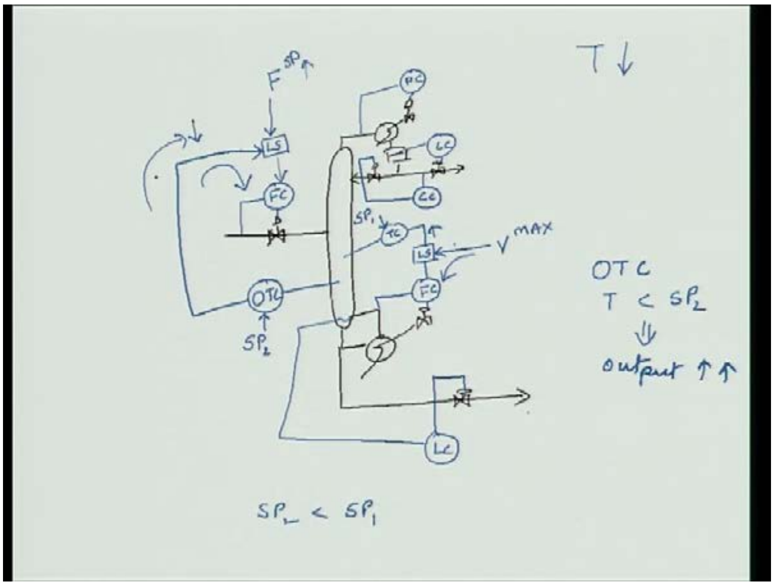
Plantwide Control of Chemical Processes
Prof. Nitin Kaistha
Department of Chemical Engineering
Indian Institute of Technology, Kanpur

Lecture - 40
Contrasting Conventional and Top-Down Approach

I thought I will deliver the last lecture, but I, it is been a long time, and in that long time, many people have asked me, what is the difference between the way you pair loops for a plant wide control system, and the way it is conventionally done. And so I think it will be appropriate to highlight the differences, so that it is clear to the audience, as to how it is done and how we are doing and then people can make a choice as to what is appropriate where. Before I do that, I must highlight that conventionally constraints are handled using over rides, and it is best done as an illustration.

(Refer Slide Time: 00:59)



For example, let us say I have a simple distillation column, and it is got a certain feed rate that needs to be processed, and let us just say that, I am told maximized throughput. So, conventionally what is done, is you have your throughput manipulator is here. This is set probably by an upstream process. And the conventional way of doing things, is under pressure control, this is under level control, I just say this is under temperature control. This is the conventional way of doing things and let us just say this level is controlled by adjusting the bottoms, and let us just say the product composition is being controlled by adjusting the reflux. This is the way conventionally this process, would be. This is the conventional control system, on this distillation column. Now let us say the idea is to maximize throughput, if I want to maximize throughput, this flow into the column will increase, and as it is increasing. Let us say the constraint that goes active is, the column starts getting flooded.

So, if the column is getting flooded; that means, that you are putting in too much boil up, there is too much vapor traffic, there is too much vapor traffic, and because of this vapor traffic, the liquid on the trace is not able to fall down, and therefore the liquid starts getting struck on the trace, and this is called flooding. So, when you are trying to maximize the feed processed, if that is your objective, you find that the maximum amount of feed that can be processed is limited by the flooding limit of the column. So, what would be done is, that you have a maximum limit on the boil up, and let us say there is a boil up controller here; that is adjusting the steam. This boil up cannot go beyond a V max; a maximum boil up, because beyond this boil up the column gets flooded, and then what I have is a low select, and my temperature controller my temperature controller, is setting the boil up. Now what happens is, the temperature controller is setting the boil up, but if temperature controller is asking the boil up, that is beyond the flooding limit; that means, the temperature controller output is beyond V max.

Then the lower of these two signals, between these two signals, the lower one gets selected, and now temperature control is lost. Well if temperature control is lost, then what will happen to the bottoms; what will happen to the bottoms is, too much of the light key will start to leak down the bottoms, the light key will increase. So, as so you will lose the control of light key dropping down the bottoms, because temperature is uncontrolled, because temperature is uncontrolled too much light key will leak down the bottoms; that means, your column will lose too much of light key, down the bottoms. Now, let us say that light key, let us say the bottom stream, is a waste stream, and let us say the light key is precious. Then what that means, is since too much light key is being lost, it is an economic loss.

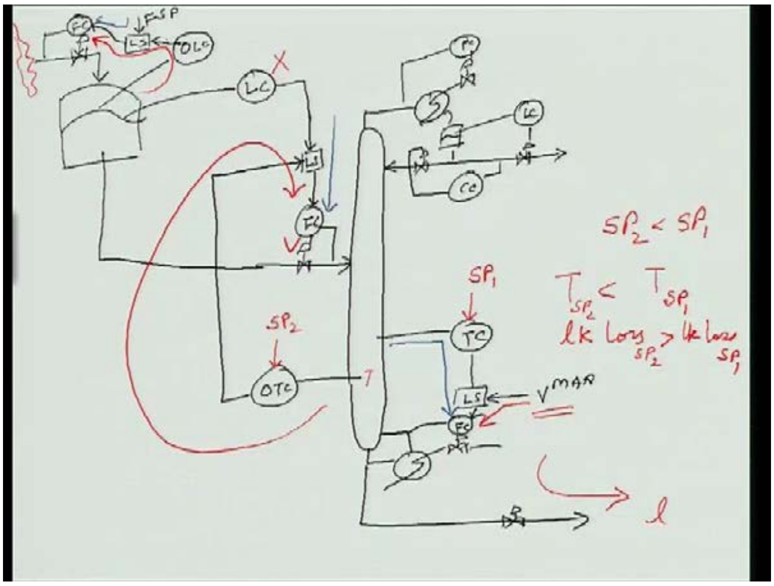
So, what that means is, I do not want to lose, temperature control on the column, what do we do then. Well conventionally what is done is, you have, let me put it. Well let us not worry about the colors, you have another temperature controller, and I am calling it OTC override temperature controller. And what this temperature controller does is, it is adjust the feed, I will put a low select here, this is the operator setting the feed well let us see. This is the operator setting the feed, or an upstream process setting the feed, and the other signal to the low select is from this. And now, the set point of this temperature controller SP 2, and let us say the set point of this controller is SP 1, what we have is, SP 2 is slightly less than SP 1. So, now imagine when the boil up is unconstraint; that means, the temperature is, you know the boil up is unconstraint, then temperature controller, the nominal temperature controller will be controlling the tray temperature, and therefore what will happen is.

Well let's see, so for the over ride temperature controller, temperature will be greater than SP 2, because temperature is greater than SP 2, the over ride temperature controller will say that look, my column is too hot, give me more feed; that means, this signal will be. No, the output of the temperature controller will be large, this implies its output would be large, because the over ride temperature controller is saying that look, the actual tray temperature is higher than my set point. So, put in more of the cold feed, so that the tray temperature comes back. Now because this output this signal, is large, this would be greater than the operate the flow set point, that is being set by an upstream process or by an operator. So, because this is greater than that, the feed is being set by the upstream process, this signal goes through, this signal goes through, and therefore the feed is being set by the upstream process, or by the operator.

Now let us say the operator or the upstream process, is increasing flow set point. What will happen the sequence of events, is a flow set point has been increased, you are putting more feed, to maintain the tray temperature, the boil up will go up, as the boil up is going up, this signal will keep increasing, ultimately this signal will become greater than V max, and therefore at low throughputs you had this signal going through, there will come a stage, when this is what will go through, and now temperature control has been lost, because temperature control has been lost you cannot increase the boil up anymore, so the tray temperature will start to go down. Now as the tray temperature is going down, ultimately the tray temperature will cross set 0.2. It will go below set point, and once it goes below set point. Now the over ride temperature controller says, well the temperature is going down; that means, I am putting in too much feed, I should be putting less feed, and this over ride temperature controller will now start to decrease.

This signal, this signal that is going, this will start to decrease. As this starts to decrease, ultimately this signal will become lower than the input set point by the operator, or by the upstream process. And then what will happen is, instead of this signal going through, what will happen is, it is this signal that will go through, through the low select. So, now my control structure has changed, if I see what is happening my control structure has changed to V max being constant. My control structure has changed, V max is constant, and temperature is getting controlled by the feed. So, this is an over ride scheme; that cuts the feed, when the boil up becomes maximum.

(Refer Slide Time: 10:27)



So, I think it is important to show this again, how do we go back (no audio from 10: 27 to 12:02). So, we were talking about the over ride temperature control scheme, there was some technical glitch. So, what I wanted to say was that when I am running at low throughputs, what I have is, at low throughputs. So, let us see pen, let us see low throughputs ink color is, let us say blue. At low throughputs flow is fixed, and temperature is controlled this way. Once the throughput goes high, then once the throughput goes high V 1 goes maximum. So, therefore, V 1 is fixed, and temperature is controlled this way, by adjusting the feed. Do you see how these low selects actually end up altering the control structure, when a constraint is hit. So, the over ride temp the disadvantage of this scheme, is the fact that SP 2 must be less than SP 1.

So, SP 2 must be less than SP 1, why does it have to be less than SP 1, so that when temperature is being controlled by the boil up, when this loop is on, when this loop is on, I do not want the over ride temperature control to be adjusting the feed. So, that will require that, the set point for the over ride temperature controller, be sufficiently away from SP 1 what; that means, is when this over ride scheme takes over, I will have greater loss of light key down the bottoms, because the temperature set point when throughput is increased. This controller takes over, and now the tray temperature set point here, the temperature operating temperature at high throughputs, is less than the operating temperature at low throughputs.

So, when TSP 2, when this is active TSP 2 is less is less than TSP 1, and what that means is, that once the over ride temperature controller gets activated, my column tray temperature would be lower. The fact that my column tray temperature is lower, implies that I will be having more leakage of my light key down the bottoms. The light key what this means is, light key leaking down, light key loss will be greater than, light key loss at SP 2 would be greater than the light key loss at SP 1. So, what this is saying is, that in my control scheme, in this over ride control scheme, at higher throughputs I will have more loss of my precious light key down the bottoms. Now let me take this a little further, let us say this flow set point out here, the feed to the column. Let us say this is being set, let us say there was an upstream tank here, maybe it was a reactor, I do not know.

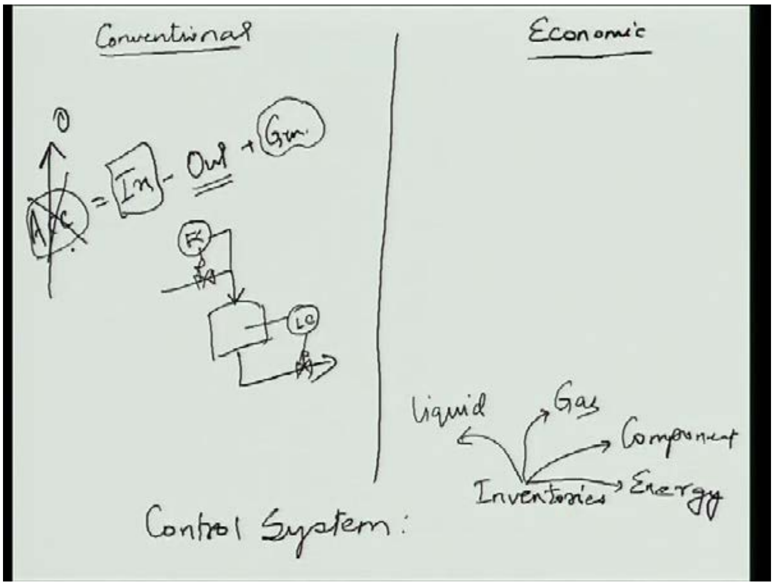
And what was being done, was that this flow set point, see this flow set point, the outlet of this tank, was flowing into the column, and ordinarily what I have is, I have my level controller adjusting a outlet. Since the level of this tank has to be controlled, what I will have is, ordinarily. Well again there will be a low select here, and I will tell you how that is done, let me draw it, and then I can explain it to you later on. I have an over ride level controller, there is a flow controller on the feed to the column, and I am setting the feed set point, feed set point and I am comparing it with the over ride level controller set point, the lower of the two signal sets the feed to the reactor or the or the tank, now let us see how this works. Now my ordinarily what will happen is, operator will, operator ordinarily, this is how things would go, the operator is setting the feed to the tank, or the feed to the process, is set by the operator.

Now let us say the instruction comes, jack up throughput. He keeps on jacking up the flow set point, and what happens is as the flow is being increased, the boil up becomes max. Once the boil up becomes max, temperature, the over ride temperature controller takes over manipulation of the feed to the column. Now that it has taken over manipulation of feed to the column, I do not have level control on the tank. See what is happening, once again, let us see red color. So, once this gets activated, my level control is lost. I lose level control, because the level signal is, the output of the level signal is not going through. So, since level control is lost, what will happen is, the level of the tank will keep rising.

And as the level of the tank is rising, the over ride level controller; please show the picture, the over ride level controller will basically say, this guy will say decrease the feed, and ultimately what will happen is this signal will go below the set point being set by the operator, and therefore what will happen is, you will have this guy going through. So, do you see how it works once V one max goes active, once this goes active temperature control is lost, temperature starts to go down, and in order to maintain the temperature, the over ride temperature controller takes over, manipulation of the feed to the column. Once the manipulation of the feed to the column has been taken over, level control of the tank is lost. Therefore, the level starts to rise, and then the over ride level controller says, cut the feed, and ultimately its signal goes below the set feed rate, and therefore the manipulation of the feed to the process, or the feed to the tank, passes from the operator to the level controller, to the over ride level controller.

If there was another stream, another unit upstream, we would have a similar scheme. If there was something else, there were some units upstream; you know the material balance structure will have to be altered all the way up to the process feed. So, this is how, what should I say, this is how constraints are handled in practice, you are actually handling only one constraint. If the through if the if the if v if V max goes active, material balance is altered all the way up to the feed, this is how things are done in practice. So now, I want since many people have been asking me, how is the pairing approach that we are recommending different from what is done conventionally, I though it is good to contrast it, and then take a few examples to show, what is, how things get done conventionally, and how we are doing them. So, let us take the conventional approach.

(Refer Slide Time: 20:18)



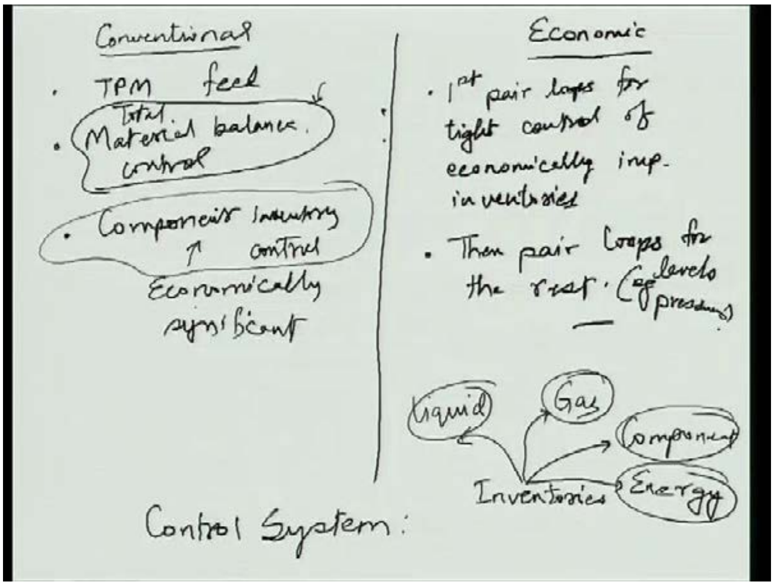
Let us take the conventional approach; in the comp conventional approach, you see, you have convent what I would call our approach is economic, where we have discussed this many time, but many a times, but basically what we are trying to do is, in any process, you put a control system. Why do you put a control system, you put a control system, so that all things that can drift, do not drift, what are the things that can drift. It is basically inventories, and when I say inventories, I mean tank levels can drift, if you are putting in too much gas, and taking out less gas, then the pressure in that system will build up. So, gas tank levels, gas pressures can build. Similarly we have also seen that if what you are putting in to the process, is not being consumed by reaction, and has no place else to go, it will build up in the recycle. So, component inventories in the recycle systems, in recycle loops build.

So, when I say inventories, I mean liquid inventory, I also mean gas inventory, I also mean component inventories, and we could in the most general sense, we could also include energy inventories, you see what does the cooler, what does the reaction heat removal mechanism on a reactor, do it basically removes the energy released by reaction. Now it is the job of the control system, to ensure, you see you must have seen this equation so many times; accumulation of whatever of material, of component, of energy is equal to in minus out plus generation. When we are designing a control system, let us say what we are doing is, setting the throughput. You are setting how much, what is being fed into the process. Now depending on how your reactor is operating; that also sets the generation. Now our job in a control system, is to make sure that the out term, is such that, it matches in plus generation.

If the out term does not match in plus generation, you can rest assured that there is some kind of an accumulation; that is going on, and this in that very simple tank example was, if I do not make sure that the inlet feed. Let us say I am flow controlling the inlet feed, and let us say I am controlling the. So, if the outlet does not exactly match what is being fed in; hence there is no generation term. This level controller is basically ensuring that, whatever is being fed in, the level controller ensures that exactly that same amount is being, fed is being taken out, so that accumulation gets driven to zero, so that your process settles to a set steady state. Now this basic logic, or this basic rational is applicable to all quantities, and in material energy balances, you would have seen that you try you write an equation for material balance, and equation for energy balance, you also write equations for component balance.

When you are writing that equation implicit, and if you are saying that, the left hand side is zero, and you are looking for the steady state solution, implicit in that is, either in is matching out, or out is matching in, and that is what the job of the control system, is to make sure whatever you are putting in, either gets taken out, or gets consumed by reaction, and does not build up in the process. So, this is the whole thing that a control system does. So, one way of looking at a control system is, it is basically ensuring or balancing process inventories. What are the process inventories, in the most general sense, you have liquid, you have gas or vapor, you have got components, and you have got energy. My control system is basically making sure, that the that all these inventories held within the process, do not drift, and it sure turns out that, some of these inventories are economically more important, while the others are not as important.

(Refer Slide Time: 25:06)



For example, If I take a reflux drum on a distillation column, its level makes; no does not affect the steady state of the column at all. Let's say I am doing it this way. So, in on this reflux drum, what is the set point for this chap, really does not affect the steady state at all, because it does not affect the steady state at all, it has no steady economic impact. So, there are things, so this has no economic impact, this has steady impact, no steady state effect, no steady state effect, and because it does not affect the steady state at all, it has no economic relevance to at least for steady process operation, so that is that. On the other hand, if I take that same distillation column that I had looked at, well did I. We were saying that what is going out here, what is leaking out here, is the light key.

And let us say this stream, is actually a purged stream, or a waste stream, and let us say the light key component is my product. Now, if the light key composition going out in this waste stream, increases. What that means is, I am losing out precious product, I am losing out precious product, which I am not able to sell. So, the inventory or the leakage of the light key down the bottoms of this column, has a significant economic impact, because for every mole of product lost down the bottoms, I would have consumed that much extra raw material to produce that product, but now I am not able to, because the leakage is more, I am consuming extra raw material, and I am getting no economic benefit. So, this is the inventory, so the inventory of the light key, leaking down the bottoms, is actually economically significant.

On the other hand what is the level here, what I did not draw this, but what is the level here, what is the level here does not really make any significant any steady state effect, and it is economically insignificant. So, you see between the inventories, there are inventories that are economically important, because they have a large steady state effect, because you know basically, and it is got to do with material loss. You would like ideally that, all the raw material that you are taking in, because raw materials are expensive, all of it gets converted to products, and none of it goes down goes out in waste streams, because the waste streams actually, do not fetch you any money. So, what I am saying is, if you think of it this way, then there are inventories that have no steady state effect, and economic significance, and there are other inventories, that affect my process economics big time.

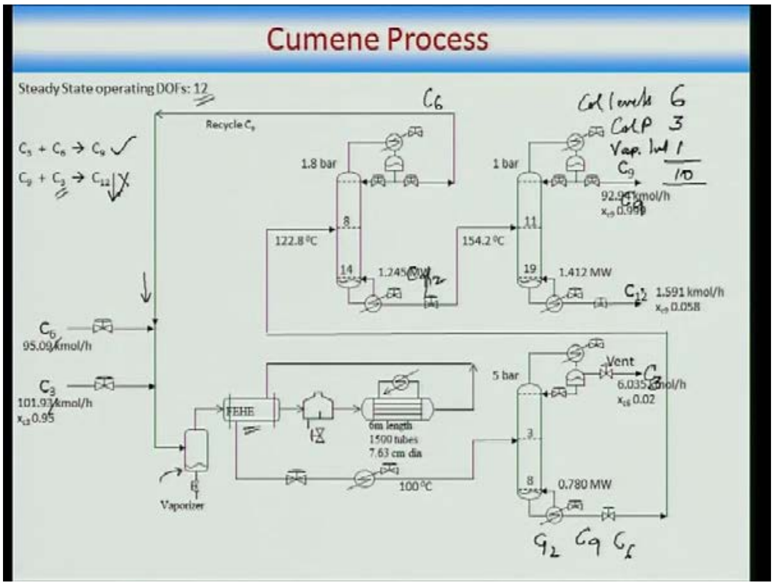
And what I want to really want to do is basically. When I am designing a control system, I basically want to make sure, that the liquid inventory, the gas inventory, and component inventory, and the energy inventories do not build up, but it turns out that liquid level in search drums, not in reactors, because the level in a reactor does affect the steady state. Levels in search drums, pressures in search in search vessels, actually do not make a significant impact on your economics. So, therefore, our approach is basically saying, that look you have to control all the inventories. If you have to control all the inventories, what we are basically saying is, control those inventories that have a significant economic impact tightly. So, first pair, first pair loops for tight control of economically important inventories.

Then pair loops for the rest, that is the basic order that, then pair loops for the rest, how are things done in conventional practice. In conventional practice what is done, if you look at, for the rest and these less rest include levels; for example, levels, and pressures etcetera. How are things done in conventional, in the conventional pairing approach. Well usually what is done is, the throughput manipulator is chosen at the feed, at the feed to the process, material balance control is then implemented, basically levels and pressures, loops for material balance control, and then finally, loops are put for material balance control, total material balance control, then you start putting in loop for component inventory control. And as it turns out it is the component inventories, in leak streams, or in purged streams that are economically significant. It is the inventory of the recycle rate that affects your energy consumption.

It turns out that actually these are economically more significant; many of these component inventories are economically significant. And so in the conventional approach, because you are pairing loops for material for control of levels and pressures first, what happens is, the valves that remain for component inventory control, may actually not give you the tightest control, because material balance control has already taken up loops, and it is this basic difference between the two approaches. In the conventional approach, you are pairing loops to avoid drifts in variables, which are the total material, you know the total level; for example, the gas pressure, or the column pressure, which really do not affects the steady state at all, and which are economically irrelevant, have no economic effect.

Because you are doing this first, the valves that get left for controlling the inventory, the component inventories are not dynamically the fastest, and because dynamically they are not the fastest, what you will basically end up with is, less tight control of the economically more important inventories. In our approach what we are doing is we are controlling, we are pairing loops for the tightest possible control of all inventories, that have an that are economically important, and then we take care of things that have only a regulatory significance, no steady state or economic significance; that is the basic difference in the two approaches, and instead of blabbing a lot and trying to you know, convince you this way or that way, what I think I should do is, take you through a simple example, this is actually a complicated example, may not be this, let us see, let us see a simple.

(Refer Slide Time: 33:34)



Let me take you through a very simple example, let us this is the Cumene process. If you count the number of valves, it is actually I do not know 1 2 3 4 5 6 well 7 5 5 5 15 plus 7, there is actually 22 valves, this process has got 22 valves. Well now if I look at the levels, I would like to. You know the columns have got 6 drums. The columns have got 6 levels, and these have no steady state impact. Also I would like to operate the columns at the given pressures, so three column pressures which I have given, 6 plus 3 is 9. Is there anything else, yeah I would like the you know there is a vaporizer level out here, this level out here. This also has is just a serge level it has got no steady state relevance. So, column levels 6, column pressure 3, vaporizer level 1 that takes away 10 valves, 10 things that can drift, but really their drift does not affect my steady state. Therefore, 10 valves will get used for controlling these things, which have little or no economic significance already. If 10 valves go what I am left with these 12 things, that can affect my steady state.

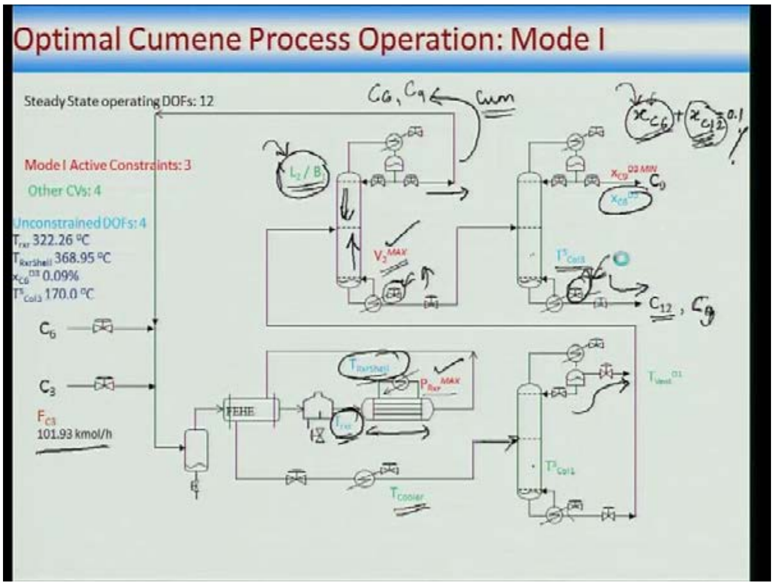
This is the steady state operating degrees of freedom, and now I say I will optimize these 12 degrees of freedom, for a given throughput. So, if it is a given a throughput, I am left with 11 out of 12, 1 is setting the throughput, now 11 degrees of freedom remain. I optimize these 11 degrees of freedom to; for example, maximize my operating profit for the process, this is what we have been doing, and now if I. So, I have got 12 operating degrees of freedom, throughput is fixed that leaves 11 degrees of freedom. Those 11 degrees of freedom or 11 decision variables are optimized, to maximize my plant operating revenue. By the way let me explain the process two, what we have is, what we have basically is, propylene alkilates benzene to give you cumene. Cumene is my desired product.

The cumene can further alkilate, get alkilated by propylene, to give you disoprophyle benzene, which is C 12, and this C 12 is not desired, you cannot fetch any money for it, this is my desired product, C 12 is undesired product. So, I would like to ensure, that my process is operated in a manner; such that C 9 is maximized, and C 12 is as small as possible, because C 12 cannot be sold, it is. Any C 12 will consume reactants, but I do not fetch any money for it. On the other hand any C 9 that I produce will fetch me a lot of money. So, basically the way the process has to be operated, the way the reactor has to be operated, you have to make sure that C 3 is limiting, propylene is limiting, so that the side reaction is as small as possible. If the if the two basic reactants are C 3 and C 6; what that means is, that the reactor has to be operated in excess benzene environment, so that C 3 is limited. If the benzene environment is excess, what that will make sure is that the C 12 formation is small.

Now the process flow sheet is very straight forward, you have C 3 coming in, C s fresh C s fresh C 3, fresh C 6 coming in, C 6 is mixed with recycle benzene, this is recycle benzene, and you send it to a vaporizer, where heat is put in to vaporize the liquid. This is pre heated in feed effluent heat exchanger, this is the feed effluent heat exchanger, what does the feed effluent heat exchanger do. It takes the hot reactor effluent, and that hot reactor effluent, is used to pre heat the cold feed, the cold feed to the reactor. Then you have a furnace that heats the feed to the desired reactor temperature, and actually the reaction temperature is quite high 320 330 degree Celsius. The reactor is a shell and tube heat exchanger, with catalyst loaded tubes, and it is cooled by circulating coolant at a very high rate, on the shell side.

So, what that means is, that the shell side temperature is essentially constant; this is what is being shown here. The reactor effluent is actually; its pressure is reduced from the reaction section to the separation section pressure. It is cooled in a condenser, to liquefy everything that can be liquefied, which is basically C 6 C 9 and C 12, this is fed to a purged column, and what does the purged column do? It takes out the C 3 at the top, and all the liquid, basically is a C 6 C 9 and C 12 go down the bottom. So, this will be C 9 C 6 and C 12, all of this goes down the bottom. And in the recycle column what you do is, you take out the C 6 at the top, C 9 and C 12 go down the bottom, the C 6 is recycled back, because it is precious. The C 9 and C 12 are set to a product column, where you take out C 9 up the top, and C 12 down the bottoms.

(Refer Slide Time: 39:15)



So, this is the basic process and. Well this is just a base case that we had now, if I am given a throughput, so the throughput is given, and I optimize the degrees of freedom that I have, what I find is, V 2 max should be active, the column should be operated at maximum boil up, P reactor max should be active, and also this should be active; that means the purity of the C 9 should be as small as possible. What does V 2 max do, if V 2 max is high, the higher the boil up. Let me just show it you, the higher the boil up, the higher the recycle rate. If the recycle rate is higher, then what that means is, the excess benzene in the reactor is higher, what that mean is, the d p d I p b rate is suppressed as much as possible, so this make sense. P reactor max, well P reactor max is maximum, because as you increase the reactor pressure, the rate of reaction of the main reaction, and the rate of reaction of the side reaction goes up by the same amount. You know the ratio of the main reaction, and the ratio, the ratio of the main rate main reaction rate is to the side reaction rate, remains the same regardless of pressure.

So, what you have is, you get an increase in conversion, but you do not have any selectivity penalty. On the other hand, if you change temperature, the rate of the side reaction, if you increase the temperature, the rate of the side reaction increases faster than the rate of the main reaction. So, when you increase temperature, you have a selectivity penalty, conversion goes up, but then more of the junk product which is C 12 gets formed. So, it makes sense that you are maximizing conversion, by maximizing reactor without any selectivity penalty, so this also makes sense. What about this chap, this is legal adulteration. If your cumene product should be 99.9 percent pure; let us say, then I can have 0.1 percent impurity. I would be a fool to sell, for example 99.95 percent pure, so what that means is, what are the impurities.

The impurities here are benzene and d I p b. So, if 0.1 percent is benzene and d I p b, benzene is much cheaper than C 9, so I sell cheap benzene for the price of cumene. Similarly d I p b does not fetch me any premium, so I sell cheap, or useless d I p b for the price of cumene. So, I would like this to be, I would like the impurity in the product to be as high as permissible, which basically means that the purity, minimum purity constraint is active. So, these three constraints, is sort of understood. Now what else is going to be economically important, let us just think about that. I want t vent to be as small as possible, why, because the lower the temperature, the lesser the benzene loss of the top, basically see benzene is volatile, C 6 is volatile, this is basically C 3, and the principle impurity in this will be with some amount of C 6. The lower the temperature of the condenser, the lower will be my benzene loss. So, basically I say that my vent temperature is basically set by cooling water.

So, let us say cooling water is available at, I do not know may be, 40 degree Celsius 35 degree Celsius, then I will say my vent temperature is about 50 degree Celsius, and not 60 70 80 degree Celsius, because at 50 degree Celsius I have sufficient driving force in my condenser, 15 degree Celsius driving force in the condenser, and that basically ensures, that I am running my condenser at as low a temperature as possible, so that my benzene loss is as small as possible. And benzene is precious, I pay money, any benzene that gets lost here does not fetch me any money, where as I pay money to for benzene. So, benzene is precious to minimize the benzene loss, this should be as small as possible, and this is set by the cooling water temperature; L 2 by B 1. L 2 by B 1 the reflux ratio on the recycle column, it should be high enough, so that you do not get too much cumene, leaking, you see P cumene is the impurity in the distillate.

The distillate is C 6, the impurity is then C 9, so cumin is the impurity, because if too much cumene leaks out, then what will happen, is that cumene, extra cumene will actually form d I p b from the reaction chemistry, because cumin propylene adds on to cumene to give you d I p b. So, if you have more cumene in the inlet of the reactor, obviously you will get more d I p b formation rate; that does not mean that the cumene should be very small, because if you tried to minimi, if you if you keep increasing the reflux to feed ratio of the column, what will happen is, the cumene leaking up its percentage, mole fraction of the cumene; that is leaking out will keep going down, but if reflux is increasing, if reflux rate is increasing, what that will mean is, that the boil up is also increasing. So, there is actually some kind of an optimum, and basically what you want to do, is that this L 2 by B 1 should be high enough, so that C 9 does not leak up the top, too much C 9 does not leak up the top. So, that is basically this chap, what this chap is doing.

What about this chap, well you need to hold the tray temperature here constant, you need to make sure that no C 3 leaks out here, because any C 3 leak that leaks out here, will essentially accumulate here in the benzene recycle loop. So, you do not really want too much C 3 leaking out, because if too much C 3 leaks out, then it is going to accumulate in the C 9 loop, and what about the T cooler, well you want the T cooler to be reasonably, you know the temperature of this guy to be reasonable, so that all the condensables are condensed, but you do not wanted to be so cold, you know you do not want too much sub cooling, because then what that means is, this feed is cold, and if this feed is cold then your boil up here will increase, because to heat up the cold feed, to boil the cold feed will require heat, and the only hope is this re boil here.

So, you want to make sure, that you have chosen your cooler temperature properly, so that you are in the two phase reason, where C 9 C 6 and C 12 condense, and then that is about it. Now what else, now let us go further, so we have got feed is fixed one, three active constraints that is 1 plus 3 4, these four things I have just explained, that makes it 8, and what that leaves are four unconstrained degrees of freedom, which are economically quite important, and I will say, I will tell you why they are economically important, and these are put here. temperature of the stripping section on the column, why is this important, because the main impurity here is C 9, and you do not want too much C 9 to be going out, because then what that means is, I am loosing product down a waste stream, not charging any money for it.

On the other hand a every molecule of C 9 that I leak here, I am consuming one molecule of C 6, and one molecule of C 3, so I do not want too much C 9 leaking down. So, therefore, holding a temperature in the product column, at an appropriate value is important, because cumene leaking down the bottoms comes with an economic penalty; that makes sense. What about the temperature of the reactor, and the reactor shell temperature. Well these two things are important, because if the reactor is too cold, basically if the reactor is too cold, what will happen is, you will not have C. So, if the reactor is too cold, then there will be un reacted propylene; the conversion will not be 100 percent, and there will be un reacted propylene, and that un reacted propylene will basically go out here.

So, I do not want the reactor to be too cold, because then I will lose precious cumene up the top, up the top of the purged column of the first column. On the other hand, if I increase the temperature too much what will happen. If the temperature is too high, then I will be producing too much of C 12. And therefore you have to choose the right inlet temperature, and the right shell temperature, so that the reactor is neither too hot, for proper selectivity, nor too cold to ensure that all of the propylene that you are putting in gets consumed. So, these two things are economically important, this is economically important, this is also economically important, to ensure the right balance between selectivity and conversion, basically you want near complete conversion, and you do not want select selectivity to be too low. So, I have explained 1 2 3, which is the forth thing. yeah Well the forth chap is this, and this effect I need to explain a little.

You see what are the impurities in the product, the impurities in the product are; C 6 plus x C 12, and I would like this sum to be 0.1 percent, because my product is to be 99.9 percent pure. So, between these two C 6 and C 12 impurities in the product, only one is independent. If I chose x C 6 as independent; that means, if I set C 6 equal to let us say 0.05 percent, then x C 12 will be 0.1 minus 0.05 0.05 percent. If I chose x C 6 to be point a 0.08 percent, then x is C 12 will be 0.02 percent. Now why is this economically important, it is economically important, because V 2 max is active for selectivity, if I try to in increase throughput what happens is, this one also goes active, and what that means is. Well let us see, how do I put it, what that means is, that how much impurity level I allow here, sets how much impurity level I allow here, that sets how much steam I consume here.

So, my steam consumption here, the total steam consumption is this plus this. You know the boil up here, plus the boil up here. If I make C 6 too small, then what that will do is, this will go too high. If I make C 6 too large what that will do is, x C 12 will be too small, and then this will blow up. So, either ways I will get a blow up in the energy consumption per kg product, since I do not want that this x C 6 has to be chosen properly, and it turns out that if you have x C 6, and x C 12 to be comparable, then you are at the right balance, where this is not blowing up or this is not blowing up. So, that is why x C 6 is important. So, I have explained the four things that needed to be explained. So, 8 degrees of freedom were taken care of, and now I explained you 1 2 3 4, four other things that need to be taken care of, that is taken care of all the 12 steady state degrees of freedom.