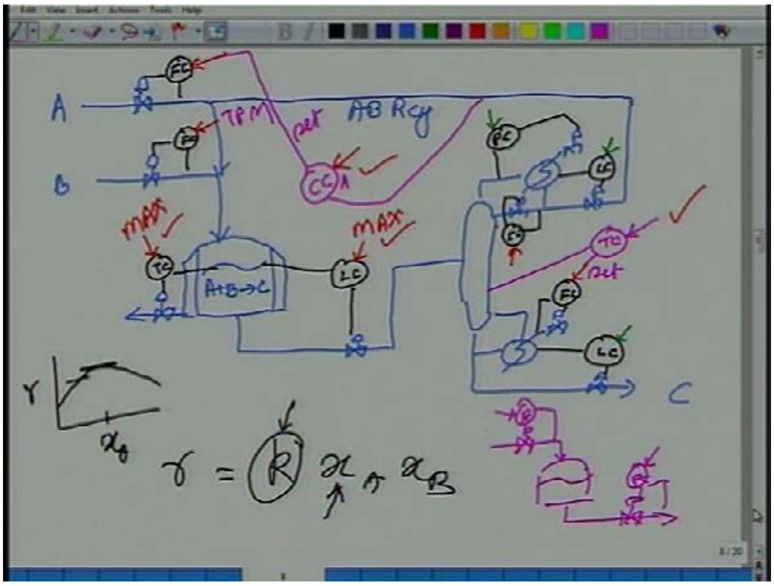
Plant Wide Control of Chemical Process
Prof. Nitin Kaistha
Department of Chemical Engineering
Indian Institute of Technology, Kanpur

Lecture - 25
Illustration of Considerations in Control Structure Synthesis

(Refer Slide Time: 00:22)



Welcome to the next class, last time you were looking at a process very simple process, which consisted of C S T R cooled, a cooled C S T R, A and B going into the C S T R reacting to form C, reaction occurs in the liquid phase, reactor a fluid which is in A B C mixture is sent to destination column; where the un reacted reactance are recovered at the top; because the light and recycled, and from the bottom you would draw product C right, and this is AB recycle, R c y; R c y means recycle. And we saw that the steady state operating the degrees of freedom for the process is what checks, then we decided to put in place a simple mind it control system, where what we do is flow control the two fresh fields, temperature control the reactor for the reactor temperature is fixed.

Now, we need to control the level of the C S T R, we just done this way, we need to control the level of the condenser we just done this way, we need to control the pressure of the column, we just done this way by adjusting the cooling duty, we need to control the level of the bottom, column bottom which is done this way, the amount of steam flowing in is set by the operator, the amount of reflux is also set by the operator. So, what are the 6 degrees of freedom for this control system.

Operator set this, operator set this, operator set the reactor temperature set point, operator sets that reflux, operator sets the reboil or the steam to the column; and these are the 6 also the level, the level at which you operating the reactor 80 percent, 10 percent, 20 percent, whatever; these 6 set points are your steady state degrees of freedom for this control systems. Of course, there is a set point of association with this, there is a set point association with this, there is a set point of association with this, but these two set point level set points do not affect the steady state, also the pressure is fix because you want to operated whatever is the design pressure of the column. So, these three in green are not really study state degrees of freedom, the red are the study state degrees of freedom.

Now, when you running it like this, we discussed last time even if you see a 1 mole of A reaction, 1 mole of B to give 1 mole of C. So, if you look at the plant, as if you look at this over all plant boundary, and now this goes back to material energy balances, ok. If you look at over all plant boundary, if you take, if you want to take out only pure C, or let us say 99.9 percent pure C, what that means is you putting 1 mole of A, you are essentially putting you have to essentially putting 1 mole of B, if you are not putting 1 mole of B, exactly and what that means is either there is a excess of B putting, or there is a excess of A that being putting right since, you cannot let that drop out the bottoms.

That excess is bound to build up in the recycle loop, that not make sense to you or not, once that makes sense now, let us say we are operating the plant forget the yellow boundary. So, let say we are I rub the recycle of, let say the operator decides this is the way, these are the set points I am going to set, operator understand that you put in 1 mole of A 1 mole of B, let say you got really a dump operator, what does is the dump guys I say this is put in some mole of A some moles of B not necessarily equal. So, that two set points are not equal, we are going to build up the operation from the dump guy to smart guy, ok, so that you understand how degrees of freedom are very important.

So, you putting in some amount of A fresh A, some amount of fresh B not necessarily equal, that been in the case what will happen to the purity here at the bottoms, whatever is the excess has to find the way out right. So, if you have, if you have set the steam at some value, you are getting the excess whatever is the excess coming out. Management says well this is only 95 percent pure, we want 99.9 pure, we do not like this please operate your process, so that we get 99.9 percent pure product, what does the operator do? He looks at process because out this where is too much A drop in down the bottoms, let us say. So, what does he do?

He increases the steam, then he got the irritated every time, I have look at the quality and change the steam. So, you get a little smart this is a well, all put in a at temperature controller that sets this set point, because the management was not happy with what you was producing its quality was not good, ok. Once, you does this what happens is because, you putting in excess amount of B or A whatever the case which was drop in down the bottoms. Now, the temperature controller does not allow it to drop down the bottoms yeah. So, what will happens to steam, you have excess of a B put in that is the temperature controller is not allowing that excess A to drop down the bottoms.

What is the controller doing? It is essentially increasing the steam yeah, they you will definitely come a stage where you cannot increase the steam any more. So, let say then the temperature controller has been increasing the steam, or may be the column get flooded, because you are boiling up so much, you are boiling going is increasing, increasing, increasing. Now, the liquid cannot drop the column the flooded, by the ways what will happen is you will heat a constrain, or before you heat the constrain, or may be if the steam goes to the maximum, you cannot increase the steam anymore. And now, the A which was sent up cannot be sent up, because you increase the boil of anymore and therefore, he start’s contaminated the product again right, what is the problem?

The problem is over this control system is not respecting the overall material balance for the process, over all material balance dictates that A should be equal to B, is A equal to B? No, you are setting it independently, it cannot be set independently right. So, you need to do something to ensure that A or B does not build up in the recycle loop, the operator then finally understand this, then what does it do is it you control some composition inside the cycle loop. So, let say A controls A composition inside the reactor of let us say, may be A, and to hold this constant what he does is, he sets the fresh amount of A been sent in.

Now, tell me is the overall material balance being respected with this control system in place, or we still have some problem, is a question clear? Do not struggle too much, this will work. Because, if two much B is building up A composition will go down, you reduce the A, then A will match B. If A building up A composition will go up, because you reduce A ultimately match B yeah.

So, now we got again 6 set points, what are those 6 set points: one the fresh B fluoride, reactor temperature, composition of A inside the reactor, stripping the temperature, reflux to the column, and Level of the rector, these are still 6 set points is just that the variable that have been specify are different. Earlier, you are specifying F A, F B temperature, level, steam, and reflux. Now, we are specifying F B composition inside the reactor, reactor temperature, reactor level, column temperature, and reflux, you see what you are specifying the 6 specifications for the process have changed; with these sets of specifications yah overall control system is respecting overall material balance. The composition controller here will ensure that, the A and B fresh fields are psychometrically balanced, this dictated by the psychometric reaction, ok all right.

Now, how do we choose? What we do with these 6 set points? What should the temperature set point B in the column? How do I choose this set point? Column temperature set point it has to be chosen, so that the product is 99.9 percent. So, product purity specification basic fixed this, so I know how to fix this, yah, what should be my level set point in the reactor B maximum why? So, so conversation is more, so what I mean near to answer, so what, until, so why? That is the question, why is economical better to run the reactor at highest possible conversation? Yah.

You will required put in more steam to send, send the A and B up in the column, he is saying economic should be better? You need to further quantify that, why economics is better? Because, if you have more and reactor coming to the rector, you need to send it up, that mean you need to put mostly in the column yes or no. So, all steam consumption per kg product produced goes up, if you are operating at a lower level, so you could operate the level at max yah, the set point to the level controller for the, for the C S T R could be what max. So, I know how to set the level, what about temperature?

Let us say there are no side reaction, very simple case no side reactions, how could you set the temperature? Any value, design value, while I said the what happens to the conversion if temperature goes up, increases. So, your boil up will again go down, but can you keep on increasing the temperature in unbounded way, no for example, your liquid may not remain liquid everything vaporizes. So, there will be some limit on the temperature or may be your catalyst starts to get coked and so on, so forth; some process constraint will limit, what is the maximum temperature at which you can operate this process? that max where I operate it, yah thinking in it, ok.

How do I choose the composition set points? There is a C C A know this set point composition of A inside the reactor, I can choose the set points to be whatever it could be too much A very little B, it could be too much of B very little A, it could also be A and B are comparable, why comparable? No. It is not clear to me, no I do not think you understood material energy balances, whether the set point is 10 percent A or 90 percent A if this loop is on A and B, fresh A and fresh B psychometric; you can choose this composition set point will be 10 mole percent A, you can choose it to be 90 mole percent A, ok. No matter, what you choose it? As long as you maintain the composition fresh A and fresh B will be balanced psychometrically, you can think it of this way.

If I let say A and B initially balanced, exactly 100 100 kilo moles per hour, I give A plus up of some duration, so B is fixed at 100, A went from 100 to 110 let us say 1 hour, that extra 10 kilo moles of an hour did not drop out, where it will go? It went into the recycle. Therefore, that that extra A has belt in the reactor, and the reactor composition as gone from let us say 10 percent A to 40 percent A, but after the pulse has been drawn the two field are psychometrically balance, so you can operated 40 percent A, 10 percent A, similarly 90 percent A.

As long as the composition controller is on, psychometric balancing of the two fresh fields will occur automatically, so that makes sense or no. So, my question is, what should I choose it? Should I run it at 10 percent? Should I run it at 90 percent? Should I run it at 40 percent? Reaction is only A plus B goes to C, there is no side reaction. So, let say the rate of reaction is thinking is on the right line, rate of reaction is equal to k times x A x B, you know it is an elementary reaction, let say this is the rate of reaction expression; by maximizing the temperature, I have set this at max, what should I said x A mole fraction which is what the composition control is trying to achieve.

When I will get back some r com, but if I you see, if I plot rate of reaction versus x A, it look something like this, you know 50 percent whatever it look something like this, right. You really cannot operate here, because you can operates likely below it, because they become do later on it, so maybe you will say ok 40 percent, why 40 percent? Because that maximizes my reaction right which maximizes consumption conversion. Therefore, lesser boil lesser energy requirement for recycling the un reacted reactors, thus it makes sense or no, yes or no.

So, I got 6 degrees of freedom the moment I start thinking about the process. There are ways of fixing things to reasonable values, this fixing those degrees of freedom to reasonable value, yes or no. So, now I know how to fix this, what is it that is left? The two things that are left are the fresh B fluoride and reflux, ok yah, yah; while, yes that is true. So, may be what should be doing is yes just I saying, just a saying chill man, chill may be we control this composition this only A and B right, where you let you see now, this can be made 45 percent, probably this is work some composition inside the recycle loop, yah does it make sense or no.

Now, the make sense. So we know, how to set the composition controller the set point? We know, how to set the temperature set point? And we know, how to set the column temperature set point? we know, how to set the level temperature set point for the reactor? Only thing, that the left is what? Reflux that only thing that remains while set reflux to reasonable value, so that too much C does not go up the top. That much sense any operator would have sufficient reflux, so that C does not go up the top, yes or no, how to know? Either you measuring the composition, there is no composition or you know measuring the temperature, shortly temperature are measured.

If C is going up the top temperature in the top section of the column will be higher, so you know that temperature of the top section is increasing too much is going up the top, let me increase the reflux. Particularly, the boiler being set the operator was given by the problem of having no control over by product impurity right. If A is too much B is too much go down to fix that problem I designed to control the temperature yah, but they may happen, if even there is side reactor A and B in the boil keeps on increasing, and then you have to start because A and B or not means, not means fresh in the exact to maintain that stability.

To maintain that stability so you are free to choose degrees of freedom in any 6 variables can be chosen, if number of variables minus number of equation, how many things to be specify to get the square system of equation, any 6 can chosen. But the moment you start, how to run the process? So, that my production objective in terms production in terms of quality, what should be specify? Or what are those? What variables are used to specify those six degrees of freedom? That choice become quite limited. By the way the only condition is, what I do with this set point F B? If you want to produce to increase the production rate to increase the amount of fresh B, fresh B means got it.

If you want to produce less decrease the set point here. So, this is called through put manipulator TPM. Now, this through put manipulator namely under level control steam process, in which state are not in your hand, up steam process is setting it; how much would the plan produce? May be your management is telling you, in which state the set points is setting, it could be a real degree of freedom where you have the flexibility of choosing, what is my optimal through put? This what I am saying, what is my optimize through put? So, what is my optimize through put may it divert by the prices how expensive is energy? what is the selling price of C? And what is the price taken for raw material A and B? Tthis what I am saying.

So, now you optimize what should be my though put? So, that my operating profit as per exceptive market prices today is maximize that can be done, right. Now, for the sake of simplicity we are just handling the case, when I am told how much B must process, when the degree of freedom I am free to choose this set point. So, that the amount of profit that my plant make because of operation is maximize, we are looked at the case where though put is not a degree of freedom, it is a disturbance either the process is telling you or up steam plant is telling you, this is the stream process.

Does it make sense? No, in this process you have, yah, yah we could of course, it is (( )) So, what will happen is the operator looking at what will happen to the composition of A, at the beginning of the shift and the end of the shift. Because, let say you get two samples from the lab may be 4 hours 8 hours. So, you looks at what happening to the composition, if the composition of A is increasing, what it would you do, could decrease a amount of very important, you just know, so it is slow, agree. This is only way because, they does not grantee declare the time column same thing.

I discuss with you, when in the first may be some time you know, you are trying to set the two independent flows, when you cannot, even if you get the two set points equal, because of this my centralized, centralized by either we put in more can you taking out, or taking out more then you put right. If that happening the tank level either increasing or decreasing, and some along we get it, high level tank along or low level tank along right, same thing is happening in this process two, if you do not put a product purity constraint specify A and B independent is because, if you put in more A, it can come out to bottoms, it putting more B it comes out the bottoms.

The moment you put in purity constraint that look my bottom product has to be 99.9 percent C, what does it means is it changes the nature of the column, fundamentally what is that fundamentally? Basically, whatever your putting in must be consume in the reactor, if it is not getting consume in the reactor, if it is not getting the digested or reactor way in the reactor; it cannot go down the bottom it going to build up the recycle loop. So, the component inventory is behaving like a level, right the mismatch can be very may it take months inventory to build up, before some constraints gets set and you know you start getting contaminated power.

So, the fundamental thing was again the moment product purity constraint, which is A and B independently, cannot be done, if you did not have get the product purity constraint, you could have fix A and B independently, we never go nature we could have come down the bottom, this what I am saying. So, what is your production objective that also fixes what is that set of six degrees of freedom which makes sense, if you want 99.9 percent purity in the bottom fixing A and B independently, does not make sense. It is grantee to valid material balance for the whole plant, you must say I realize it, I want to set A and B equal, but interactivity never be equal, but because you do not have sense, it is grantee, grantee; So, so that control system is grantee to say.

How, it will take the essentially to fill up the recycle loop with either A or B, that what do not want to do. So, you measure a composition make inside the recycle loop, some place may be in the reactor, may be in the column, may be in the recycle, wherever, but some place and then only concentrate, because building up I just how much A or B, yes or no, please note that the nature of the problem has change the moment you put in that product purity constraint. Because, now we cannot take out, because now all of A and all of B must be reacted on it; if it is not getting reacted away, you have some excess that bound to build up. So, that makes sense, so here the component inventory is behaving like a level, the component inventory is non self regulatory.

If it is non self regulatory, the control system must regulate it, how is it done that is being done by that composition controller, yes or no, just like in the tank the level is not self regulatory; so you control, you must regulator the control system, must regulate the level, so you put in a level control. Component inventory is non self regulatory, why it must be regulated that? It must be control, if control system is not doing that, you see you put in control system in that, it bound to take, and it is failing because of, because of what yah. So, it essentially violating overall material balance you are setting things independently, which you cannot just like in the tank setting two flows, it cannot be done right.

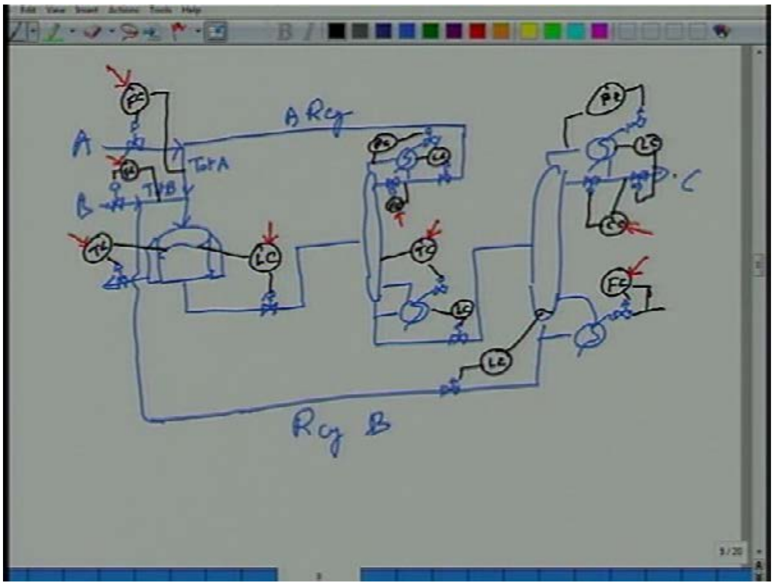
Similarly, for this process fresh A and fresh B cannot be set independently, if you are only taking out C from the process, this you done something, so this is material, this is essential material balance. So, your control system must respect over all material balance, all right may be you should have some example. Now, let move to another example and by the way, the other point I want make was degrees of freedom, what are reasonable ways of specifying those degrees of freedom is dictated by the process, hopefully dictated the moment.

Also, what are reasonable values for those six degrees the moment you bring the economic operation, you care of level max, reactor temperature max, column temperature product purity, one degree of freedom goes for through put 4, what else is it let composition. If there is no side reaction, it has to be such that A and B are compatible fixed, the only thing that was reflux, where it set the values some value, so that some reasonable value. So, the moment you start thinking of how do I operate this process well? You left nothing yes, as you know you started as so much of degree of freedom, what is what are production objective of the plan? But that look these are reasonable variables, degrees of freedom these are un reasonable variable.

If you define F A and F B together, independently is un reasonable and so on, so forth. Of course, and then the moment you decide, how my maximize the operator by minimizing energy consumption, the how do I minimize the energy consumption by maximizing conversion, how do maximize conversion maximum level, maximum temperature, maximum concentration or comparable concentration of A and B criteria right, that takes care of three four component purity take care of 5 only thing you left. So, degree of freedom is a essentially a colleagues we think that we free to do, but when you start thinking the appropriate think to do, you are not free to do whatever you want that, there are thing that are appropriate everything is in appropriate, you not free you see what I am saying, freedom is actually a very colleagues conflux right, not only in control system design in life also.

So, now, let us look at different example, where probably we do not have a composition because the process is of example. So, let say A plus B goes to C, for some reason let us say C is intermediate boiling, you see a C is heavier than A, but lighter than B. So, now, you need two columns right, the process will start new columns.

(Refer Slide Time: 34:43)



So, now let us take two columns then so, here is my C S T R, I am putting in A putting in B of course, I have some cooling for with renewal A plus B goes to C, I am not writing it. What comes out in A B C mixture? That mixture is so let take out the A first, and then the B. So, we take out the A first, we could also take out the B first, then the A, but let say the program design get this way, may be A is (( )). So, you have to take it first or it corrosive it, so you want to take out first it bound whatever may be the reason. So, that is the A recycle, B is the heaviest, so C will go up the top, B will go down the bottom, and it is also recycle. So, how do you recycle it.

So, how the recycle for some drawing, let say A this is fresh B this is open, A and this is open, B fresh A plus B recycle yah, this is recycle B. Now, tell about the degree of freedom of this process, steady state operating degree of freedom all right. So, this is the process its degree the steady state of operating degree 8, 2 for the fresh A, 2 for the reactor, 2 for 2 each for 2 column, so 4 plus 4, 8. Again I want to produce like a 99 percent pure C or 99.9 pure C. So, if you start drawing once, so there is fresh A, there is fresh B, there is also cooling duty that you have in reactor, there is a discharge, there is discharge there are all this charge which familiar.

Now, you want put in place control system for this process, which respect over all material balance that is fundamental, respecting over all and local material energy balance is the control system must respect that. Impact, that should be design to maintain in the overall material and energy balances all right. So now, one want to do is well let us see, what the point that I want to make, ok, two things: why is the lightest component? Yeah, if A leads down the bottom of the first column, where will it go for second column, it go in the product right. So, you have to ensure that A does not lead down the bottom of the first column, because if it does, it is down to contaminate my product, this is just by the nature of the process, ok, all right.

So, I must have this, no I should use some other, some other colors what was I using black, red, or whatever this must be there, because this prevent A from leaking from the bottoms, yes or no. This has to be there an equal to real time all right, as for the rest of the control while, lets me just draw what comes to my head, and then I explain whatever the to do while, I am doing of course, temperature controlling for the reactor power.

You will have fresher control, level control, product purity must also be control, right because it granting, so may you have a composition controller that sets the reflux, you have a flow controller on this stream, and you have a level controller that goes like this. Similarly, you have a controller that goes like this, what else now, how do you mange A and B? Let us say putting in some amount in reflux flow control, level control and of course, fresher control, this is also standard stuff right, now how do you mange A and B?

Notice that, let us say I am putting let do what you do earlier, now the flow control fresh A and the flow control the fresh B, not the total B, but the fresh B. So, what are a set points that I am setting 1, 2, 3, 4, 5, 6, 7 and 8. So, these are the 8 set points for the steady state of the degree of freedom for this control system yes or no, does this suffer from that hypsometric balancing of fresh field problem, yes, no, yah we are setting a two fresh fields.

Hypsometric is still the same a 1 mole of A reaction, 1 mole of B to give 1 mole of C, there is you know and you are setting two fresh fields independently. So, there is a status balancing problem yah. So, so what, if there is let say I am putting too much, what will happen? Putting in some amount of B and I am putting more A more than necessary A, what will happen? Of course, that is true, but what will happen, how will I know that I am putting it more than A? That is the question.

How will I know, but I am putting I am taking out now, I am looking process whether I am putting more than B by looking at the composition? In this process we cannot put more A than B, but steam is to control the pressure. So, there is something the from fundamentally different, what is the column number one doing? No, what is the column number one doing? Separating A and B yah. You cannot put in when will the extra will go? It go to the top, it go the top why. So, what will happen to the level of the top, I will start building up, level controller will start opening the wall of the recycle history.

And the recycle A flow will increase, yes or no. If the recycle A flow is increasing, total A will increase, because fresh A fixed, if fresh A fixed, in fact amount of fresh A that I am putting more than amount of fresh B, put in slowly. But, surely recycle a stream will go up, yes or no. Now, in this case process itself is separating A and B separately, A is how to do I find, how do I figure out? Whether A is building up the process or not by looking at the recycle fluoride, but looking at the recycle fluoride and putting it too much A recycle fluoride is going down, and putting in to little late right A. So, what do we do?

Instead of controlling fresh A yah recycle A or total A same thing, total a because it reflect immediately, recycle A have to flow and then come back; you see if I am controlling total A the moment I change the A fluoride, total A fluoride changes immediately, if am doing it like this. Now, this is the dynamic consideration this fluoride has gone up, recycle fluoride has gone up, I change the amount of A, where this flow will not recycle fluoride will not get effected immediately, will go to the reactor then the level here will build up, and then this flow this will be a very slow loop, conceptually this is also work; however, this loop will be very slow, that’s because the effect takes the long time to pass the reactor and then the column.

So, this will be slow loop, I do not want like slow loops, if I can help it, can I help it plus instead of controlling recycle fluoride, I control the total fluoride; this loop will be fast I change the fresh fluoride, total fluoride immediately changes, yes or no. I can do the same thing what? I can do the same thing, this way with the B any one of these two set points can be used as a through put manipulator, if there are no side reaction, what are we talk about for the three for the previous case also hold, temperature should be max; level should be max.

This temperature set point what should it be? So, that it is governed by the impurity in the B right, similarly this composition set points is again governed by the impurity in C and so on, so forth, its 950 to 53 I think, but I do not want to hold you that long. But the point is in this process I will putting in too much is the process itself said that because it will be a A B separation, A separated out separately B separated out separately. So, you how much A is there? And how much B is there? Therefore, you do not need A composition analyzer here, the recycle flow and telling you putting in too much A and two much B yah. And since, just like in the tank force this, if there is a mismatch level build up and then level control, if there is a mismatch, total A will increase then control the total A and total B as simple that, ok, will continue next time.