Plant Wide Control of Chemical Process
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Lecture - 26
Two Column Recycle Process

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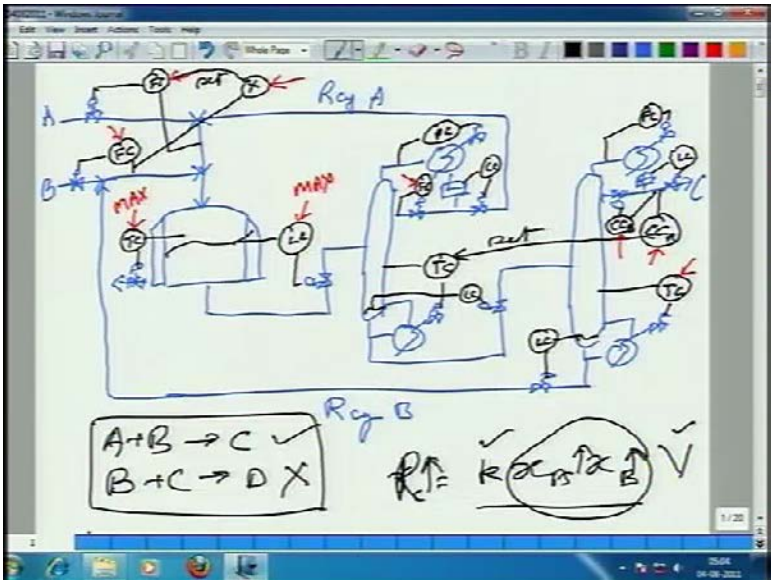

So, welcome to this next class. I think last time, we will looking at the same thing A plus B goes to C is just that, C is intermediate boiling and so you had to have two destination columns right, to do the separation. And we do the light out first (( )), which means the lightest component is separated out first; why did we do that well may be a doc cycle something, so you want to remove it first so that. So, this is A recycle.

Then you have the product column; in the product column, C is the light component; it goes up the top, B is the heavy component; it was drawn the bottoms, this is fresh A, this is fresh B, this is recycle A, this is recycle B, this is product C yeah, and if you draw wall shown it, I do not remember, how many walls? But we can just draw it, see what it.

These are the walls, did I miss anything? It is quite possible something I miss yeah. And it is the cooling steam, and in the absence of any other information, let us say fresh A something that is coming from. We basically said that, if you do things, this way it will be total B control the total A and total B; that takes square of Psychometric field balancing problem.

And, the rest of the control system, you have to have a temperature control here, because if any A leaks on bottoms, contemned your product C right. So, may what we can also do this, we are measuring the impurity, you see, you will always have an operating plan, product quality is always measure, no matter how hard it is to measure, may be takes it as, may be get reading once a shift, but product quality will always be measure. So, you know how much A is contaminating it, and if too much A is going up top, we can always adjust, the set point of this jam, how the temperature controller.

So, what to do, so much A going in the product, what we do with temperature set point in this column? You increase the temperature right. So, A sent up, yah and so on. So forth, level control; that is straight forward actually, pressure control, level control, sufficient reflux, level control, level control, pressure control, you would have temperature control here.

You definitely have A, what does column two do, what does a rectifying session of column two do, what function does it does it complies is question? Clear, there what is the functions of the rectification section in the second column; it is a question, please answer it, make a wrong yeah of course, a separation; what separation I am asking, the column separate B and C, what is the rectification session do? What does the stripping session do, and answer C well I do not think that.

The correct answer, that does the stripping session do? What does the rectification session do? What does the reflection in the column do? And what does the re boil do? Reflux prevents the heavy thing going from the top, re boil prevents the light key from contaminated going down the bottoms. So, the function of the rectification section A is to prevent heavy key, which is component B from leaking of the top from the leaking of the desolate. What does the stripping section in that column do, in the product column do? It prevents C from dropping down the bottoms, yes or no?

Now, this understand has to be fundamental, this understanding has to be very clear, by adjusting the reflux; if you increase the reflux, the amount of B going up, the top decreases. But, if too much A is leaking down, the bottom from the first column, from the recycle column, your impurity is going to be of spec, do see what I am saying? So, it is not enough to say, I want 99.9 percent pure product, that 0.1 percent impurity what is it? How much B? How much A? The B is been set by the reflux in the second column, the A is been set by the first column yeah. This must, we understand be, if too much A is leaking down, no matter what you do, you have to live with the impure product, because too much A the that that leak A bound end up in the top, by the lightest component yes or no.

So, therefore, I am controlling the A composite by adjusting, the temperature set point in the recycle column, and controlling the B impurity in the product stream by adjusting, the reflux. Yes or no? Now, since degrees of freedom 2 for 2 each column that for 2 for the 2 fresh field, 6 plus 2 for the reactor temperature level on temperature hold up yah. So, that A 8 degrees of freedom, what are the 8 things, that the operator is said setting 1, 2, 3, 4, 5, 6 is not checking temperature here in the first column that being set by the composition controller; is setting the amount of impurity in the product.

Amount of A impurity in the product, does make sense or no, how many times I did know, I told you 1, 2, 3, 4, 5, 6, 7, 8 degrees of freedom is 8 operator is setting 8 set points yah. How do, we set this set points temperature? Well, in the absence of the side reaction, we can see temperature should be max, because if temperature is max conversion is max and reacted A and reacted B is list. Therefore, the recycle caused basically the boil goes down, as you know similarly, boil up here will also go down, because there is less B going around.

So, I will say temperature in the absence of the side reactor; temperature should be max, this hypothetical example will may real example just shortly, but I am just trying to work you through simple rational arguments to figure out, how to reasonable specify by are, what you are degrees of freedom, you are set points level of course, should be max, because again that maximize, the conversion and therefore, the minimize is boil up. So, your steam consumption per kg product goes down composition A and composition B set points should some to, whatever is my impurity that is maximum allowed. So, if 99.9 percent and mole fraction of A, plus mole fraction of B to be by 1 percent right.

How do I decide, A versus B? Should I have 0.01 A, and 0.09 percent B or should I other way 0.09 percent A, and 0.01 percent B or should I have 0.05.05, you know comfortable A and B. Mostly, A little bit B, mostly B little bit A, basically that is the question, when I look at the economics, what will given that, whether you should, what should be the simple impurity in the product. You got 0.1 percent it could be mostly A little bit B, and mostly B and little bit A or it could be 50 50, what will govern that. And, I am asking you as an engineer of course, I can do an optimization, and the optimizer will throughout some unsplit answers, some numbers and I can be blindly implement them, Right.

I was a fool before, I did a optimization. Again, I remain after I did the optimization, because I did apply my mind, that need to remove, why no now, we are talking, which separation is more difficult that, what we govern it. So, if you if you look at your base case design condition, you actually look at the revel duties, it is revel duty are comparable.

What that means, is the separation is about the same, and then most probably, you are optimizer, will tell you look about the same 0.50 percent of this, then 0.50 percent come back may be 0.04, 0.06, 0.07, but comparably amount A and B, if you turns out for example, let us say that the C B separation is very easy, the B C separation is extremely easy, then what will have is the product column, will have very low boil up right. If the product column have very low boil up, what will be optimal allowing as much A to leak out, the bottom of the first column as is allowable without violating the product purity constrain.

So, then my solution would tend towards 0.09 percent A, 0.01 percent B, because separating B and C is very easy. Of course, relatively quantifies is of separation of course, optimize will give you something, but the point is you have to look it and try to understand it, right. Now, after having try to do that, I found something that is, what I am trying to trying to impact you. So, it all dependence on, which the easier separation; it could be both separation are about the same as difficult, it could be that first separation is much easier, and second separation is very hard; or it could be other way all second separation is much easier, the first separation is very hard and based on this, you will find that, yah.

You are optimizer is going in that direction, in this direction in this direction or in that direction you see, and when you have this understanding, whatever the optimizing is throwing out, you will say yah that make sense. If the optimizer is throwing out something, else most certainly you will question it, right. I am trying to answer to the question, you figure out; whether the optimizer was correct or you thinking itself was plot, in which case correct? You are thinking and that is the learning, that you take the point is you just cannot leave it optimizer to split out some result; let it go under into prêt it alright.

So, what should composition is A set point, and composition is B set point. B that dependence on the difficulty of separation one and separation two yah; that test that what should be the temperature set point in the second column B, see why do want to prevent C, from the leaking down the bottoms, because it is unnecessary goes round and round right; this cause associated with circulating something round round. What is the trade of, if you try and do very tight separation; that means, you want essentially known C leaking down the bottoms, what are you do is jack up your boil up?

Because, you do not want any C leaking down, as far you concern 1 percent, 2 percent, 3 percent, 5 even, 5 percent C is on the other hand; if you allow too much C to leak down, you see the everything. You see the C will call, the extra C that is floating around will cause the boil up, here to increase we cause the boil up here to increase. There is cause associated with re circulating something, that round and round. yes or no? So, if you have two tight C separation, you do not allow any C to leak out, then you boil up in second column look up, if you make it too loose, then again the boil up flow up, because the flows up because you know that, the fluoride is recycle fluoride; it is higher. yes or no?

So, in this extreme, the energy cause flows up in this extreme also energy cause flows up. So, only there is A optimal, somewhere usually what happen in practice is you would not like too much to C to leak down, because what will happen is this C this much goes back to the reactor, it can degree to something else, usually they will always be some sort of side reaction blah blah blah blah, and that essential said look, you not have A too much C leaking out, but this is hypothetical example; where assuming there are no side reactions, if you assume, there are no side reaction.

Then, we try to optimize process, there are there is 360, where the boil of two column suites up, there is a at extreme, where the overall energy cause, because the higher recycle follows goes up, there is optimum somewhere, this what exactly optimum is not clear, you will have to do an optimization, but from practical stand point there are always side reaction and, because there are side reactions, there is a limit as to how much C?

You need allow to leak out, while you allow as much to leak out, you see what I am saying.

So, you have a way of setting the temperature controller, set point 2 in a similar way, the reflux set point also get, set in the first in the recycle column, you cannot allow too much A to get recycle too much, what should I said? What is the impurity? Is see you cannot let too much C in the recycle stream in the recycle a stream, because that C again degrades to something. So, whatever reflux is necessary to keep the composition or to make sure, too much C is not leaking out, the top that much reflux you have to provide it. So, this is a reasonable way of fixing the temperature set point, here fixing the reflux there.

Now, we come to the last part, total B and total A, how do you fix that, total B and total A, if there is no side reaction, total B and total A should be comparable, you cannot have, because in your hand the operating on top of the hill, it later drop down you are essentially unstable. So, you would have to be slight either on this side or slight either on that side; it cannot be exactly equal yah, what is does it do keeping the A, total A and total B comparable given that, there are no side reactions the combined yah. So, it maximizes, this is your conversion, because it is maximizing your conversion, minimize your recycle load yah.

So, basically that fix is this is that, if you want. So, basically what I am saying, the total A may be kept in ratio with total B and the ratio set point may be for example, 1.2, 1.3 yah. So, what I am saying is let us do this, total A is fixed and I am going to take this, total A plus do it other way, which is easy to draw, total B is fixed, I am going to take this total B reading multiplied by a number, which is close to 1, but not exactly 1 may be 1.1 and 1.3, 2.9, 2.8 and that will be the set point for this.

Now, the operating is setting this ratio set point and the total B set point, yah still 8 things, it still setting 8 things, but this is the more reason way going things, it automatically gets you close you right. What does this flow control do? Where the set point of B? Total B flow controller, this will be used to increase or decrease. If I look at the reactor, and let us I increase the B, the total B flows set 0.50 percent, how does the production inside the reactor increase? Or why does it increase? Is very important to understand, this is a question clear; I am saying that, I am increase the total B set point and I will get more production of C yah my question is why does it? What happen inside the reactor to produce more C? The production is governed by this equation, rate of generation C is equal to rate of reaction times concentration of A, inside the reactor concentration or more fraction of this is, what governs the C generation rate?

So, when I am increasing that total B set point, what is happing to see, k is fixed temperature; is maximum volume also effect, but volume also fixed. You are not change that, the only thing is change sorry times B total, this is a per unit volume reaction, A the total reaction rate is this per unit volume reaction, A times the volume, the reactor is fixed, because I am operating it in maximum level. So, this is fixed this is fixed the only thing; that is changes this, my question is how does it change? Why does it change? Is a question clear.

If I put more B, what happens the ratio set point will sure that, I am also putting it, I am putting in more fresh A, I am putting in more fresh B, I am putting in more. So, that the concentration of A and B beside the reactor, actually goes up. yes or no? This guy is saying, yes or no? See there these also see them reactor is also see, because C is getting generator right; this requires some thoughts, I knew, I get struggle this, but what I am saying is correct? I will due to think about, what happening are basically, what happen flow see.

I am putting more fresh A, more fresh B, let say nothing happen to reaction A. So, I am putting in more fresh A, more fresh B, C remains the same, where does the excess A and B go it; goes in the recycle right. If it goes in the recycle, my x then I am putting in more recycle A, more recycle B did you see, what I am saying? So, what happens is essentially, you are getting more total A in, more total B, in x A and x B will increase based on C will essentially will get diluted it yah; if C is getting diluted out, your x A and x B is increase therefore, you generation rate of C has increase.

You see, what could I am saying, this essentially dilution effect diluting, the reactor further by putting it more fresh reactor, you are diluting the product out, sorry you are diluting C out by putting it more A, and B into the reactor, yes; that is not matter. v is fix look at the expression; v is fixed, k is fixed, because you are putting in more total A, more total B; it will essentially dilute out, the composition of C x C will go down, x A and x B will go up.

So, generation rate of C will go up, even though x C itself has go down, do see what I am saying? And this needs to be understood, no it will not increased eventually, this is what need to be understood, it will increase, but if you look at this study state versus, this study state, where total A and total B was small, this study state total A and total B to the reactor is larger, see what could got down. Now, x C could have gone down, now grantee because you are taking out the C right, there is not equilibrium reaction, this is a reversible A plus B, irreversible goes to C.

If it is equilibrium reaction, we have a different way of dealing with that; it is an easy reversible reaction and this is what each to be understood; if you do not understand this, you cannot come with this skim. In fact, you cannot tell, whether it is a self regulating or not shall we proceed for further.

So, how is the generation rate been increased, the generation rate is been increase by essentially jacking up x A and x B, because x A and x B goes up, or C goes up, generation rate of C goes up; however, x C does not go up. In fact, it go down like A, because of the dilute; that not we talking more fraction, see whatever C is generated; it is not getting recycle is essentially been taken out as product right. So, C never accumulates, if anything accumulates, it is A and B C never accumulates, that C is taken out. yes or no? There is no question of C will final raise.

Because, you are taking it out. So, the molar fluoride on the exits stream of C would increase the fluoride, of you are putting more total A and more total B in term of moles molar fluoride of exits stream will also increase, but the concentration of C would I have got now, but it would not have gone down. So, much if you multiply flow, and x C that component fluoride of C would have gone up, that is the extra generation, that is why I am getting more production; that what make sense or no yah hu. Once, you have understood this, then you can proceed latter for the other, through very simple qualitative plain English reasoning.

Now, we are devising control systems for something; that does not look t0o simple, at least yah. This approach will work for everything, system attachment may be I leave for the couple of lecture, you know, what is the systematic doing it? I just want to walk in through various examples. So, that where I am coming from becomes to you, and then when we give you the systematic procedure, step 1, step 2, step 3, step 4, step 10; it will be clear. What we try to do? Alright by the way just as I assign suppose as I just side reaction, and I do not know. Well, let say there is side reaction, which is in series A plus B goes C; C for the reactor for example, A to give B and let say the vitality of the d is same as that of C and of B comes out with C in the process.

If that is not the case, D in the another column to take out the D, but for this loch if there is side reaction C plus B goes to D, how do you mange this process? You want to minimize the side reaction, because C is what is fetch to money for D, you have to essentially separated and then process it, you essentially charge may be D is contaminant, which is to be dispose of and there is a disposal penalty, that can be. So, you earn money for C and you been analyzed for D. So, basically now, you want to write the process; such that C is maximize and you produced A little D, let say B plus C.

Goes to D, this is A; that product this is unadvisable, how could you manage A, we will keep excess, what is that mean about the is a ratio set point of course, it should be greater than probably 2, 2 ½, 3, 4 that depends exactly on, what kinetics of 2 reaction, but basically you will not be operating 1, you will operating around 1 or 2, 3, 4 yah, no n depends just in the kinetic, yah it will not be closed to 1; it will be much greater than greater than 1 yah; that is ratio set point has to be much clear to suppress the side reaction, what about temperature temperature of the reactor with two reactor.

Just, common sense again, what are the capitals do did the decrease the activation energy in the desired reaction, that what the capitalist, this what place, where decrease the activation of this is designed. So, that it. So, that reaction A is much more faster than reaction B. So, basically what that is say is, that the activation energy of the desirable reaction is actually greater than, the desirable reaction, if your system is irreversible reaction something follows.

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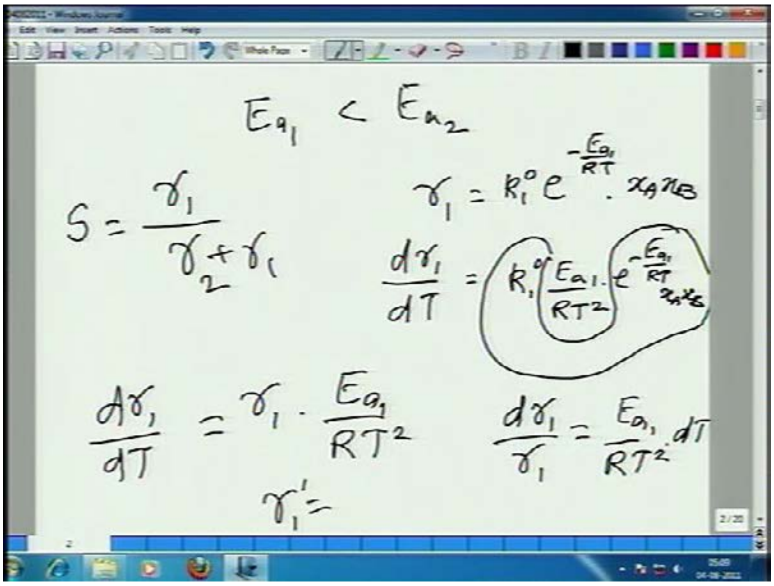

$$E_{a_1} < E_{a_2}$$

$$S = \frac{r_1}{r_2 + r_1}$$

$$r_1 = k_1^0 e^{-\frac{E_{a_1}}{RT}} \cdot x_A x_B$$

$$\frac{dr_1}{dT} = k_1^0 \frac{E_{a1}}{RT^2} \cdot e^{-\frac{E_{a_1}}{RT}} x_A x_B$$

$$\frac{dr_1}{dT} = r_1 \cdot \frac{E_{a_1}}{RT^2} \qquad \frac{dr_1}{r_1} = \frac{E_{a_1}}{RT^2} \cdot dT$$

$$r_1' =$$

So, this energy of activation of let say, reaction 1 is desirable will be greater less, than yes will be less than energy of activation of the side reaction, yah. Now, we want to figure out, how the sensitivity? How it is defined selectivity? Have heard the word selectivity engineering, how you define the selectivity? Let us say a for the same distance. So, rate of reaction 1 divided by rate of reaction 2, this is called selectivity right yah. So, how much the product has been produce in the reactor, I do not know this, if it is the r 1 plus r 2, sorry what r 1 not is constant, I think e a by R T square and minus minus will cancel out times e to the power E a 1.

Minus E a 1 by R T, times x A x B, x A x B is constant yah this gone out, here is nothing, but what this a reaction rate at original condition, yah my reaction rate right, now this much I change the temperature slightly, how do my reaction change write. So, that density of reaction temperature d r 1 by d T yah.

So, d R 1 by d T turns out to be r 1. I am sorry it actually this x A x B included. So, d R 1 by d T is equal to r 1 times energy of activation is divided by R T square d r 1 by R 1, this is the percentage in reaction rate, yah is equal to E a 1 by R T square times, what d t? What is this expression say, if I change my temperature, if let us say 1 degree cellules, my change in my new reaction rate R prime will be is equal to r 1 plus d r 1, whatever it was plus d r 1 right. So, the new reaction rate or the change in the reaction rate is propositional to energy of activation.

Now, I know for the side reaction the energy of activation is higher, for the main reaction it is slower. So, when I change the temperature, my side reaction is more sensitive, to change in a temperature than the main reaction yah. So, if right now, my reaction rate was x, main reaction and side reaction was y, x changes by 2 percent; when I change the temperature, y could change by more than 2 percent, because it is activation energy is high, yes you know all right. So, the side reaction used will be more sensitive in temperatures.

So, when start jacking of temperature, your selectivity will start going down does it make sense. So, if you have a side reaction, I depended to the same process. If I have a side reaction n, if I have a no side reaction t, should be max reactor temperature should be max maximum allowed, but if I have a side reaction, as I start jacking temperature, the side reaction rate grows first, then the main reaction rate. Therefore, I start producing more d per k g product C, produce or per kilo mole, product C produce my selectivity or unit two desired product start down, there is then trade off, what is the trade off at lower temperatures converge is low.

If converge is low, recycle cost goes up, because un reacted reacted has to be recycle, has you know right. If I increase the temperature too much, I start producing the too much jack, right and that this creating penalty for me between these two streams. There is some optimal or regional value, for the rate reactor temperature, yes you know. So, you have a side reaction, you cannot just blindly keep checking up the temperature; the temperature should be high enough. So, could be not to low, but you cannot, simply take it back, because very likely the side reaction will start killing you, yah.

Now, earlier there was some constraint; that was saying that, look the temperature of the reactor, cannot let see let us take 200 degree Celsius, the liquid starts to become, you know you are approaching the boiling point, again say you cannot go 200 degree Celsius, or may be because starts to deactivate coke start to deposit at least, this is the physical constraint. Economic if let say, if not way from physical, now economic constraint saying do not jack up the temperature, beyond temperature, because when you start producing too much jack, now becomes essentially economic constraint; the point some constraint will become active, whether it is physical constraint or it is a economic consideration.

Well, why did I say this, yah the point is this depending on the chemistry of the process; it is fundamentally type two, how you said two set points? There is no control theory your are reaction scheme, whether the prime reaction, series reaction, or parallel reaction etc… That determine, how the hell, you operate the process, there is a side reaction. I guarantee you would not maximum temperature, you will somewhere in the middle. How much, where that comes from in a optimization, what should what should temperature exactly, that will come from optimization yah.

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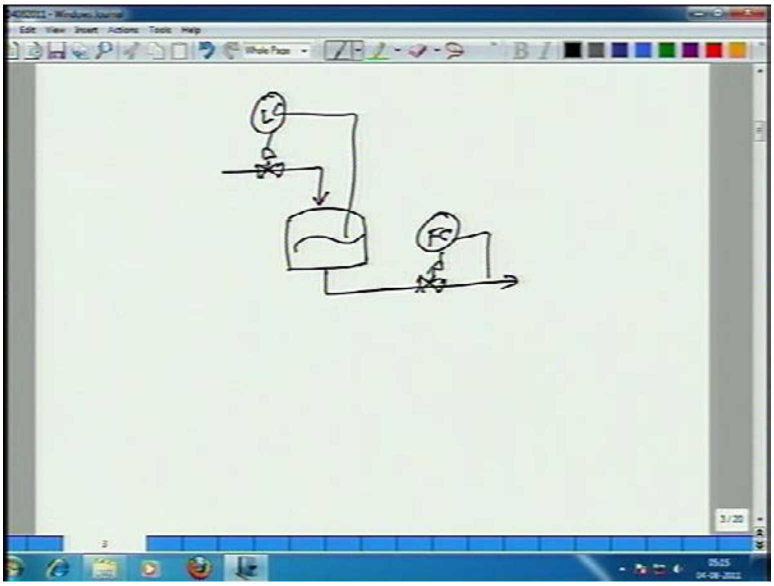

Now, let us get to the next point. Next point is, I want to throw something for that, start again with the tank, we can count the degrees of freedom; degrees of freedom is 1.

By default, I am always being doing this, yah by default, I am always doing this, can I do this, is this workable? Is it is it work, where instead of setting the feed flow, I said out flow and then the feed flow adjusted itself. Earlier, I was setting the feed flow and the out flow was adjusted itself, under level control. Now, I am setting the out flow and the feed flow is adjusting itself under level control, yah. Will this work? Yeah this is this is perfectly reasonable way of doing it.

Yah, this through in the question, when should I do this? And when should I do that? when should I will having? You know, when does this make sense? When does that make sense? Degrees of freedom is 1 in both cases, are actually 0 1 meaning the through put, how much is flowing the degrees of freedom is 1 through put.

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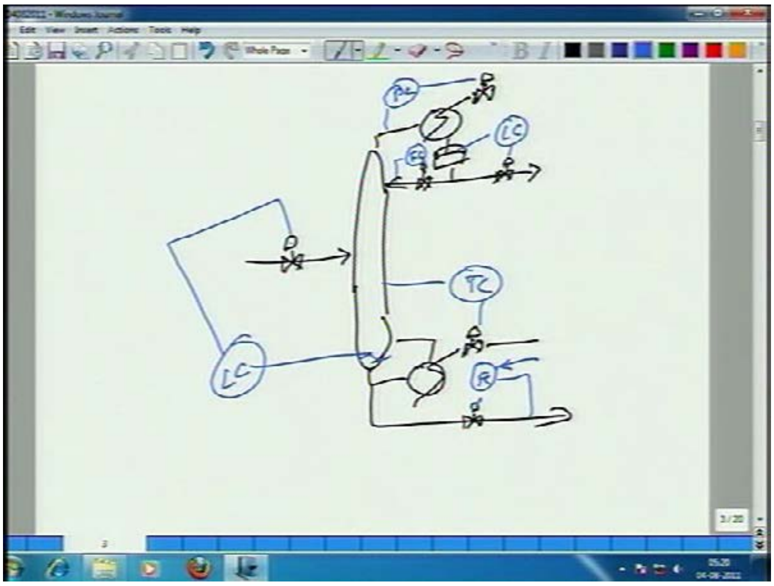

Let us look at the (()) column, earlier what I was doing was, I was fixing the feed fluoride flow control, and then I was putting in level controllers, and temperature controllers right. Is that only way of doing it hell know?

I go for example; for example, I go flow control, the steam to the column may be, I should use different colors for this could stay to the column, may different column, it can be do, then I would have level control; this level control to this way reflex under flow control.

Pressure control this way, and I can control the temperature in this way. So, now, this is my through put manipulator. See earlier, I was setting, how much flowing through the column at the feet. Now, what I am setting yes, how much steam I am putting column? And that would said, how much is getting under temperature control? Yeah. So, the point that, I am trying to make is, that degrees of freedom is ok, how you manage the philosophy, behind the manage degree of freedom also, but it is many times free to choose, where you want to set the through put, at the fresh field. If I would through put through column, I can that controls the structure brought in number of times, yah.

Here, I am setting through put at the boil up, I could have also said through put at the product. Let us say that, the bottom steam is the product steam, there is a customer more giving mail thus immediately, what do I do in that case? What I do in, what I do in that case? This is under flow, but this is set point for the, this is coming from the product customer demand, this is on the temperature control. And now, the level is getting controlled by the field, that you putting into the column right, that it makes sense, this is another perfectly legitimate way of running the column.

Well, if the level is going down, put more liquid free, it will drop down and level at the bottom some slowly, but slowly go back, yah it will work, because the level is going down therefore, you get extra field the extra field should be got from the early sure you see.

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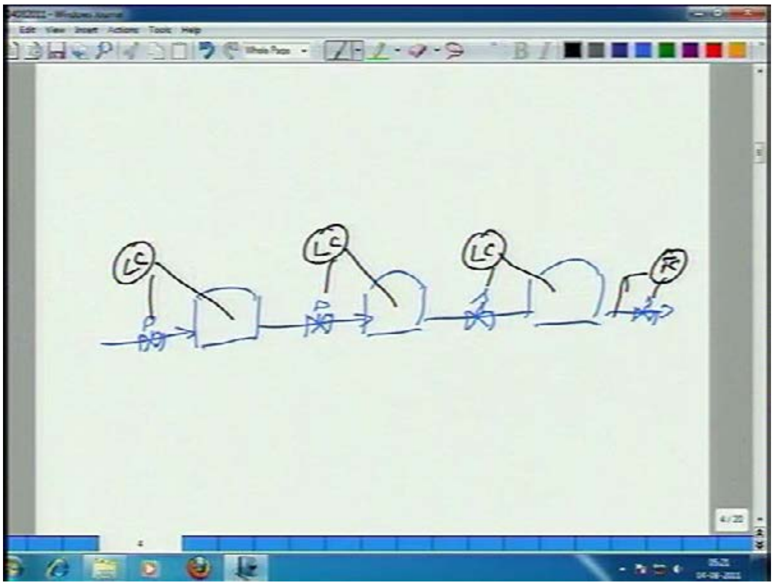

Let us have, it is 10 50 may be its time to go, but leave me, just take very simple 3 tank process; tank 1 is feeding to tank 2, tank 2; this tank could be plant in itself, and I am talking about, over all material balance on the plant. Let us say, something like this, I can do this set feet here and then, what I have is level control, this way level control, this way level control, this way there is one doing it, yah is another way doing it level control, this way level control, this way, this is also work just like for a single tank, yah.

I could also do it, may be this is also perfectly legitimate. So, the through put in many situations, can be set any where inside the plant by default. I am saying, we set it, the feet but in many situations, where the feed is degree of the freedom; that means, your are free the through put is the degree of the freedom. You are free to set it, it is not be set by this.

Well, you can set this the feet, you can set it that the product, you can set it somewhere, inside, and intermediate steam, and the control system can be made, that will work as how do we decide? What to do at the feet at the out let, intermediate, where, and how do we go about synthesizing the control system given? I am going to set the through put here, that is the next thing. We are mono talk about, the point is the through put can be set in anywhere and device. The control system to manage, your degrees of freedom appropriately respecting the over all material balance around the plant material may be and given energy balance.