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

Lecture - 23
Degrees of Freedom Analysis

Good morning everybody and welcome. Today we are going to talk about Degrees of Freedom.

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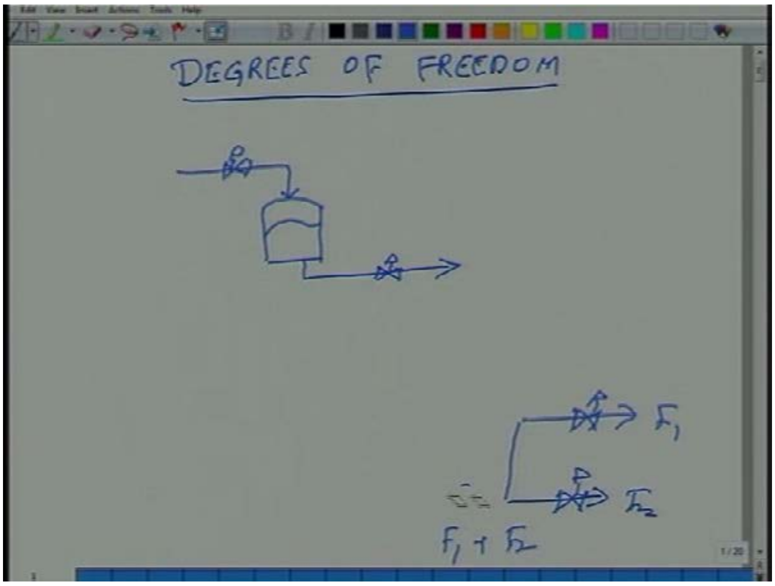

It is one of the most fundamental concepts in any subject actually, degrees of freedom. what do we mean by degrees of freedom, as the word suggests what are you free to change, what are you free to set. So, in a process, you would be used to for example, counting the number of equations or number of variables and subtracting the number of equations, what is left that is, what you understand by degrees of freedom.

When you want to control a process and let us say, you are not that mathematically inclined or you are not an expert at modeling. You still need to know, what the degrees of freedom of the process is for example, an operator of a process must know what is he free to adjust. So, he has an understanding of what degrees of freedom or even though he does not know the exact model for distillation column or a CSTR or a plug flow reactor or whatever else.

So, what we are going to try here is, come up with the very simple way of figuring out what the degrees of freedom for a chemical process is... And let us just start with for example a simple tank, it is a search tank, you got a feed coming in, you got a feed you know you got a you got an outlet stream, an inlet stream and an outlet stream. How many independent valves can you put in? 1, 2, 3, 4; how many independent valves, can you put in. (( ))

No, I am not talking degrees of freedom, we will come to degrees of freedom later, how many independent valves are there for this simple process one feed in, one feed out. How many valves will be there? Two valves, one at the inlet, one at the outlet right. Let us say, I have got a t junction, let us say I have got a I have got a simple pipe, how many valves can I put on this pipe. (( ))

How many of them are independent? there is only one independent valve, is that clear to you, you can put as many valve as you want but you see you can only set one flow, you are only adjusting one flow. Now, let us say, I have got a t junction, how many independent valves can we put on this, let me put it differently let us say let us say, I have got a tank, two is correct there are inlet streams, we are not worried about inlet streams let us say, I take an outlet stream.

And I split it into two, one is feeding you know stream 1 is feeding at process strain, stream 2 is feeding another process strain. How many independent valves can I put on the outlet side? Only two right because incompressibility dictates that for example, let us say, I put here then the flow here, this flow F total must be equal to F 1 plus F 2 right.

That is, the requirement of incompressibility, incompressible flow yes or no so first of all you need to know, how many independent, how to put in independent valves, the idea of how many flows are independent, once that is clear to you, we can look at degrees of freedom. So, if I take this simple tank process, I have got two independent valves, one at the inlet, one at the outlet. There is another way of saying, I have got two independent flows, the inlet flow and the outlet flow.

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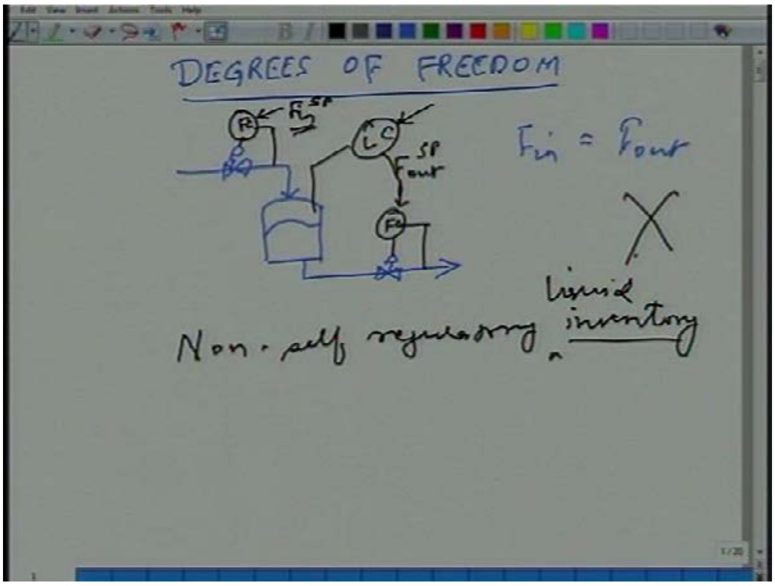

If I look at the steady state material balance around this tank, I know that flow in must be equal to flow out. What that means is, of these two independent valves, of these two independent flows, there is you know two independent valves only one can be set, only one flow can be set independently. The other flow for steady operation must equal you know you know you know whatever flow you have set, so only one of these flows can be set, the other one must match whatever has been set yes or no.

Yes.

Once that is clear clearly, if I put in a flow controller, maybe I should put in controller in a different, if I put in a flow controller and I have two set points, set point for the outflow, set point for the inflow. So, F out set point F in if I implement, this scheme is guaranteed to fail why is it guaranteed to fail? Because even though, if you put in these set points to be equal the sensors are never exact.

So the inflow may be 100.1 kilograms per hours and the actual outflow may be 99.9 kilograms per hour even though, the set points for both the even though even though, both the flow set points are the same yes or no.

Come here.

So, this is guaranteed to fail in the sense that, either inflow is more than outflow, no matter how small the difference or outflow is more than inflow, no matter how small the difference. So, what that means, is the tank level, which is the inventory of the liquid contained in the tank is either going up or going down, depending on the mismatch. So, this is not acceptable this is not acceptable and this is also brings the concept of non-self regulatory inventory, inventory means here, we are talking about liquid inventory.

So, the level in a tank is an indication of the liquid inventory inside the tank so inventory is by their very nature, unless they are matched, either things are building up or depleting. Inventories are either building up or depleting, unless it is ensured that, in and outflows are matched, is that clear. So, what that essentially means is that, we will have to have a level controller and that level controller may be this way and it sets this set point alternatively.

And then what we have is, the flow in set point sets the flow through the process, flow through the tank. So, F in is the throughput, is called the throughput what is flowing through the unit that is, the throughput through the unit and then you have got a level controller. Now, for a given throughput, is the operator free to adjust anything let me rephrase the question, if this is given to you for example, your manager asks you have to process so much of feed through this tank.

Manager has told you this is what, it is so it is given to you, to run this tank, does the operator have anything that he can adjust, What can he adjust, The most he can do is, he can adjust the set point of the level controller. Does that have any influence on the steady state flows, so really speaking operation operator has for a given throughput no degree of freedom.

So, what have we, for this simple, for this very simple example what have we learnt? What we have learnt is well liquid inventories are non-self regulatory therefore, they must be controlled. Because if you do not control it, it is either building up, levels are either building up or depleting that is, point number 1. Once you put in that level controller, for a given throughput, whatever you know, so there is there is two independent valves, if one of the flows is given, one valve is left but that is under level control or inventory control.

Now, the operator has got nothing left to adjust so what is the degree of freedom as far as the operator is concerned, running this process is actually zero, it is a very simple process.

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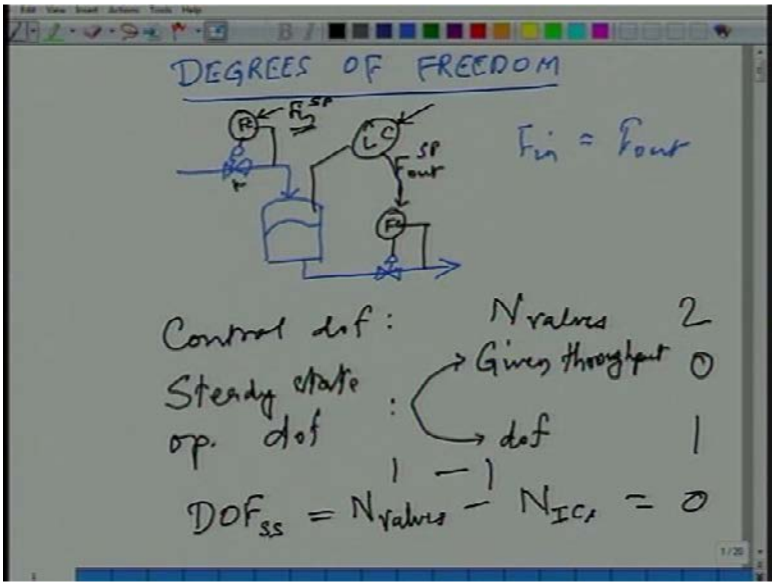

So now, we come to, what is called controlled degrees of freedom, what is controlled degrees of freedom? Controlled degrees of freedom is number of valves, number of independent valves. How many valves are there in the process, that can be adjusted then there is so what is the controlled degrees of freedom for this process, 2 for this simple example, it is 2.

What is the, what should I call it, steady state degree of freedom, steady state operating degree of freedom, for this process there are 2 scenarios, one is, one scenario I just presented to you. Your boss is telling, you have to process so much, so then the inflow is not in your hand, it is set for you, it is given to you. For a given throughput, the degrees of freedom of this is 0, if throughput itself is in your hands then the operator can adjust the flow in set point and then the flow through the process is whatever it is and the operator is free to choose it.

In most situations, the given throughput scenario is, what is relevant because somebody from up there, tells you production should be this, because our estimate of the market demand is this. Therefore, the production should be this so the production is actually so the throughout is actually given to you, that is the most common situation. Other times what happens is for example, this inlet flow controller, this may be the, it’s flow must may be set by the level controller for an upstream tank.

Do you see what I am saying So, some unit upstream is setting this flow, yes or no some unit upstream is setting this flow so either your boss is telling what the throughput should be or some unit upstream is setting the flow. So, most common throughput is not in your hands, it is either said by an upstream unit or it is told to you that you're supposed to process so much so the most common scenario is given throughput.

And if I am not specifically mentioning that, through put is given or not then assume that throughput is given, by default throughput is given. Given throughput, the other is that, it is actually a degree of freedom, you are free to choose what the throughput should be then it is a degree of freedom. Does that makes sense to you? Yes or no? So, for the given throughput scenario, for this simple tank process, the degrees of freedom is what? 0 through put is given, outflow must be under level control that is it, you are done, yes or no.

If it is a degree of freedom then the operator can set what the throughput is, he has that degree of freedom, degree of freedom is 1, does that makes sense yes or no We took a very simple example, no equations no nothing now, will take this, what comes out of this is, if I am looking at a given throughput scenario, I take the feed valve out because that is feed to the unit, I take the feed valve out because that is given, that flow is given to me.

I called I count total number of independent valves and when I say, N valves this is actually excluding the feed valve, if I am excluding the feed valve that means, the throughput is given to me. So, I called I calculate N valves minus number of invent number of, I will call them inventory controllers, IC'S. Level is level is a sign is a sign of is an indicator of liquid inventory, you could also have component inventories, you could have gas inventories, what is the sign of gas inventory? Pressure.

Pressure is increasing that means, the gas held up in the unit is increasing so there are different kinds of inventories, you know the inventories you could have, how many cars are there in your store house or in your whatever, parking lot in a dealership that is, the inventory of cars right. So, inventory is a general term, it could be liquid, it could be components, it could be gas, it could be number of things in my shelf or in my storehouse or in my shed or whatever, inventory could be of anything.

So, I have number of valves or number of controlled degrees of freedom minus number of inventory controllers, that gives me my degree of freedom steady state, For steady operation of the process, I have put in independent valves excluding the feet, count them so N valves excluding the feed is actually one. How many inventory controllers are there? Minus 1, that gives you what? 0 so degree of freedom of this tank, steady state operating degrees of freedom of this process is what? 0.

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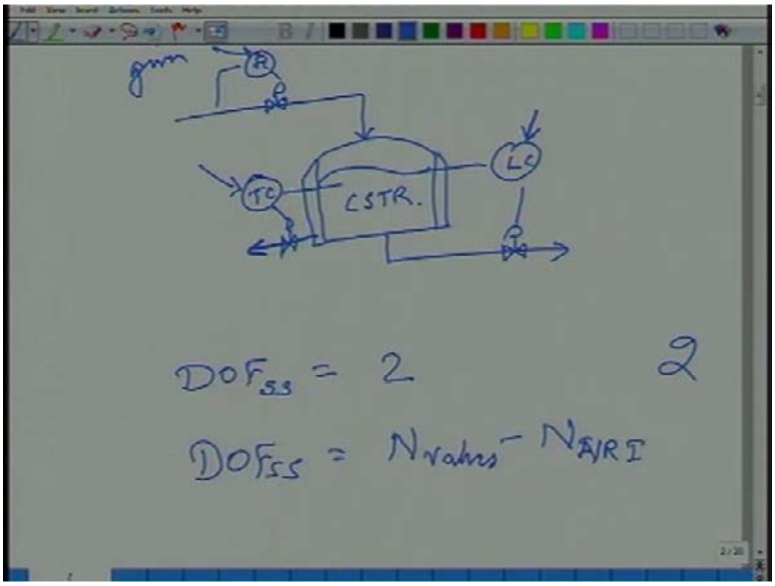

Now let us let us take this approach further let us see, we have got let us say, I have got a CSTR continuous tank reactor. It is still a tank but now, there is reaction occurring in the tank, liquid phase reaction so pressure is will not involve pressure here. So, there is feed that is coming in, there is a stream that is going out so this is CSTR, it is a CSTR. Some reaction is going on inside and you are taking out reaction heat by cooling in the jacket, so this stream is denoting cooling, the jacket stream this guy this guy is denoting cooling.

How many independent valves? 1, 2, 3 DOF steady state, how many do I have to put in a level controller do I have to put in a level controller? Yes or no? Will the level in the CSTR liquid level, in the CSTR regulate itself, is itself regulatory? I have to control it, right. If in is not equal to out, kilograms in minus kilograms out is not equal well either the level is building up or it is deputing so I have to put in a lever controller.

So, let us just say, I have so number of valves excluding the feed or excluding throughput is two, how many level controllers do I need to put? 1. So, let us say, I have put in a level controller that is that is, like this. Now, I ask you a question, in the tank, if I change the level set point, did it make a difference to the steady state solution. If I looked at the tank, if I made a change to this level set point, did it make a difference to the steady state solution flows, flows in flow out yes or no it will make a damn difference right.

Here, when I make a change in this level set point, does it make a difference to the steady state solution, what happens to the resistance time, let us say, you are operating at a 50 percent level or procedure operating at 80 percent level, your resistance time changes so conversion changes so what is going out changes, the steady state is affected by it yes or no.

So, since the steady state is affected by it, when the operator changes this set point, he is free to change this set point to get something, to change the conversion of the reactor or may be to improve the selectivity or whatever. This is something that, the operator can change and as he changes, the steady state will get affected, yes or no.

What would you do with the cooling duty, you will typically put a temperature controller right so given so throughput is given so this is given, this is not in your hands. So, there were two valves and the set point or and whatever is the cooling rate and whatever is the level so these two set points affect the set affect the steady state solution. So, actually the steady state operating degrees of freedom of this CSTR is actually what? 2.

Our rule that we took out is actually broken, why did it get broken? In the previous case, if the inventory was non-reactive, it would not have affected the solution, the steady state solution so we had to discount that valve. Here, the inventory is reactive. So you have to count that valve because how much amount of inventory you have, is affecting your steady state whether you are operating that that reactor at 10 percent level or 90 percent level, is affecting the conversion that you are getting, yes or no.

So, we need some sort of a modification to the rule, modification to the rule is essentially degree of freedom steady state is equal to number of independent valves excluding the throughput, minus number of in number of non-reactive inventories here, the inventory is reactive. So, how much you have in there must be counted so earlier I had said number of valves minus number of inventories. Now, we are modifying it, number of valves minus number of non-reactive inventories does this make sense alright.

And let us come to something slightly more interesting let us say, I take a distillation column, a simple distillation column.

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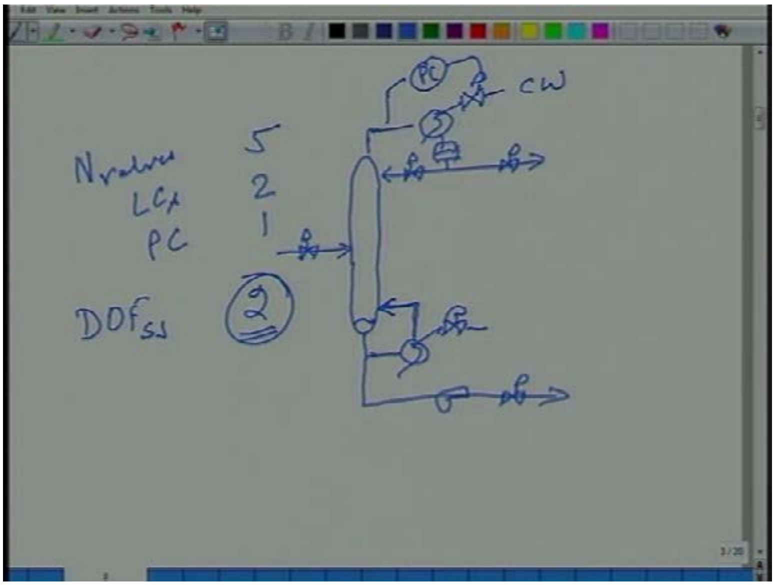

So, here is a simple distillation column, I have got a feed of course, it has a valve however, I am not going to count it because this feed is being set by an upstream process, it is not in my hands. Vapour, condenser, reflex drum, reflex distillates, there is liquid that accumulates at the bottom, I have put in some steam sorry before, I start asking you questions, I want you to know that, this is the distillation column right.

Now, how does the reboiler work typically, it is a thermosyphen reboiler what is a thermosyphen effect? It is actually reboiler is hot, the bottom sump is slightly colder and because of, whatever convective effects, the liquid actually flows like this, automatically. So, there is no pump here, to make the liquid flow, you see this out whenever, I show a valve that means, there is a pump that is, driving the flow and the valve can be adjusted to get whatever flow you want.

But, at the bottom of the distillation column you do not have any pump, what you have is, from the bottom sump liquid is flowing out by gravity, part of it goes to the reboiler and because the reboiler is hot, you know it, there is a driving force that, sucks in liquid. This is called the thermosyphen effect, thermo you know the syphen effect, thermosyphen because temperature temperature gradient is creating the syphen effect because the reboiler is hotter than the bottom of this of the column so this flow is by gravity.

What is coming out here is vapor of course, you got to draw more or less you got a pump here and of course a valve here, and of course, you got a pump here, which I am not showing, you have got a valve here and you have got a valve here. You also have in your hands, how much steam you are putting into the reboiler, you also have let us say, cooling water, how much cooling water you are putting into the condenser to condense the vapor that is, coming up the top.

I am not showing a valve here or maybe I can show it and then rub it and I am not showing a valve here why? Because it creates unnecessary pressure drop that is, the basic reason. It creates unnecessary pressure drop then the reboiler you see there is some pressure work, a control valve will always have a large pressure drop. Why is that in the case? In any line, if you want to control the flow, whatever you are moving that, will have to be have a large that will have to have large resistance, it has to be the controlling resistance.

If it is the controlling resistance, pressure drop across that piece of valve will has to be large do you see what I am saying, otherwise you can move the valve, flow will not get affected because it is not the controlling resistance, does that make sense or no. So, you do not put a control valve there. Of course, you will have a valve, which is fully open or fully, know a kind of a gate valve or a or a or a probably a gate valve, which is basically fully open or closed, that valve will be there but it is not a control valve, do you see what I am saying.

Because, control valve will create large pressure drop, large pressure drop means, you know your reboiler is unnecessarily hotter because at a higher pressure you will have to operate the reboiler at a higher pressure. At a higher pressure for the same liquid, it will boil at a higher temperature, water boils at 100 degree Celsius at 1 atmosphere but if the pressure is 5 atmospheres, the temperature will be 130, 140 degree Celsius yes or no.

So, I do not want to unnecessarily jack up the temperature of my reboiler right so there is no control valve here, for similar reasons there is no control valve here too. And in fact, you can imagine, you see this is vapor, vapor lines are what, vapor is so much less denser than liquid, try putting a valve on a vapor line. (( ))

No, it is not a question of condense, the vapor line will be so big because vapor is less dense and therefore, it requires a greater area otherwise, a velocity will be you know too high, do you see what I am saying?

For reasonable pressure drops, your pipe will have to have large dia to accommodate low density vapor, kilograms per hour may be the same. However, it requires a large, just try putting a valve there and try moving it, either the valve will be expensive like hell, it creates unnecessary pressure drops right and moving it will take ages. You got a pipe that is this thick and there is a valve on it and then you are trying to move it, just does not make sense.

So, there is no valve here, does that make sense or no so now how many, excluding the feed or excluding the throughput, how many valves do we have? N valves 5, how many levels do I need to control, is there a pressure that I need to control, I also have vapor inventory, you see I am boiling vapor so there is vapor that is, stuck inside the column. What if I am boiling more than I am condensing in the condenser, what will happen to the pressure? It will increase right, so I need to control the pressure also.

What is the most obvious way of controlling the pressure? I will put a pressure controller, if the pressure is increasing condense more then the vapor will be killed or the vapor will be condensed and the pressure will drop down. Alternatively, if the pressure is decreasing, condense less and the pressure will be, where it is, does this make sense or no. So, you will have to have a pressure controller so two level two liquid inventory controllers, one gas inventory vapor inventory controller.

So, how many inventory controllers? PC 1, total 3 degrees of freedom will be what, now, if you think about it and you would have done this in your courses. If you are not getting the desired separation that means, let us say that the distillators getting too much of the heavy key up, too much of heavy key impurity in the distillate or too much of light key impurity in the in the bottoms, what will the operator do? If there is too much light key that is, dropping down the bottoms, he will increase the steam.

So that, whatever is, whatever light component was dropping out the bottom, which it should not be, is sent up. If there is too much heavy key that is coming out the distillate, what will the operator do? Reflux more. So, what are the two degrees of freedom, reflux and reboil essentially and this comes out in your (( )) analysis etcetera, etcetera reflux ratio, reboil ratio etcetera, etcetera you would have seen in, you know. So, the two things that the operator has in his hands is, essentially the reflux and the reboil.

Usually that is the case, in some unusual circumstances, you he may he may do, he may adjust the reflux or reboil indirectly by adjusting the distillate rate or the bottoms rate or some such combination. Those combinations are also possible but basically he is got two things in his hand, how much he is putting back into the, how much liquid being is being put into the column and how much vapor is being put into the column that is, your two.

By the way, none of the inventories are reactive yes or no, none of the inventories are reactive therefore, they have to be discounted so I hope this very simple procedure is clear to you.

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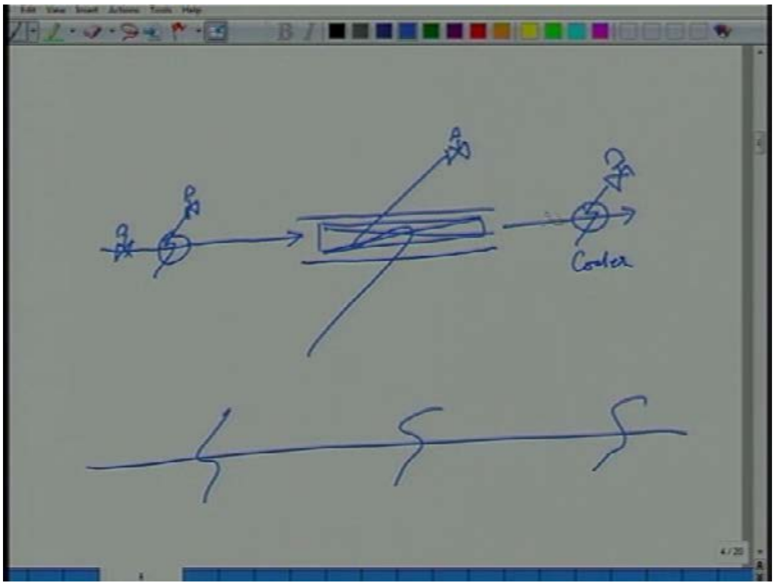

Now, let us take for example, may be let us take a plug four reactor, I do not know how to cook it up and exothermic reaction is going on in there and there is some mechanism, by which you are removing heat. What is that mechanism, there are n number of mechanisms or n number of designs for different applications, how you remove heat. But the heat is being removed, reaction heat is being removed, it is a cooled exothermic pact bed reactor so maybe it is a packed bed two.

There is some catalyst in there, the feed is compressed let us say, it is a gas phase reaction sent to the reactor, it is heated. This is a heater that heats the feed to the reaction temperature, there is a cooling, reaction heat is removed using the cooler. And what is coming out is actually, I do not know condensed let us say, it is condensed so this is a cooler that liquefies the vapor.

Let us just say, this is the process let us let us not worry about the co compressor so there is some feed that is coming in, it is heated, reaction heat is removed and there is a cooler that, condenses the hot reaction effluent. Degrees of freedom, independent valve first of all, can I put a valve here? yes no I will put it but then it set by a by a something up stream or I am told that, this is the amount of heat.

So, the valve is there but I do not count it, fair enough, do I need to put a valve here cooling heating duty? (( )) Do I need to put a valve here cooling duty in the reactor? (( )) Do I need to put a valve here? Can I put a valve here?

Why? Why? (( )) What is the...what is the plug...what is the...what is the plug...plug flow reactor? (( )) It is essentially a straight tube.

So, once you set the flow through the tube at one location, you cannot set it at another location, this is essentially a single straight tube. You are putting in heat here, removing heat here again removing heat here all that is fine. But there is no hold up, do you see what I am saying this is essentially flow through a tube, heat exchanger is also nothing but a tube.

Material is just flowing through the tubes, heater is also nothing you know, whether it is a furnace or a do you see what I am saying there is no hold up. What you are having is, flow through a straight tube therefore, you cannot put a valve here once, you put a valve here you cannot put you cannot put it here, does that make sense or no.

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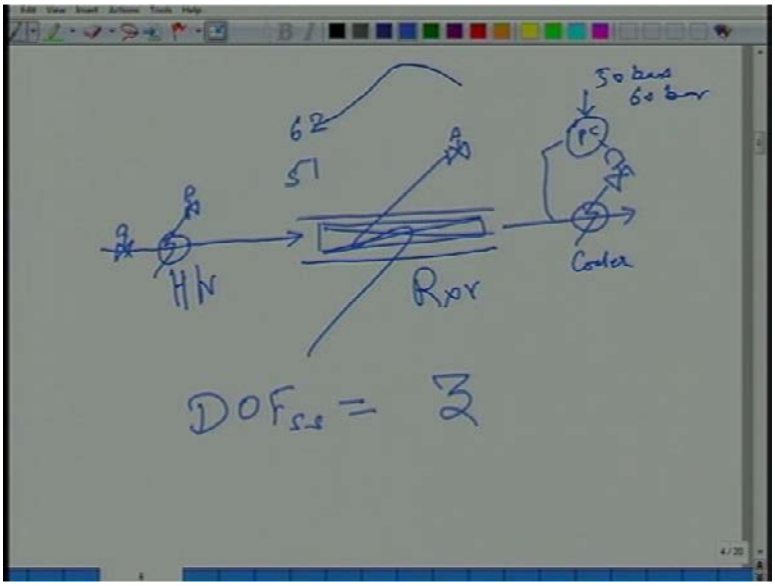

So, this is the reactor, this is the heater, that is the cooler so you can set the flow through this train only at one place. Because it is essentially a pipe and there are no drums or surge drums or you know large hold up's anywhere, is essentially flow through pipe. So, you cannot put a valve here similarly, you cannot put a valve here, either etcetera, etcetera. So, feed valve is discounted because through put is given, total number of valves is then 1, 2, 3.

Degrees of freedom how much, what would be the degrees of freedom now, you tell me DOF's steady state, it will be actually 3. What are those three degrees of freedom, what is the inlet temperature, outlet temperature or how much heat you are removing, you know heat you know outlet temperature or may be the reactor will have a hotspot temperature. What is that hotspot temperature because the hotspot temperature will set the cooling rate required in the heat removal rate inside the reactor, what about this cooler, what will this cooler do?

Condensing.

Yeah, it is condensing so how will you decide whether I need to condense more or less, what did you do in the distillation column. If the pressure is going up, condense more if the pressure is going down, condense less, same thing here. Now, pressure controller is an inventory controller basically, how much vapor or gas is stuck inside my reactor system right. If the pressure is increasing, more gas is stuck if pressure is decreasing, less gas is stuck.

So, it is essentially an indicator of vapor inventory, I am however counting it why, I am not discounting it because if the pressure set point is increased, what happens to the reaction rate inside the plug flow reactor? It will increase usually, it will increase. If I decrease this pressure set point, reaction rates will go down, because reaction is proportional to partial pressures, higher the pressure right.

So, in that sense, the degree even though, this is an inventory controller, this inventory must be counted because it is a reactive inventory. It is not a non reactive inventory, does this make sense or no, yes. (( ))

No, but you see whatever is the pressure here, is the pressure in the reactor, yes or no. If this pressure if this pressure is increasing except for the pressure drop across the reactor, this pressure is also increasing right. So, if I if this pressure set point is 50 bars for example, and I make it 60 bars, I guarantee you the pressure inside the reactor is also gone up, safe for the pressure drop through the reactor.

So, may be this was it 51 bar and then pressure drop across the reactor was one bar but then when I have increased this to 60, this may be, I do not know may be, 62 bars or 61bars something like that. So, the moment I change this pressure set point, the pressure inside the reactor also changes, reaction rate changes, what is coming out of the reactor the steady state changes so it is a degree of freedom right yes or no.

Therefore, it has to be counted or rather not discounted, I can complicate it a little bit more, but now, let me let me get to economics if you are running this reactor would you like to run it at a low pressure. (( )) Why? (( ))

Low conversion, reaction rates would be smaller so once the reactor is designed and it is designed to operate at a maximum pressure of, I do not know let us say, x bars. You would typically operate at x bars, do you see what I am saying because that is what gives you the maximum conversion, yes or no. So, I am counting it as a degree of freedom but in practice the reactor is operated or gas phase reactors are operated at their high, the highest possible designed pressure, do you see what I am saying.

Similarly, if I go back to my CSTR example, in the CSTR we said that, the level inside the reactor affects the conversion. If I am operating at the low level, conversion will be lower if I am operating at a higher level, conversion will be higher. Similar to the plug flow reactor or the packed bed reactor, gas phased packed bed reactor, I would always operate the CSTR at maximum possible level let us say, 80 percent. Because beyond 80 percent, alarm goes off and you have to take some safety precautions etcetera, etcetera; let us say, 80 percent.

I will always operate at 80 percent, do you see what I am saying however, it is important to realize, I am counting it because it is important to realize that, changing that affects the steady state solution. In practice, I am always operating at the maximum level, I am always operating a gas phase reactor at maximum pressure. However, from a steady state point of view, it is important to realize that, the pressure, operating pressure and the operating level of a reactive volume, of a reactive inventory affects the steady state therefore, I am counting it.

But, when I am running the process, I will always choose the value of this and that, to be maximum allowable because that gives me the maximum conversion. What does that do? It reduces the separation low downstream, there will be lesser unreacted reactants to be recycled that, cost goes down. So, in practice, you will find that, there are always very reasonable values for the different degrees of freedom that there are, that you have. But first things first thing you need to realize, how many things am I free to set, next thing is what is the best setting?

Now, what I am telling you is the best setting for the level set point or the pressure set point in a CSTR or the pack bed reactor, a gas faced pack bed reactor respectively, you see what I am saying. So, first I know that, this is my degrees of freedom, I am free to set this this and this, the next is, how do I set it, what value should I set it, that is a separate question. But in terms of degrees of freedom, degrees of freedom in a CSTR is the way I have drawn, it is 2, degrees of freedom pack bed reactor system, the way I drew it was 3 alright. Now, let us take a process, let us take a complete process and we will probably take the simplest 3 is also drawn, 4 is also drawn, 5.

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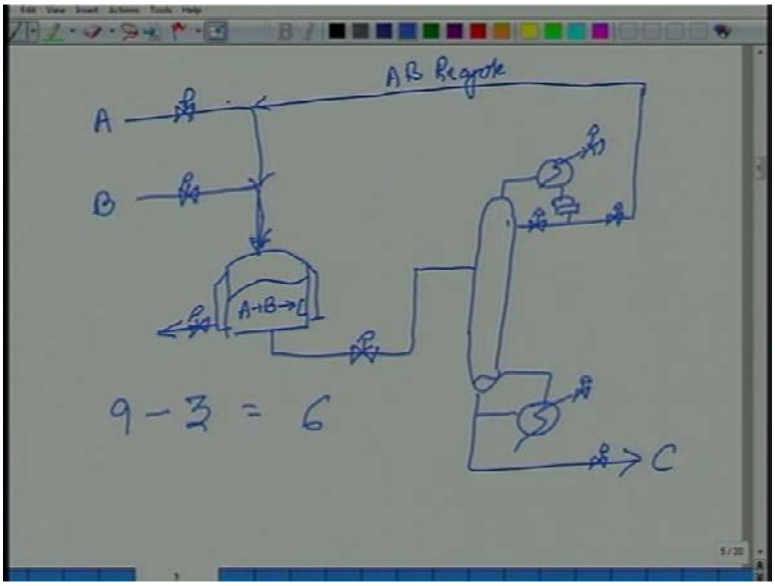

Let us take a simple, I do not know A plus B goes to C type of process so here is a CSTR, I do not know A plus B goes to C, this is the reaction that is occurring inside the CSTR. You are putting in fresh A, you also putting in fresh B, so let us say, you are putting in fresh A, you are putting in fresh B, reactor affluent is distilled in a distillation column, simple distillation column. A and B will typically be obviously because the molecular weight of C is the molecular weight of A plus molecular weight of B, C will be the heavy component right.

So, A and B will go up C will go down, yes or no so I have got this the reflex drum, A and B come up the top because A and B are freshest raw materials, I do not want to dispose them. So, I am recycling them right and C comes down the bottom so this is nearly pure C product and this is essentially AB recycle. This is my process now, first of all, draw me independent valves next, tell me the degrees of freedom. Here, throughput let us say, is counted what is the production rate of C that you want, is in your hands.

Tell me the degrees of freedom, first of all valves, will there be a valve here. (( )) So, there is a valve here, will there be a valve here? (( )) Will there be a valve here, while distillation column, you all know how it was drawn so you can just copy paste. Will there be a valve here? No. Will there be a valve here? (( ))

Exactly because this flow is set, this flow is set, this flow is set, and this has to be this plus this and this has to be this plus this alright. So, these are the valves, how many total valves 1, 2, just a second let us say, it is an exothermic reaction and I am removing some heat usually, reactions are exothermic, some of them are endothermic too so how many valves 1 2 3 4, 4 plus 5, 9.

If I count all 9 that means, throughput is a degree of freedom and I am counting throughput as a degree of freedom, my production rate of C, so many kilo moles per hour or so many kilograms per hour I am saying, that is also counted. So, 9 valves, how many non-reactive inventories, non-reactive inventories 2 levels 1 pressure, degrees of freedom 6. What are those 6 degrees of freedom, 2 for the column reflux reboil, 2 for the temperature and level, and 2 for the two fresh feeds, does that make sense or no. (( ))

Two levels distillation column top, distillation column bottom and pressure of the distillation column, vapor inventory, three. Total valves were 9, 3 of them are going to used for inventory control, vapor inventory, liquid inventory that leaves leaves me with 6. (( ))

Of course, non-reactive, reactive is being counted, that leaves me with 6 so degree of freedom of this process is 6. So, the operator can set 6 things independently to run this process and in those 6 things, the production rate is also one of them. If I exclude the production rate, they are saying that, the production rate is given to me by my boss then the operator can set only 5 things.

What would those 5 things be so let us say, flow rate of A is my throughput, you know that is that is, given I have to process so much of A. What would those five things be what is the temperature of the reactor, what is the level of the reactor, how much reflux you are putting into the column, how much reboil you are putting into column 4 and recycle rate. Recycle rate or maybe you can call it the total B that is, going you know either one of the recycle, any one of the flows in the recycle loop.

Another simple way of counting degrees of freedom is, well 2 for the CSTR, which I know 2 for the column plus as many fresh features there are so 2 plus 2 plus 2, 6 that is, also a another simple way of doing it. You do not have to count the equations, you do not have to count number of independent variables, you just look at the process, put an independent valves, count the valves, discount non-reactive inventories. That is, the degrees of freedom of your process, does that make sense, I think this is a good point to stop today’s lecture.