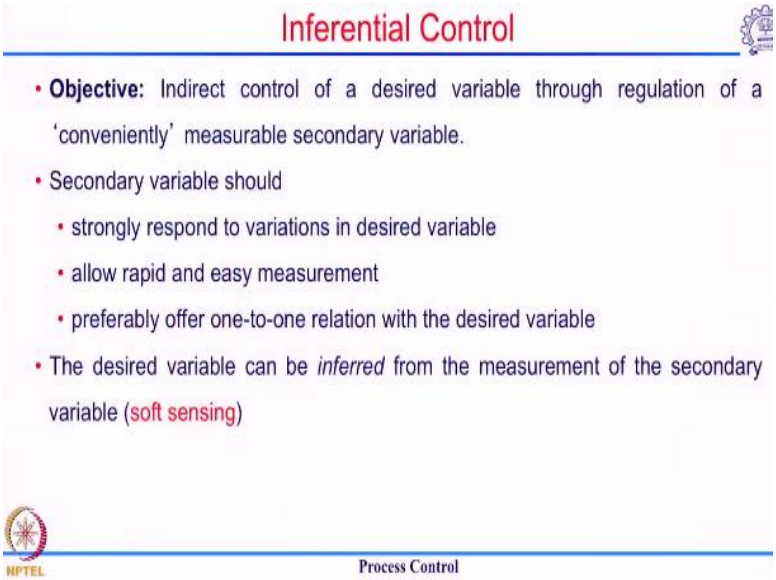
The purity lot of times may take a few hours to get to the desired value simply because you do not have the composition measurement at a very fast frequency. Now, this poses a very big challenge in terms of operation or even the design of a control system. So what can be done is rather than measuring this composition, what we can make use of some of our fundamentals of thermodynamics which says that we can take this top of the column.

If this condenser is a complete condenser whatever was the composition in the vapor phase here the same will be the composition at the distillate. Now you take this composition that

composition is a function of temperature. If I take a binary mixture, if I need a particular composition at the top of the column that will give me a particular temperature which should be at the top of the column again given the fact that it is at a particular pressure.

Most of the times you would operate your column at constant pressure. As long as the pressure in the column is set, a particular temperature, having a particular temperature will ensure that a particular purity is reached inside this column and we have seen that these temperature measurements are very fast. Nowadays, the temperature measurement can be done in the millisecond range or sub-second range. So instead of measuring a composition which takes minutes or hours, we can infer the purity inside the column by measuring the temperature. Then you can use this temperature measurement to control the purity indirectly in a sense that you will try to control this temperature by changing the manipulated variable which is a reflux ratio.

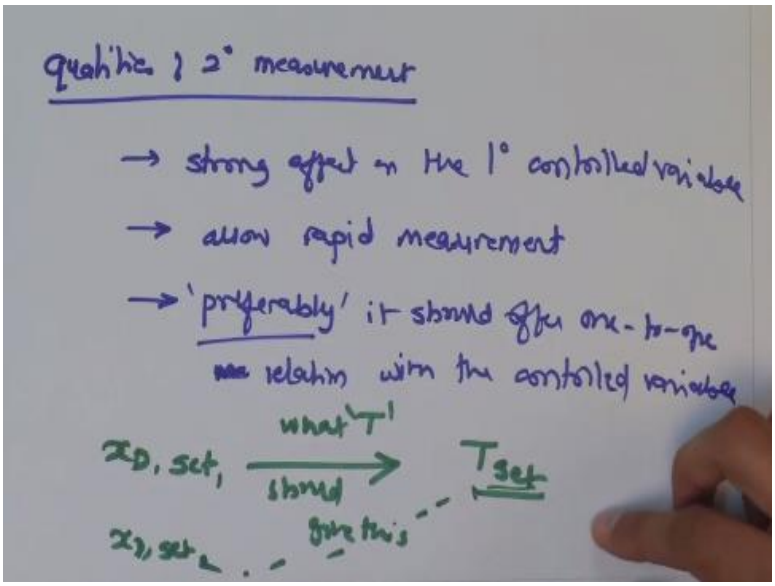
So rather than using purity measurements, you would actually measure the temperature inside the column and then compare it with whatever is the desired temperature in order to ensure that purity and then that would be used as an actual controlled variable in order to move the manipulated variable. This is known as an inferential control. So here what we did was we inferred the purity inside the column by using a secondary measurement of temperature inside the column.



Now, this is just an overview of inferential control. It is not necessary that you have to use only the top tray temperature, in fact for a very high purity systems you would not want to use the top tray temperature as a secondary measurement and there is a lot of work done in

terms of finding out which particular tray is most sensitive to the composition changes and that particular tray temperature is used as an inferential variable.

In terms of the qualities of variables which can be used as a secondary measurement, you can see that.



If I say qualities of secondary measurement, first and foremost it should have a strong effect on the primary controlled variable. That is straightforward because if whatever variable you are using to infer your main controlled variable if it does not strongly affect that variable then the control strategy would not work.

The second quality is that it should have fast measurements, it should allow rapid measurement. Again it ties up with the motivation of inferential control, the whole idea was that primary controlled variable is not easy to measure or is very slow in terms of measurement, so you want something which can be measured fast.

Then lastly which is a very tricky issue is that preferably and I am saying preferably because it is not always possible to do. It should offer one-to-one mapping or relationship with the controlled variable. What I mean by this is if I want to maintain my, if we again go back to this example, if I want my x_D to be maintained at $x_{D,set}$ and if I want to back-calculate whatever what should be my 'T', then it should give me a single value of 'T_{set}'. It should be a

one-to-one mapping between the primary and secondary controlled variable so that you can always solve this system in order to get the secondary measurement.

What if this T_{set}, at the same T_{set} you can have two $x_{D,set}$, then the system may not give you the desired performance that by maintaining T_{set}. You cannot ensure whether you are going to get $x_{Dset,1}$ or $x_{Dset,2}$. So that is why I said typically you would want the one-to-one relationship between the secondary and primary controlled variables.

That brings us to the conclusion of this section about traditional advanced controllers wherein we saw that we move from a single input single output type of control strategy in the feedback control sense and we try to see how it can be modified in terms of structure to incorporate some of the situations which are frequently encountered in chemical engineering.

Like we saw in order to reject a faster disturbance, we use cascade type of strategy. When we had multiple measurements possible in order to increase the range of controllability, we use a split range type of a control strategy. When we had multiple controlled variables, but fewer manipulated variables we can use an override strategy where one loop is overridden by the other depending on the severity of that particular loop. If you want to maintain a certain ratio we can use direct or indirect ratio control to make sure that we ensure that ratio.

The lastly, we can use inferential control where we do not measure the primary controlled variable, but we use a certain secondary measurement which has a relationship with the primary controlled variable. So this is how some of the advancements were done over as regular PID control in order to increase the applicability of PID control in processes, we call them as an advanced controller or they used to be called an advanced controller till the arrival of real advanced controllers which we will see after the break. So thank you.