Plantwide Control of Chemical Process
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Lecture - 1
Introduction to the Course

Welcome all of you, I am going to be talking to you over the next 40 odd lectures on plantwide control of chemical process. Today I am going to walk you over; I am going to introduce the course to you that is what I call module 0, which is introduction to the course. By the way most of this course will be power point presentations and may be some video modules on use of commercial stimulators such as Aspen, HYSYS, and Unisim for doing dynamic stimulations of complex chemical processes.

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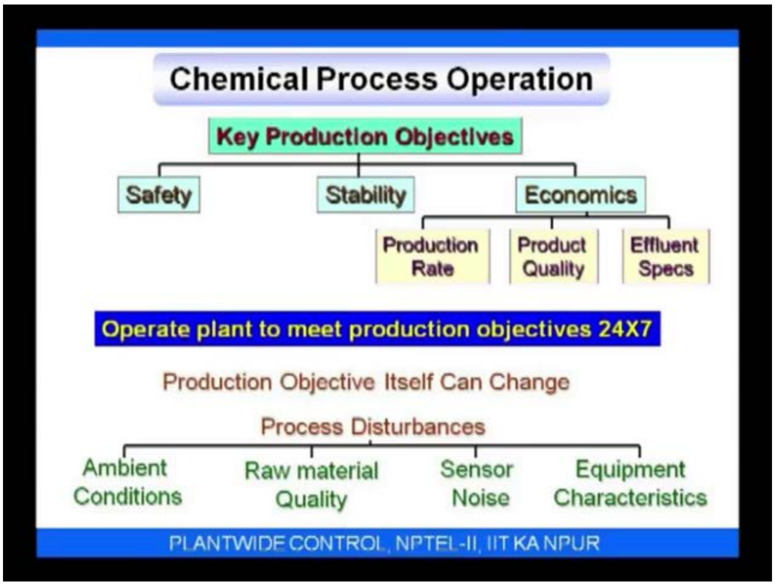

Chemical process operation, you would have seen, all those who are chemical engineers. Any process has some key production objectives, you want to produce chemicals in bulk and run the process such that the process operation is safe, also the process is operated in a stable manner and last, but not least the way you run the process should be such that you make profit, so economics you want. So the key production objectives in chemical process operation are safety, stability and good economics.

These economic objectives are typically stated in terms of the production rate. How much of crude oil for example, you want to process per day - that depends on market demand. What is the quality of the products that that the market requires? And these days because of environmental considerations your process should also be operated in a way such that, everything that is being released into the environment meets regulations in terms of effluent specifications, so that you do not pollute. Now, we continuous process is as its typical of chemical process is are typically operated to meet in a continuous manner, to meet this production objectives twenty four seven. That means 24 hours a day, 7 days a week nonstop. So, we would like to meet our key production objectives in terms of safety, stability and economics through and through all the time.

Now, as you may appreciate because of changing economic conditions the production objective itself can change. For example, in winter season a refinery may be required to produce more of heating oil, where as in summer months it may be required to produce more of gasoline. The production objective itself can change, secondly there are ever present process disturbances. Just to give you the different types of disturbances that are there in a process, the ambient conditions change. For example, the diurnal cycle, days are hot afternoons are hot nights are cool. Seasonal variations for example, rainy season your cooling towers would not be as efficient as in the summer season as in the dry seasons. The raw material quality itself can change for example, a refinery supposed to process crudes from crudes from different different sources, so you will have light crude, you will have sour crude, you know and so on and so forth.

The same process is supposed to process raw materials of, you know very large span in quality. Then you got sensors that are telling you for example, temperatures pressures and flows that are telling you the health of the process. These sensors itself are noisy, they can drift and finally, you have you know your process itself slowly changes. For example, when a process is started up with new catalyst, the catalyst is new slowly over time it centers or it loses its activity. So, the catalyst loses its activity over 6 months or a year of operation. Similarly, you may have a new heat exchanger that is been cleaned up, but due to sustained process operation, continuous process operation it slowly gets hauled up and so on so forth.

So, the equipment characteristics themselves change over time. So, we would like to operate a continuous process plant to meet key production objectives. We would like operate our process to meet the key production objectives, even as the production objective itself can change and in the presence of ever present disturbances.

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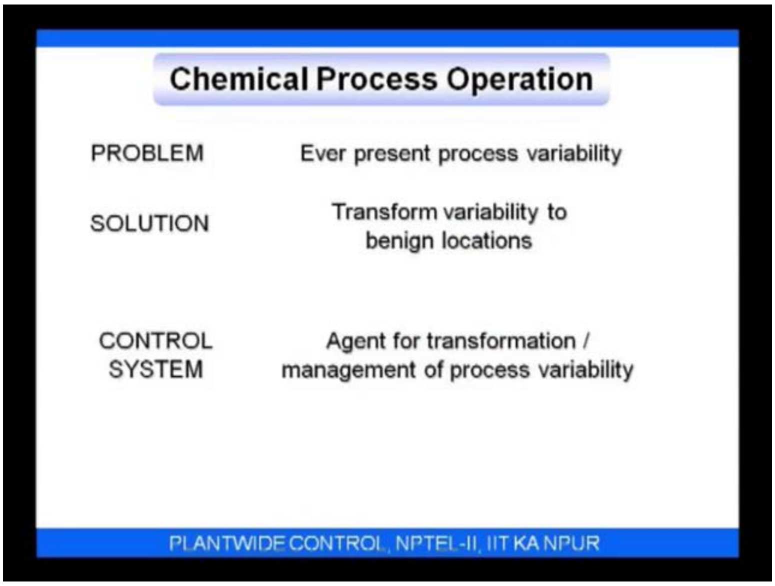

Now, the key problem in process operation is there is ever present variability due to disturbances, production rate changes and so on so forth. What we would like to do is, we would like to transform this variability to benign locations in the plant. Now, one way of looking at a control system is as this agent of transformation of transformation or management process variability.

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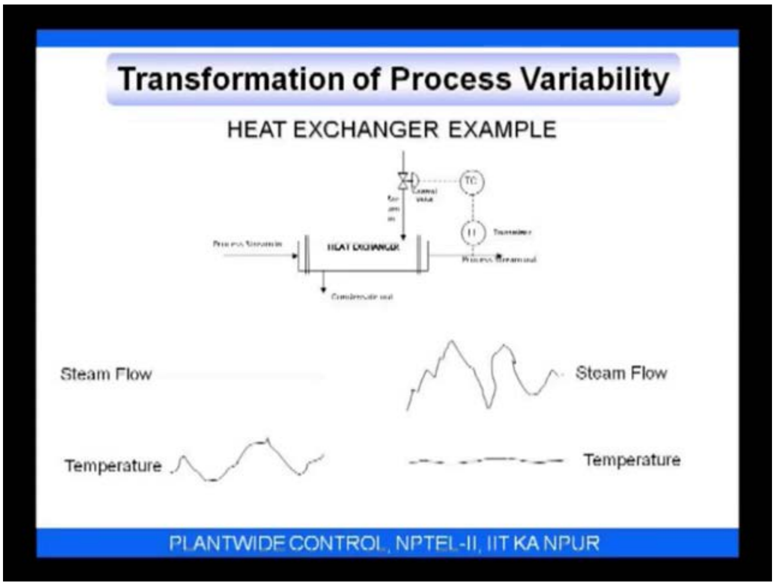

Just to illustrate the point I am going to take a very simple example. Here is a heat exchanger, you got a process stream that is coming in and a process stream it is, this process stream gets heated to a certain temperature and the heating medium is steam. Now, if the steam flow is kept constant then because the flow rate of the process stream in and or the temperature of the process stream in itself changes what you will have is that the temperature of the process stream out would show variability, and this variability is shown here, alright.

So, what you have is the steam flow is constant as shown here, the steam flow is constant. Whereas, the process stream temperature is showing variability. Now, let us say this process stream is being sent to a reactor. This variability in the temperature is not acceptable since this process stream is going to go into a reactor. So, what we do is we put in a temperature controller and here is the temperature controller. What this temperature controller is doing is, measuring the temperature and if is not at the set point it is adjusting the steam flow rate.

So, thus if the is more than the set point the steam flow would be reduced, if the temperature is less than the set point the steam flow would be increased. Now, if this temperature loop is tuned properly, what you would have in this situation where there is feedback control is; the steam would go all over the place, as you can see here, where as the variability in the temperature is much less.

So, what the control loop has done is transformed the variability from the process stream to the steam flow. The variability in the temperature in the process stream was not acceptable, was not desirable the control system has transformed it to a location in the plant, where it is acceptable to a benign location. So, this is a very simple way of looking at chemical processes or control systems in the sense that they are merely managing the ever present process variability, by transforming it from undesirable locations to locations where it is acceptable to have that variability.

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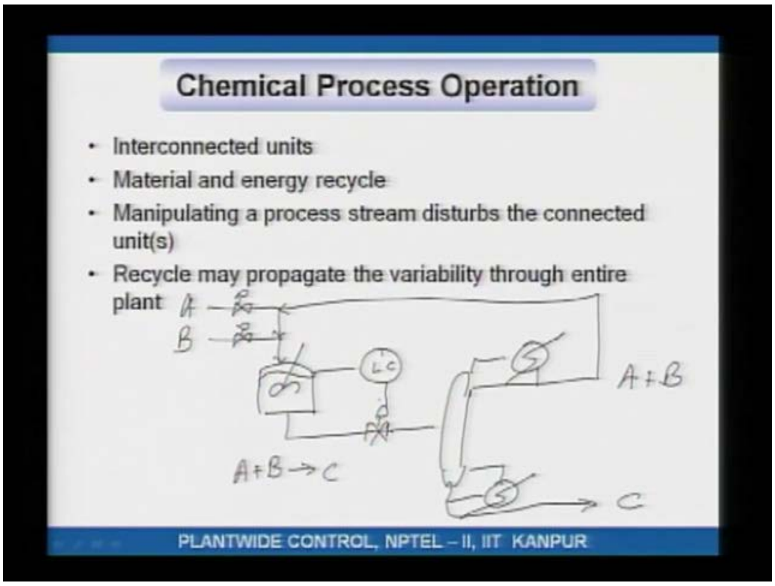

Now, a chemical process is a series of interconnected units. For example, any process will have a reaction section and then the reactor affluent, which is a mixture of products. Un reacted reactants would be taken to a separation section where the reactants will be separated from the products and since the reactants are expensive, you will have these reactants being recycled back to the reaction section. So, you have material as well as energy recycle, this is very typical of chemical processes and because of these interconnections manipulating a process stream disturbs the connected units. We also have material or energy recycle and therefore, this recycle may propagate the variability through the entire plant. Just to illustrate this point maybe I should take a small example.

So, suppose you got a reactor which feeds a distillation column, please forgive my drawing that is why I resort to these power point presentations because my drawing and handwriting are not that good. In fact they are pathetic, but in the computer age I guess it does not matter. So, here is a process and you are putting in fresh A and fresh B and in the reactor what happens is A plus B, A reacts with B to give you C, all right.

The reaction does not go to completion in the reactor, so the affluent from the reactor is a mixture of A B and C. This mixture is sent to a distillation column, C being heavy comes down the bottoms of this distillation column and the un reacted A and B come up the top, A plus B. Since, these are reactants and reactants are expensive it does not make sense to throw it. So, what we do is we recycle it back; we recycle it back to the reactor.

Now the point that I am trying to make is the following; I would like for example, to control the reactor level tightly because residence time in the reactor is going to affect the conversion. So, to hold the conversion constant I would like to hold the level inside the CSTR constant. Let us say I am doing that using a level controller and this level controller is indicated here.

Now, as I adjust the variability in the level is now getting transformed to the flow to the distillation column. Now, in order to hold the level constant, I am disturbing the column. So, whatever I do in a loop, whatever I do in a control loop to hold something constant, to hold that constant the variability gets transformed elsewhere. And because of these interconnections for example, holding the level constant in the reactor disturbs the distillation column.

Now, the distillation column is feeding back to the reactor the un reacted reactants, that in turn will. So, holding the level constant disturbs the column, whatever you do to hold the column where it is suppose to be held is going to disturbed back your reactor. So, the whole point is that this recycle may propagate the variability through the entire plant. You may think that you are only doing whatever you are doing to hold the reactor constant, but just to to hold the reactor level constant, but just holding the reactor level constant may cause variability to go through the entire plant, may cause the whole plant to oscillate.

So, that is the point that I was trying to make, that recycle material and or energy can propagate process variability through the entire process.

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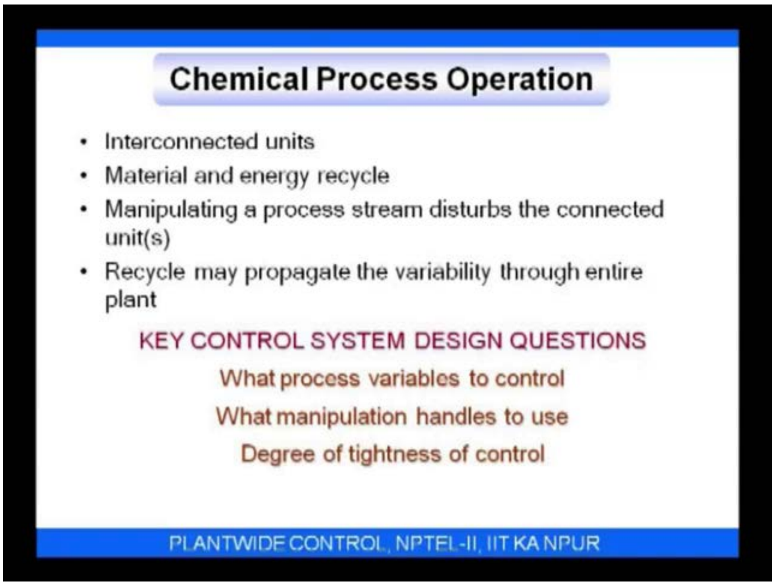

So, the key control system design questions are; what process variables should we control? You see tight control is not always good because if you control something tightly that means you are disturbing something else, probably more than you should. What manipulation handles to use? Going back to the same reactor example, I was using the reactor affluent flow to control the reactor level, I could have use the in the inlet flow to the reactor also to control the level. So, what manipulation handles to use and what should be the degree of tightness of control?

These are key control system designed questions which hopefully once you gone through the course, you should be able to do regardless of how complex the plant looks at first sight. In order to address this key control system designed questions, the one thing that one has to keep in mind always is plant wide propagation of variability. It may appeal it is not always good to control everything very tightly and hopefully we will we will learn how and why etcetera, etcetera.

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The objective of this course is to give you an engineering common sense approach for designing effective plant wide control structures for chemical processes, which will have material and energy recycle and which causes certain complexities, which will be realize. So, this is the course objective and I think in my personal opinion this is actually very useful for anyone who is either working in the industry, right now or who would like to work in the core chemical industry as a career option.

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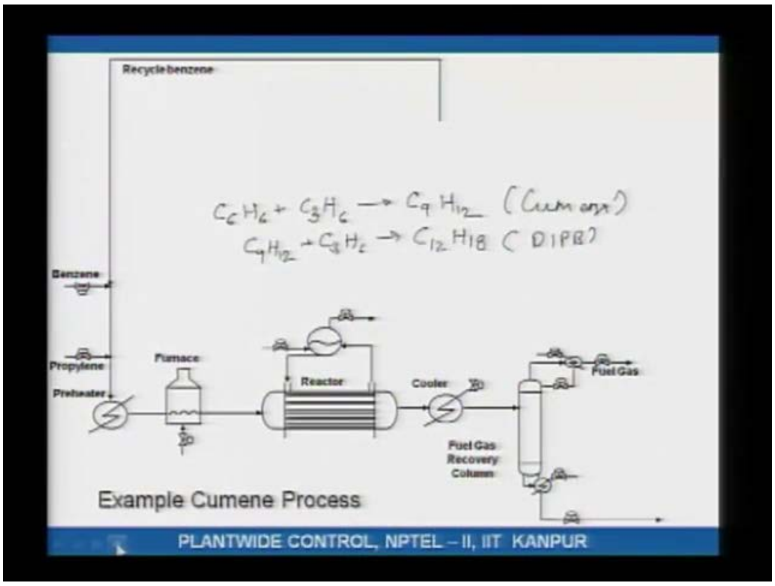

Just to give you an example of chemical processes is, here is an example process for cumene manufacturing, it is slightly simplified. So, what you have is what you have is propylene and benzene being pre heated, vaporized and then heated to the reaction temperature, which would be say around 350 degree Celsius in a furnace. The benzene is also being mixed with un reacted benzene which comes, which is being recycled.

The heated reaction mixture is sent to a reactor. Now, this the when benzene reacts with propylene it is called an alkaline, it is essentially Friedel Crafts alkylation. The reaction is highly exothermic and the adiabatic temperature rise can be of the order of 200 degree Celsius. Now, if the inlet temperature is 350 and the catalyst temperature if you if you operate the reactor adiabatically, what will happen is; your catalyst your temperature towards the end of the reactor or towards the middle of the reactor may actually shoot up to 500, 600 degree Celsius.

Therefore, what we have is the reactor is a shell in tube heat exchanger, with catalyst loaded tubes and you got pressurized water circulating on the shell side. The flow rate of this water is very high, so the temperature rise on the shell side of the water would be very small. So, the so the tube essentially see here constant shell side temperature. Now, the circulating water recovers heat from the reactor, from the hot tubes and this the hot the hot water comes to this flash drum, where because the pressure is low it it flashes to give you steam.

So, you got steam coming out here and because you are losing steam, there is some make up water in order to keep this broiler you know in order, to ensure that the broiler always, there is always water supply to the reactor. The reactor affluent is cooled in a cooler and then sent to a, to essentially a light out first distillation train. Light out first means, in the first column you will take out the lightest component then what ever is left in the second column you will take out the next lightest component and so on and so forth.

So, the in the first column you recover any un reacted propylene, which is light along with inherit propane that may be entering with the propylene. In the bottoms what you get are un-reacted benzene, some of the product cumene and actually the cumene can also further alkalite with the with the propylene to give diisopropyl benzene. So, let me just clarify that, so what you have is benzene C6 H6 this reacts with propylene.

Propylene would be what, C_2H_4, no C_3H_6 and this gives you cumene and cumene would be C_9H_{12}. This is the main reaction. What happens is this cumene that has been formed can further alkalite with the propylene to give what is called diisopropyl benzene. Di isopropyl benzene would be $C_{12}H_{18}$, I think I think I am here.

So, this is cumene which is your main product and this is diisopropyl benzene, which is your side product. Now, you would like it is the cumene that is going to fetch you the profits. So, you would like to operate your plant, your reactors such that most of the benzene goes to cumene and very little di isopropyl benzene gets formed because diisopropyl benzene is something that you cannot sell in the market. From your kinetics etcetera you would know that what that essentially requires is, that you run the reactor in an excess benzene environment.

So, if you got excess benzene propylene would be limiting and therefore, there will be deficiency, overall deficiency of propylene in the in the reactor, which would suppress the side reaction. So, the chemistry of the reaction dictates how you should be operating the reactor. So, this is the reaction scheme, coming back.

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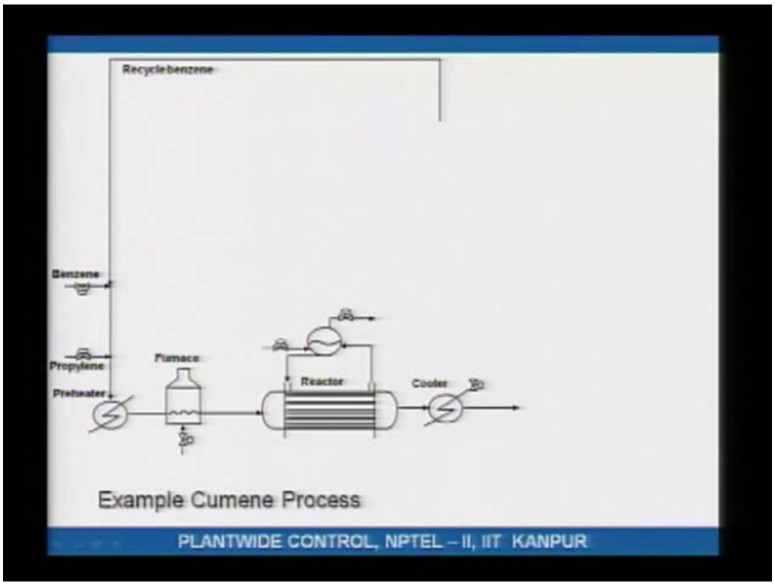

So, this is the reactor, the reactor affluent is cooled, the un condensable do not condense, the benzene, the diisopropyl benzene and the cumene they actually liquefy.

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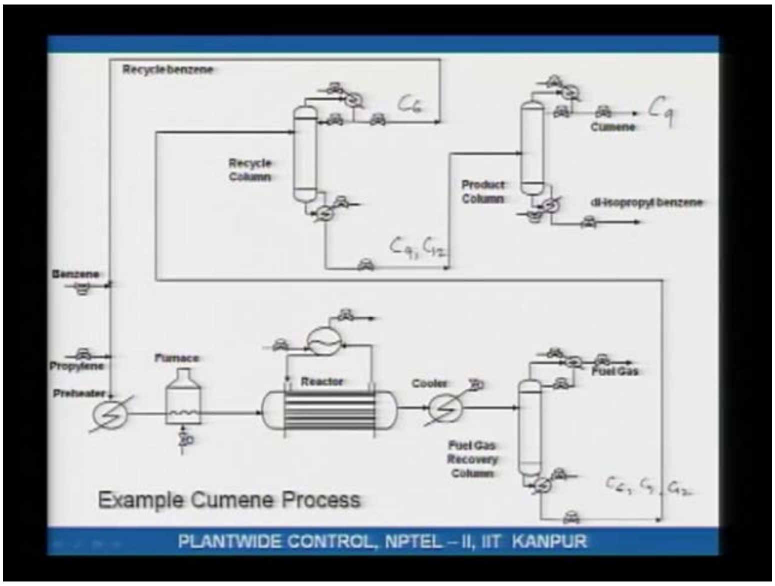

This is sent to a light out first distillation train, in the first column you take out the un reacted any any amount of un reacted propylene out the top along with inert propane. You see propane and propylene are close boiling so you will never get pure propylene, you will get propylene with some amount of n propane, inert propane. So, that inert propane and un reacted propylene goes up, the top the bottoms would be I think it would be C6 benzene, cumene C9 and C12. This bottoms is then sent to the next column and this is called the recycle column. Here what you do is you take out C6 of the top, which is the lightest component and down the bottoms what you take out is C9 and C12.

The bottoms are the the distillates, which is the un reacted benzene is recycled back. The bottoms is sent to a second to the third column which recovers C9 of the top and the diisopropyl benzene down the bottoms. So, this is a simplified process for cumene manufacture. In real processes what you have is you will also take this diisopropyl benzene and and send it to a what is called a transalkylator and there you further the diisopropyl benzene is converted back to cumene, but that is beside the point. The point that I am trying to make is this process looks complicated to begin with.

How do you design a control system for this process? What are the typical disturbances that this process is supposed to handle? One of the most common disturbances is throughput change. What is a throughput change? A throughput change is, imagine a car, you are driving a car you would like to adjust your speed depending on traffic conditions and depending on how fast you want to get to the destination. So, you would like to, so that is done by using the accelerator. Similarly, in a in a process, in a chemical process the market condition dictates how much of how much production, how much cumene should be produced.

So, a production rate changed depending on market conditions is one of the most, is probably the most prevalent a throughput change is what it is called, is probably the most common load change disturbance that a control system should handle. For this process for example, the propylene which is coming from upstream, it has got some impurity, it has got some n propone in it, inert propane.

The composition of this stream may change because of upstream upsets. Other disturbances, you got steam coming to the re boiler. This team is being supplied by a boiler house or a you know a steam plant. The boiler in that steam plant can go through pressure surges or under surges. So, the pressure there may fluctuate and so on so forth. So, there are all these disturbances and in spite of these distances you would like to process whatever is the market demand and you would like to produce cumene of the desired purity all the time. So, how do you design a control system? What are the issues in designing a control system, so that so that despite the disturbances you can you can meet the production objective all the time, always.

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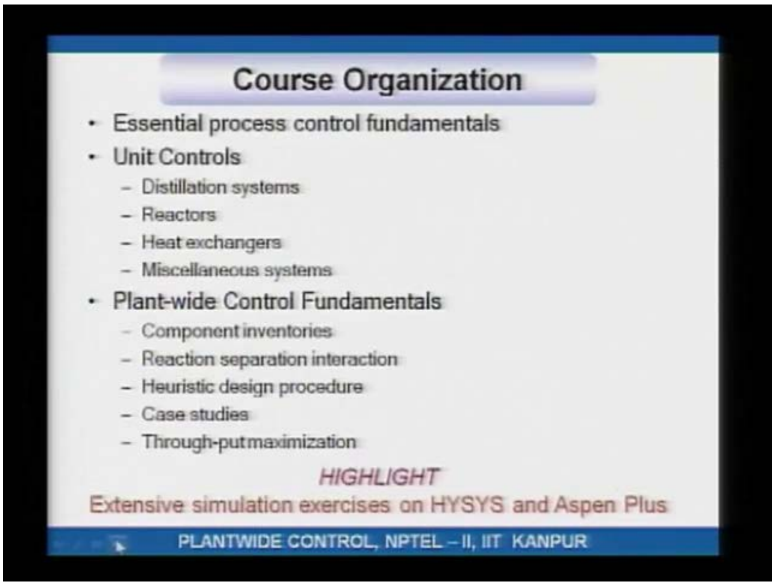

In order to be able to design an effective control system, you would need some controls fundamentals. You know, not too complicated, but you know PI controllers, how do you tune them, what type of a controller should you have and so on so forth. So, very basic essential process control fundamentals, then what we will do is we will go on to looking at controls of common unit operations in chemical processes. These common unit operations for example, are distillation distillation columns and distillation is the most widely used separation. It is the separation process of choice and separation is very common is is required in a chemical process because you may want to purify the raw material and of course, you want to purify your product. Reactors which are the heart of any plant where you produce the value added chemical. Heat exchangers, and heat exchangers can be a utility to process stream or process stream to process stream type heat exchangers and then miscellaneous systems. For example, refrigeration systems, steam plants and so on so forth.

After going over the unit controls then we will go to do plant wide, to cover plant wide control fundamentals. What are the issues in designing a plant wide control system? These issues I have just highlighted a little bit, but I do not think if I expand on it you will understand much. But never the less component inventories, reaction separation interaction, a commonsensical design procedure.

You see not lot of mathematics, just pure engineering common sense to design an effective control system. Then we will go through case studies and an example case study would be the cumene process that I just showed you a slide earlier. Then we will also cover throughput maximization, what do you mean by throughput maximization? See for continuous processes, typically the margins are very low. So, the profit is driven by volumes. What what is it mean volumes? Well to give you a very common, cocaine cocaine is a very you know the premium on that is very high. You can sell may be a cocaine for may be 1 crores or 2 crores. On the other hand, in a refinery your crude is costing you 55 dollars a barrel or 70 dollars a barrel, your refined product per barrel may be you know just 5 dollars more.

So, the margins are very small. So, when the margins are very small the way to maximize your profit is to maximize your throughput. The more you produce, the more profit you make. So, in many continuous processes throughput maximization is equivalent to maximizing profit. Now, since now a control system a plant wide control system can significantly affect the maximum achievable throughput in a process. So, the next issue is how do you design a plantwide control system, such that it maximizes your throughput. So, we will also cover throughput maximization which is actually a very, of much practical interest in operating plants.

The highlight of this course is we will have extensive simulation exercises on HYSYS and Aspen plus. Now, HYSYS has been bought by Aspen, so it is essentially Aspen tech. These exercises will be available as supplementary modules, which which I will develop over time. That is all that I have probably for today. So, welcome to the course and I hope it will be an enjoyable experience for all of you.

Thank you.