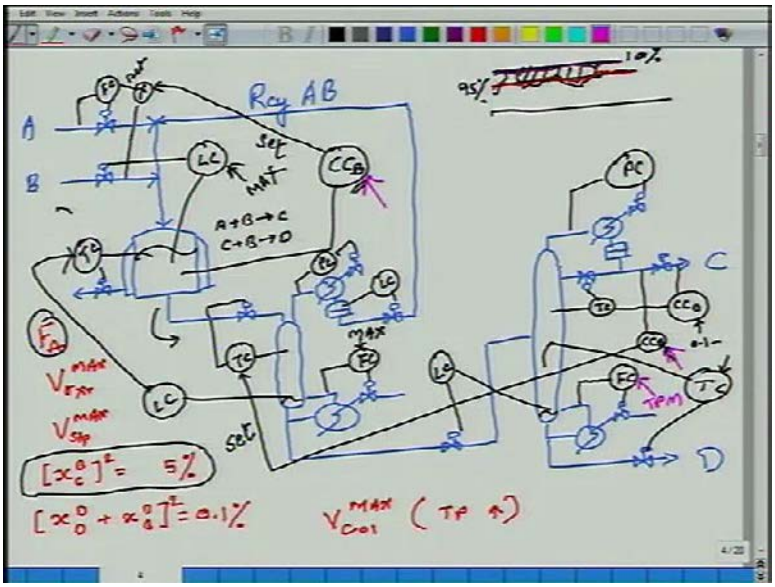
Plant Wide Control of Chemical Processes
Prof. Nitin Kaistha
Department of Chemical Engineering
Indian Institute of Technology, Kanpur

Lecture - 32
Recycle Process Case Study

(Refer Slide Time: 00:19)



Welcome to the next class alright, so we discuss that optimal operation of this process corresponds to, to what active constraint it, corresponds to v reactor at max, at low throughputs it corresponds to v reactor at max, v stripper at max, x composition of the C leaking down the bottoms of column 2 is equal to, I do not know something; something reasonable may be 0.5 percent, what we did was said was 5 percent is reasonable, let us just say some reasonable value. So, 1, 2, 3 and of course we also had what did we have x D in the distillate plus x B in the distillate of column 2 should be exactly equal to 0.1, feed rate of a… So, 5 things are taken care of, I am left with two unconstraint degrees of freedom and what we said was those two unconstraint degrees of freedom are reactor temperature and b composition in the reactor right.

Now, I know v reactor should be at max, now you see now let us say v reactor is not max, max value is 80 percent, I am operating at 75 percent; my objective function would take a hit because I am not operating at maximum. Similarly, v stripper should be at maximum, my objective function again takes a hit, if I am not at maximum yeah, do you think the hit will be same, if I back of 5 percent from v reactor maxi and if I back off 5

percent from v striper max; do you think the loss in objective function, the loss in profit or loss in production or loss in revenue will be the same exactly. So, you see economically speaking a back off in some of the constraints will be much, much more than the back off in other constraints yes or no, and let us say for the time being that v stripper max is economically dominant, if it is economically dominant what; that means, is if you back off by a from v striper by even 1 percent, your economic objective function takes the largest hit, your economic loss is the largest your sensitivity of the objective function to a back off in v stripper is maximum, let us just say for the sake of argument.

Now, I want to draw a control system given that these constraints are active, I have also told you that I as I start jacking up the production, because the instruction has come that maximize production; second column boil up becomes max yeah. We will transition we will do that transition later, but since I know that second column boil up is going to become max, so as I transition v column sorry, becomes max at as throughput is increased yes or no alright; we have agreed on this was done last time, this was the problem that we were trying to, now that I know that v column is going to be at max, v stripper is going to at max; v column can go to max; if I need to jack up my throughput, I will start doing things, let us say choice of throughput manipulator is mine; simplest thing to do is use the last constraint that becomes active as the throughput manipulator you see because there is the last constraint to became active we can reduce the throughput by reducing it, and if you want to go to max production, you just max it just like pressing on the gas pedal in a car drive at maximum speed, you just press the gas pedal operate at max production throughput manipulator is maxed out.

So, then the most appropriate thing to do would be from the point of view of not having to, you know from the point of view of having a single gas pedal, you want to max production that throughput manipulator is maxed out, you get max production; if it turns out that the economic hit because of a back off in that throughput manipulator or that because of the back off in that last constraint to become active is also very large, then it is a very nice choice, this is the last constraint to became active and a back off from this hits me economically the most, then I say the throughput manipulator has to be there then what I have is a single gas pedal gives me low production, intermediate production, high production, max production.

So, let us just start doing things and I will I will I will I will talk about it as to what I am doing, so I know that this guy is going to become max, I do not want a back off here, so I say well, let us flow control it ordinarily what would I do by adjusting the steam temperature or level in this case because D rate is very small, I will control the level using steam and temperature using the bottoms rate, but I know this is going to become maximum, if I am controlling level using it, using the steam or maybe even a temperature using the steam then what happens, temperature controller require some variability in the manipulated variable guaranteed you will need some back off, because of that back off guaranteed, you will be losing some revenue or your objective function would be slightly lower than what it could have been yeah, so therefore, the best thing to do is because this is going to become active, I say that do not use it for control just hold it hold it there, similarly this is something going to be active.

So, I flow control it conventionally, I will use this steam for temperature control in the stripper, so that benzene does not leak down the bottoms yes or no, if I am using it for temperature control then what happens steam is varying to hold temperature constant therefore, I need a back off from the maximum amount of boil up yeah, I take an economic hit, now because it is an active constraint, it is telling me do not use this for control; if I did not this is an active constraint, I would have conventionally just put a temperature controller there that is adjusting the steam yes or no, because I know it is an active constraint, I leave it alone, if I leave it alone it can be maxed out yes are no, no back off does that make sense or no Ganesh it does not make any sense to you then, you say no why does it not make sense, see my constraint value on boil up is this, if I am using the boil up for controlling something whether it is level or it is a column tray temperature what; that means, is boil up will have to move to control the tray temperature right; yes or no.

It cannot be constant because feed composition is changing, there are disturbances coming, the boiler pressure is changing etcetera right, that being the case feed to the column, the temperature of the feed to the column is changing etcetera right, that being the case my boil up is varying, we have discussed this before, if my boil up is varying; what is this my boil cannot exceed that black straight line, this is lost production right or this is lost whatever lost revenue, so I am operating on average at this level which is let us say 95 percent my optimizer is saying, I want to operate at 100 percent, because of

variability in the boil up, I am forced to operate only at 95 percent, where I was capable of operating at 100 percent, because 100 percent limit can never be violated, it is a hard constraint; if the boil up exceeds this value column floods, you need to take a shut down or you need to do other things overrides come into play into play right that in itself screws up my economics, If I choosing the flow control you also ensure the valve is opened to the maximum, no it is not valve is opened to the maximum, I think, I drew it improperly, what I am doing is the following just a sec, just a sec, just a sec, hang on hang on hang on, I am manipulating the steam to hold the boil up constraint, since the boil up is the constraint, I am manipulating the stream to hold the boil up constraint, does this make sense; now you notice that the manipulation handle for the boil up to maintain boil up is right there.

So, this controller will be really tight, if this controller is really tight then my boil up will be almost constant all the time, because the flow control does not let it vary at all; see temperature controller was deliberately varying it, to hold temperature constant temperature can change, because feed composition to the column has change, temperature can change, because the temperature of the feed to the column has change, temperature can change because the reflux is slightly colder or hotter, because the day is hotter or colder; it is day or night or whatever the hell right, so the point is if I do it this way, the variability in the constraint variable is much less.

Now, I am operating here, I am 5 percent away and I am not touching my 100 percent constraint right then what I can do is? You know I can I can jack up and maybe I can operate at 99 percent without violating 100 percent, so at the limit of flooding of the, of the striper or of the column yes or no right. So, my optimizer is stay saying operate at 100 percent, if I am using the constraint variable for controlling something, maybe it is a level, maybe it is a temperature, maybe it is whatever, if I am manipulating it, I need extra back off right, because it is an active constant, I say do not use this for controlling anything hold it right there right. If you hold it right there, you can go closer to your max limit yes or no, the closer you are to your max limit, the better economics or better whatever objective function you have, you are better of that much yes or no, does this make senses? Therefore, I have flow controlled this and I flow controlled that, I also no guaranteed that I want to produce product which is 99.9 percent pure yeah.

So, what do I do? What color is? This black, what do I do? I do, may be this is what I do? I control a stripping, a rectifying tray temperature, I control a rectifying tray temperature using the reflux and this tray temperature set point is coming from a product quality measurement, product impurity measurement, so if the impurity what would C C which component are you measuring B C D A what no no, no C, why C, no this I think this is, this is, what is this rectifying section doing? Yeah of course, the column separates what the hell is it separating? Well B is the lightest component whatever B leaks down is bound to get ago into C, it is preventing D from leaking up the top, so by adjusting reflux, what are you going to control amount of D.

Let us say you said no, I am going to control the mole fraction 99.9 percent what is the problem with that, is there a problem with that or are the two things were equivalent; that is my next question, you see the two are not equivalent, why are they not equivalent? Suppose for some reason extra B leaks out the first column, you are saying 99.9 percent pure, adjust reflux to maintain purity at 99.9 percent right, let us say for whatever reason 1 percent B leaked down, no matter how much you change the reflux, you cannot go beyond 99 percent, you can you infinite reflux and still bloody it will be right.

Now, with that kind of a controller, you are seeking something that is not feasible 99.9 percent with 1 percent B leaking in the first column or in the first stripper is simply not feasible right, that controller is bound to do things you know, that is a not well designed controller, not enough thought was put do you see what I am saying, yes or no using 99.9 percent, but here it is 99, you know whatever 1 percent B is leaking down no matter what you do, that control is bound to fail, what will it do? It will just keep jacking up the reflux, reflux will hit its max or may be the column will get flooded earlier, because you are dumping, so much liquid into the column, and then you will say hit this column is not doing its job, it is not this column, it is the previous column from where extra B leaked out right.

Your whole attention will be reflux has been increasing do you see what I am saying. So, what subscript goes here, is actually fundamental, the subscript here is D, shit just a sec we will we will absolutely, we will do that do not worry; now how do we do it? Well one by one, so you want to now detect B, how do you ensure B does not leak down? The stripper you know the this is the stripper, how do you ensure that B does not leak down? This stripper boil up is going to be active, I do not want to use it; because if I start

manipulating the boil up to ensure B then what will happen is? The boil up will have to be 95 percent; it can never be 100 percent, we need that 5 percent, so that temperature can be controlled right.

We just argued this out this picture right here yes or no. So, how do I control the temperature, I will control the temperature this way; if the temperature is going down what does it mean; that means, light stuff is leaking down put in less feed, if the temperature is increasing; that means, light stuff going down is decreasing, increase the feed yeah will this be tight? Well yeah as long as the tray temperature is close to the feed, not exactly the feed, but may be couple of trays or 3 trays below it, you change this, tray temperature will almost immediately change yes or no, so it is a reasonably fast loop, control will be tight yes or no.

What does that do? That allows me to operate the stripper at max boil up, I can set this set point at max, because my optimizer is saying, so why do I set it at max, so that the recycle rate is max, if the recycle rate is max, my reactor is operating at as much excess a as possible my side product is as little as possible yes or no, so I so now, you going to say well temperature does not exactly control composition which is true, and since I want product quality what I do is? I measure you see my lab will tell me, how much B impurity is going in it too? Right and then what I will do is I will say, if benzene is increasing yeah, but temperature will ensure that much does not leak, any way you are getting those composition measurements twice in a shift.

So, if we if after a shift, you are saying look benzene is increasing, what will I do for a temperature set point, I will increase the temperature set point that that is, that is something that the operator will do, but I am just showing it as a loop, if you have an online analyzer that is giving you a reading every 15 minutes, well then this loop is you know, it is API loop or a PID loop which is doing a reasonably good job right, you see you cannot prevent this, it has to be this way, you see you can it is for, you to decide what you want to measure, your measurement must be aligned with the function that the equipment is performing, the rectifying section it is equipment is to prevent D leakage of the top.

The stripper it is function is to prevent B leakage of the top, you can keep measuring C and you would not know whether the equipment is performing, it is function or not do

you see what I am saying, understanding of the function is fundamental, if you do not understand the function, you cannot do good control, you will do something that is just bound to fail, if it will not fail, now may be 6 months from long, it will fail, but it is bound to fail well ultimately you wended up seeking something that was not realizable not feasible. So, this subscripts are important, just saying composition control does not cut any eyes which composition, which component why, must be understood then well, so now, we need, so what have I done I have as a v reactor max well, level is something that that is that is a controlled variable, you see level needs to be controlled, because it does not get regulate itself right.

So, well now you have already taken away this valve, level cannot be controlled this way, it has to be controlled that way yes or no, so let us just say I am going to control the level this way and I am going to maintain A in ratio with B, so this is a multiplier, there is a ratio set point that is close to 1 on a mole basis; is it close to 1, is it more than 1, less than 1, exactly 1 why? Think about it well, A plus B goes to C, C plus B goes to D, now tell me is that ratio more than 1, exactly 1, less than 1yeah, so of course, much more than 1, 10, 1.05, 1.2; no I do not think you understood anything that is a said commentary on what I have been teaching, suppose there was no side reaction, fresh A, fresh B ratio should have been what exactly 1 right, there is very little side reaction.

Why? Exactly two moles of B are getting consumed to form 1 mole of D, only 1 mole of A is getting consumed to form 1 mole of D. So, if you are forming 95 moles of A and may be 5 moles of D, you can back calculate how much A was needed and how much B was needed? That will come from stoichiometry and then if you take the ratio, slight extra B would be needed, but only slight, why only slight? Because the amount of D is only very slight, if that is 100, this is only 5, C is 100, this is only 5, does this make sense or no; this is overall material balance, this has got nothing to do with control yes or no then how the hell am I having excess in the reactor?

Recycling, you see this recycle rate can be whatever it could be 100, it could be 200, see let us say fresh A is 100, B is let us say 100 200 3, because B has to be slightly more recycle could be whatever it could be 0; it could be 50; it could be 60; it could be 100; it could be 200; it could be, I do not know 300, but you see because A is the lighter component, see this is that is the problem, let us say let us say B is B is extra in the recycle composition or stream, let us say there is too much B very little A in the recycle

stream then what you are saying is because recycle is large, I am having actually, too much B and very little A that is what you are saying right, if that is the case what will I do? I will change the ratio set point, so that I start feeding extra A, less B, where does the extra A go? It is not taken out the, it has to go into the recycle, when I am putting in extra A and less B; that extra A is going in the recycle, ultimately composition will come to mostly A little B yes or no, yes or no does this make sense or no? I am putting in exactly 1 mole of A exactly, 1 mole of B; in the reaction excess extra B is getting consumed because some D gets formed, what will then happen?

Recycle rate will continue to go down and we will check to what you are saying, to do to ensure that does not happen, I will put slightly whatever my logic may have been flat, but the, but the basic point is you have to think of inventories A and B are not being taken out in C and D. Exactly; so what we are doing is reactor composition of B, why B because B is supposed to be the limiting reactant, you have too much A you, so you want to detect what is the impurity not impurity? What is the limiting reactant? That is always usually the case, this is setting the ratio set point yeah, you can set this ratio point at too much B and then the ratio will get adjusted, so that there is too much B in the recycle, you can set this composition set point as at very little B, let us say only 5 percent B inside the reactor and then the ratio will get appropriately adjusted whether you putting in extra A or extra B that will get automatically adjusted, yes or no this is inventory.

This is ensuring that all component inventories are properly account for, so in this scheme because B is going to be the limiting reactant, this ratio set point is going to be slightly less than 1, well in that well, if that happens then the composition will start changing, because as building up in the recycle loop and when that composition starts changing, the composition controller will adjust the ratio set point automatically, in the steady state, it has to be less than 1, in the steady state, it has to be less than 1 exactly. how much less than 1? That is in your hands, 5 percent, 10 percent, may be 30 percent is that is a separate question, we are not addressing that question, but in terms of understanding all component inventories are properly accounted for this is fundamental we did this last time, we are doing it again this is fundamental. Now, we start coming to whatever else levels, pressures, well pressure control is this way of course, pressure control here is this way, level control here is this way, yeah I have done C S T R level control and I am going to say this guy is going to be well almost max, but not max, why

almost max? Because level is always a controlled variable, so level cannot be held really tight, it will show some variability, so you will have to back off a little bit no matter what, because it is a controlled variable, it is not a direct manipulated variable ok.

So, level is near max yeah well, what else, what are the levels and pressures do we need to control? Second column level well available handle is here, shit then how do we control the level here? That is not a good idea well that cannot be done, you see then how do I control the level here? So, I control the level here using this, no we will touch the D flow rate because it is important to ensure too much C does not leak down the bottoms. So, there is a for example, may be a composition controller or a temperature controller that does this, yeah, this is being done to ensure this constraint is met, because if too much C starts leaking down the bottoms what am I doing I am screwing myself.

Again yes or no I do not know, if I have done everything, so now, this level remains how the hell do I control this level? You cannot not control it, by the way what is accumulating at the bottom of this column, C and D, C and D, where are C and D getting produced in the reactor right. So, if I if this level is going down; that means, I need to jack up the generation rate, the reaction rate inside the reaction by the way of course, this will be temperature control that is obvious right yes or no, sir in the second column we are using temperature control twice. So, we can no. So, no we are not using temperature control twice, where are controlling temperature of the top section using reflux, we are controlling, so that the amount of impurity going in the top, D impurity in the top is controlled, because that is my product, I also do not want too much C which is the light key going down the bottoms, what is the rectifying section doing? It is preventing the heavy key from going up the top, what is the stripping section doing? It is preventing the light key from going down the bottoms right. These are two separate tasks, so I can control two temperatures that is what I am doing, the line went away; it is a it is some stripping tray, you know do not confuse one tray it is in the above the feed some tray below the feed which tray is a separate matter that is a subject in itself, we will take care of that later, but the basic idea needs to be clear.

So, I cannot have this level floating right, I need to control it yeah, what is the option? There are two options right. So, I can manipulate the temperature set point or I can manipulate the B composition set point right, what would I do? I would say well to maintain this level, this is unconventional usually you are maintaining levels using flows

inflow, outflow and some kind of a flow, here you are adjusting a temperature to this is quite unconventional.

So, what will happen is, when I receive the instruction from top that maximize production, yeah temperature some margin temperature will have to have some margin; let us say this is my throughput manipulator, let us say this you know the, this guy is my throughput manipulator, so maybe I should show it in some other color, this is the last constraint to become active, let us say I am using this as my t p m, so the guy says jack up throughput to the max extent possible, what will I do? I will start increasing the set point as I start increasing the set point what will happen? Boil up has increased; if boil up has increased, level will start to go down; because you are boiling off more stuff, so I will start sucking in more from the stripper, level of the stripper will go down, level is going down, so the stripper is saying jack up production, level controller is saying jack up production increase, the temperature increases.

So, level in the stripper starts to go down, the level controller increases; the temperature set point inside the reactor, because the temperature set point has increased, more consumption happens, more consumption of reactants happens; therefore, more C and D are produced in the reactor; therefore, the feed to the stripper which is the reactor effluent this chap, this will be richer in the heavier components C and D; heavier components will cause temperature to raise, if the temperature is raising what do you need to do to the feed? The stripper temperature controller will say increase, the increase the reactor effluent flow rate; reactor effluent flow rate increases, level starts to go down in the reactor that starts sucking in more B, level controller of the reactor starts sucking in more B; ratio controller ensures that more a gets sucked in, yes which temperature, there are many temperature controllers precisely, we discuss this how does the controller temperature work, if the temperature is decreasing; that means, lighter components are accumulating down; that means, my boil up is not sufficient to send them up; that means, I am putting in too much material into the column so reduce the feed rate that is; how this temperature controller works right now what is happening is?

Now, we reverse the equation; more heavy material is coming in, because the composition in the reactor has changed, because of extra consumption, because the temperature has increased, so more C and D are coming into, those C and D are designed to go down as they are going down the temperature will go up, if the temperature is

going up; what will the controller do to the feed to, it will it will say increase the feed because right, so as you are pulling in more feed from the reactor, level of the reactor goes down, you start pulling in more B, the level controller starts pulling in more B; ratio controller make sure that more a gets pulled in, if there is any mismatch, the composition controller takes care of that C C B this guy, if this is there is any mismatch in the fresh A and fresh B, composition controller will adjust the ratio make minor correction to the ratio set point, may be it goes from 0.95 to 0.955 or 0.945 or whatever, so that any slight mismatch is properly account for, does this make sense or no fine.

So, I start jacking up the throughput, I keep jacking it up, I keep jacking it up; level controller keeps increasing, the temperature of the reactor then finally, what happens, this temperature reaches some max limit, I cannot jack up the temperature any further, because of whatever some reason, select when an instruction comes that jack up production as much as you can, basically selectivity is not the primary concern; it is a concern, it should not go down too much, so that you are producing more D than C as long as D is the minor component you are ok. So, now, the selectivity goes down from 97 percent to 95 percent, because you have jacked up the temperature we argued this last time, if C is earning in so much premium, because of something that happened in the market, you really do not care, how much D you are producing as long as let us say selectivity is greater than 90 percent, we did not, I thought we did, it does not matter I think that is food for thought for you, now the point is when I am, when I am increasing the throughput, set throughput manipulator set point which is the boil up in the second column, this temperature is bound to increase, temperature in the reactor is bound to increase by the action of the stripper level controller then temperature reaches maximum what do I do? So, then I say well temperature has reached max, this is now reached max may be slight back off, when I say max, if any back off is necessary, that back off is implied.

Now what do I do? Level needs to be controlled, you see I cannot have level floating, because then if level goes below 20 percent, I have to shut down the process. Well, you see we argued I do this gets sucked in that gets sucked, in that gets sucked in ultimately more feed is getting sucked in it has to happen automatically by the way you structured the control system. So, what do I adjust, now I cannot adjust temperature because its set max then I say I cannot increase production any more the question is can I increase

production further is there a degree of freedom that is left for me to manipulate, what can you adjust to increase the production of the compound in the reactor; temperature; you could have jacked up what else you could have jacked up or down level is already at max, feed flow rate.

Well feed flow rate is already under ratio control and level control that is not in your hands; the fresh feeds are already under level control and ratio control right the way it is drawn there yes or no, can you adjust something that indirectly adjusts the feed absolutely, there you go limiting reactant was 5 percent, now I start jacking up its composition from 5 percent to 6 percent 7 percent 8 percent 9 percent 10 percent, more limiting reactant going in you see the composition controller will adjust the ratio, if you adjust the ratio, you can always adjust the ratio in a manner, so that more B gets sucked in, more B is getting sucked in; that means, the composition of B in the reactor is increasing, if composition of B inside the reactor is increasing, well reaction rates are k times x A x B k times x B x C right basically you are producing more C and D yeah.

So, once you lost that degree of freedom, I am starting to use my last remaining degree of freedom, yeah yes or no; I keep now instruction from a way is max it out, drive the car at maximum throughput maximum throttle, so you are suppose to press the gas to the end right, so I keep increasing the throughput manipulator set point, ultimately what will happen? In response to this increasing throughput manipulator set point, my composition set point for B will keep going up right until throughput manipulator reaches max boil up yes or no yeah. So, this is called split range control, so you got a controller.

It is adjusting something when this becomes saturated, it is it start suggesting something else this is called a split range controller; this you should have studied in under graduate, if you have not does not matter we will cover it, but not right now, so your level controller is essentially a split range controller, it is adjusting temperature when temperature max is out, it is adjusting the composition, reactor B composition does this make sense or no. Now, notice that once, this TPM reaches max, boil up cannot be increased anymore, because the column is flooded, whatever a is getting sucked in whatever B is getting sucked in well, your process is floating at whatever is the maximum throughput for this process does that yeah.

No, we use it, we are using it as a throughput manipulator, because it is the throughput manipulator when this boil up reaches max, I cannot since boil up in the column is the last constraint to become active, it is the bottle neck constraint right, beyond this through put cannot be jacked up right, you see there are multiple constraints level is active; boil up in stripper is active then temperature became active, product purities are also active right, finally column became active, column boil up became active; when it became active throughput cannot be jacked up anymore, you have reached the maximum pedal, you cannot press on the gas anymore that is it, right yes or no make essence or no, so well that is it, so now, let me back off, let me, let me, let me revise when I am at low throughputs, temperature is in my hands.

So, level control is like this, what are the two things that are in my hands, I adjust the throughput manipulator, so that I get whatever F a I want, you see let us look at what is written red, I adjust the throughput manipulator and by adjusting the throughput manipulator, I essentially figure adjust what is how much fresh A and fresh B are getting sucked in, we argued how that gets done that this level goes down that sucks in more from the previous unit that level goes down that sucks in more from the previous unit until more A or less a as is it necessary gets sucked in more fresh A or fresh B gets sucked in yes or no right.

So, I can always adjust this throughput manipulator to get whatever F a I want yeah, if the F a is too much, reduce the steam set point, if the F a is too little, jack it up right. I can always adjust it to get whatever F a I want yes or no. v reactor max well that is coming from the set point here, this set point is kept at max, second thing v stripper max, well its already at max yeah. x B C 2 is equal to 5 percent that is being I am I am adjusting this set point, so that the amount of C leaking down is here is above 5 percent and last, but not least which is not being done well.

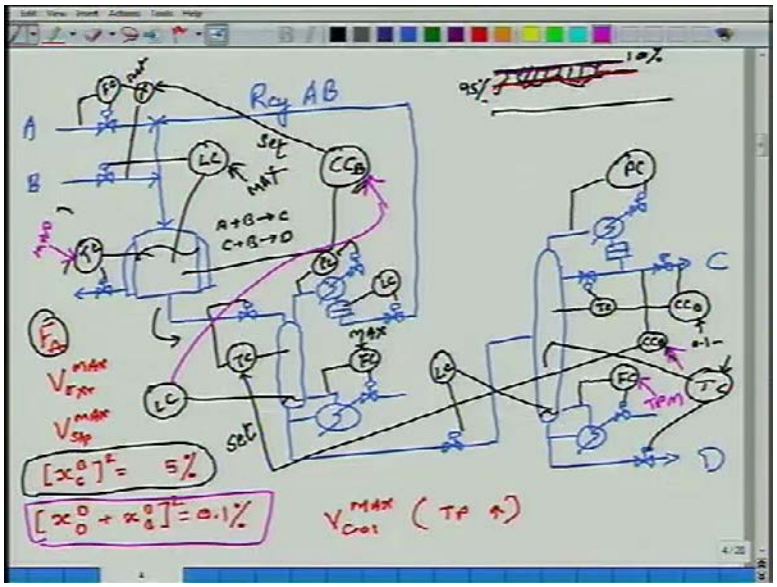
That is getting done, so I say that the amount of B, the amount of B leaking in the dislet this guy, I set it at some value, and then this guy is 0.1 minus whatever this is well, I cannot write it, but you know, this set point is a dependent variable; there is no issue yeah. So, this will come out to be negative and then your alarms will go up, how can you have a negative composition set point that is, that is just not possible; it can be 0.00000001, but it cannot be minus point whatever right, but well high level alarm, low level alarm, high temperature alarm, low temperature; these things keep going off and on

and then operators do take appropriate action to adjust the problem, so when if it is says this is going negative operator knows well; that means, too much B is leaking out; that means, I need to do something in the stripper right that takes care of that.

What was I trying to say man my I, my lost my chain of thought, what are the unconstraint everything is taken care off; the only independent things are what? This and this, we argued just two degrees of freedom, you see this guy, the TPM has been adjusted to get F a; this is literally not a degree of freedom; it is not an unconstrained degree of freedom right; we counted 1,2,3,4, 5; 5 constraints are active; two things are left; that means, the operator is free to set two things; what are those two things that he is setting, composition of B in the reactor and the impurity B leaking down the bottoms.

Once he sets that at some value less than 0.1 amount of D that is allowed to leak up the top is 0.1 minus that right, the two independent things degrees of freedom is fundamental, there is total 7 steady state degrees of freedom, 5 active constraints; that means, operator is not free to adjust, you know 5 set points will get adjusted to drive those constraints right, what remains those are in the hands of the operator, now I am saying, I want to jack up the production, so what do I do, I start jacking up the production when temperature becomes max, this becomes max then the level control has to be this way composition is no longer in my hands, do you realize the movement this movement temperature became max.

(Refer Slide Time: 48:58)



I hit a constraint, I lost a degree of freedom right; when you hit a constraint, you lose a degree of freedom, a degree of freedom is being used to drive the process to that constraint right. What is left in my hands composition of B leaking down the bottoms right, I can adjust this in that band of 0.1 percent from very small close to 0 to very close to 0.1 percent, but not beyond, if the objective is to maximize production, where would I rather keep this as well as maintain quality I would rather keep this B to be very small close to 0, because if too much leaks down is bound to contaminate my product.

Also the last constraint to become active is boil up in the second column right, if I prevent B from leaking down, the bottoms you see I the the point that I am trying to make is x a plus you know this guy the last constraint, I could have in my product large amount of B and very little D such that they sum to 0.1 percent, alternatively I could have large amount of D and very little B, I could have both scenarios the point is that is in my hands. How is it in my hands? If I set the B, set point, B set point is 0.1 minus that yes or no. Now, because the last constraint to become active is a is a steam is the boil up in the second column, I would like that boil up to get active as late as possible how do you do that.

By allowing as much what is the second column doing, its separating D and C; if I allow more impurity D in the in the top, my reflux goes down; if my reflux goes down, my boil up goes down yes or no in a conventional sense not in this control system, but in a conventional sense. So, from all these arguments I can say that to maximize production B should be in very small quantity, D should be the major impurity yes or no does that make sense that will give me maximum production. If I do it the other way round then this second convention will become active earlier, why will it become active earlier? Because it requires too much reflux yes or no if it requires too much reflux because amount of D impurity is tight then the boil up will have to be more right.

If the boil up is more then it will get active earlier throughput will suffer, does this make sense or no right. So, I had 2, two degrees of freedom left, one degree of freedom will got lost when the temperature became maximum, one degree of freedom was still remaining and I use that degree of freedom in a way so that I remain feasible and make sure that the boil up which is the last constraint to become active gets active as late as possible, because that is what give me maximum production does this make sense or no if it does I think we have done sufficiently enough, any questions; it sound so easy, but

man when you everything has to be thought through, the only problem that I have see with this control system is that this level controller on the stripper is actually quite unconventional, now let us say your reactor is actually very big, you know it is it is residence time is of the order of 2,3,4 hours then it may show happen that before the effect from the reactor could trickle down to the bottom of that column; the column bottom level has either hit 0 percent or whatever 20 percent or 80 percent the max and low level that can make this level controller fragile, yeah so, but if the residence time is not too much, let us say the residence time is I do not know maybe 10 minutes .

This will work no problem it depends on the residence time. If the reactor is really big, you do something it will take a heck of a long time for the temperature to respond, it takes 1 hour for the temperature to respond by that time, your stripper level has run dry or it has over flown right, that is also not acceptable; in that case we will have to redo something here, but the point is conceptually this is how I rather do, it if it turns out that the level controller is fragile, I will have to give upon tight control of either boil up on the stripper or boil up on the second column something will have to be given up, because it is turning out that my level control is fragile does this make sense or no. We will take care of that may be next time, if the reactor is not A C S T R, it is a plug flow reactor well.

There is no residence time, this will work guaranteed, it will work no problem, the point is to be able to come up with this kind of a scheme figure out if the inventory control will not be too fragile, if it turns out that the inventory control for example, here the level controller on the stripper is turning out to be fragile, we will have to redo it; we will have to make some adjustments some place right, but if it turns out know inventory control is also acceptable, this is perfectly when will inventory control be acceptable as long as the C S T R residence time is not too large, how large is too large well that is a separate question, you can stimulate and figure it out.