Chemical Process Control
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Lecture - 33
Selection Problem

Welcome back. So far we have seen that given any piece of equipment how do we go about identifying what the control variables are, what are the manipulated variables and what is the final architecture or structure of the control system. Even though we did not formally see how do we screen, the best alternative out of the all the possible options, a lot of time heuristics are used or you go with what is the prior experience.

And sometimes there are some techniques which we will be looking when we talk about multivariable control. So at the end of this synthesis problem what you have is a number of different controllers and each of those controllers especially within the domain of this particular course, we will have.

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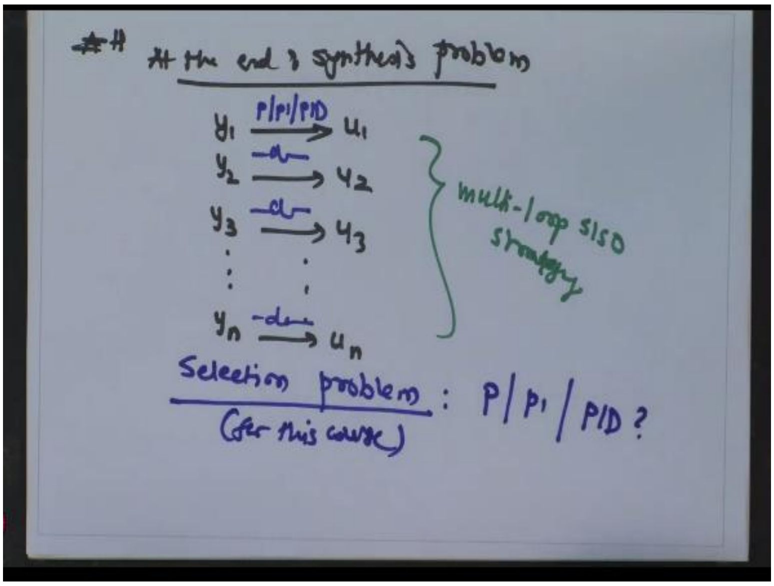

So at the end of this synthesis problem, we have these different controlled variables and then we have mapped them to a particular input. So this is within the context of multi-loop SISO strategy. Now disclaimer is that it is not necessary that this is the best architecture you can go with, lot of time this is what happens at a regulatory level or the bottom level and you would typically have these individual controllers which are implemented at the very base level of a control system.

So once you have all the structure, the next question which we have to ask is what type of controller is this? Is this P, PI or PID? Because again this is the domain or this is where we are going to restrict ourself. If you want to generalize this selection problem, it could be any advanced control strategy, or a linear-nonlinear controller, or an optimization-based controller.

So all those sorts of questions come in in this selection problem. So for this course, we will be dealing with that is P, PI or PID. So in order to answer this particular question, we have to use some rules of thumb and which are based on some analysis which we had already done when we talked about the performance of the PID controller. So let us look at all these PID controllers, and that will help us formulate this rule of thumb strategy.

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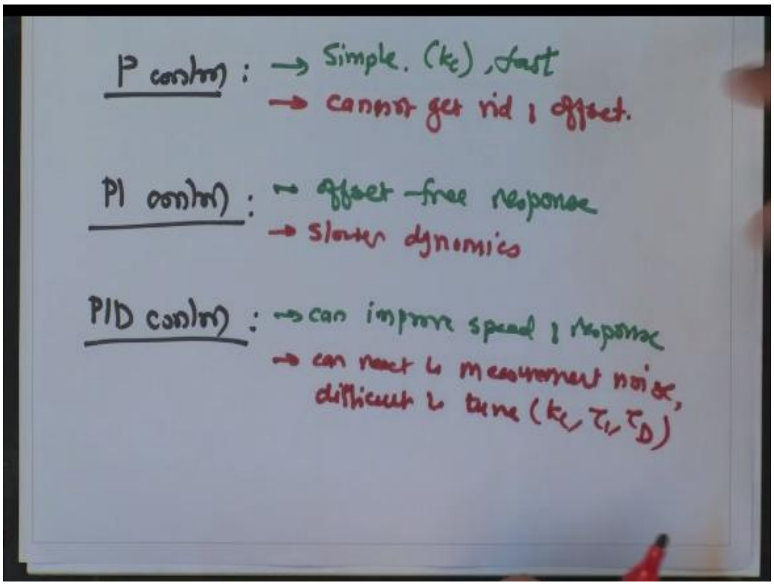

So when we say P control or the proportional control, the main advantage is it's very simple, there is only one variable k_c which you have to decide. It is often very fast and is based on the current error. On the other hand, when we talk about the limitation, it cannot get rid of offset. That is a major limitation of a P controller.

Then, we go to proportional integral control. So the advantage of a PI controller is that you get offset free response, but this comes at the cost of sluggish or slower dynamics. We have seen that a PI controller increases the order of the system, so the response of the system becomes slower or sluggish and then lastly we have looked at the full-blown PID controller, proportional integral derivative control.

The advantage is, it can improve the speed of response and at the same time it has limitations in terms of reaction to measurement noise which is a very key thing. It may destabilize a process and is difficult to tune. This is the last tuning problem that means finding the best value of k_c, τ and τ_D. It is like the controller is having 3 particular angles, 3 different directions in which it has to be optimized.

So it becomes a difficult problem to select the best values of k_c, τ and τ_D. So based on this, the rule of thumb strategy is as far as possible try to use a P controller or a proportional controller, and that means if your offset is acceptable then always you would try to go with a P-type or a proportional controller because it is fast. If the offset is not acceptable, then you have to go with either a PI or PID controller.

So the demarcation between PI and PID is that if the inherent process itself is fast then having an integral action on top of that is going to slow it down but not to a very bad or not to very great extent. So the combined PI effect on a very fast process may still be acceptable and so when offset is undesirable, and the system is fast, you will go with a PI type of a controller. If the inherent system itself is very slow or a multi-capacity process and you want to get offset series points and then having a PI controller will slow it down even further then in order to improve the speed of response, you would go with a PID controller. So we will try to use this rule of thumb to different types of controlled variables which are possible in our chemical engineering plants.

And again a disclaimer is that these are rules of thumb. This is what on an average or majority of the cases how these controllers would be and wherever possible I will try to give you some exceptions as to where this rule does not apply. So we will start with the very commonly used controlled variable that is flow control.

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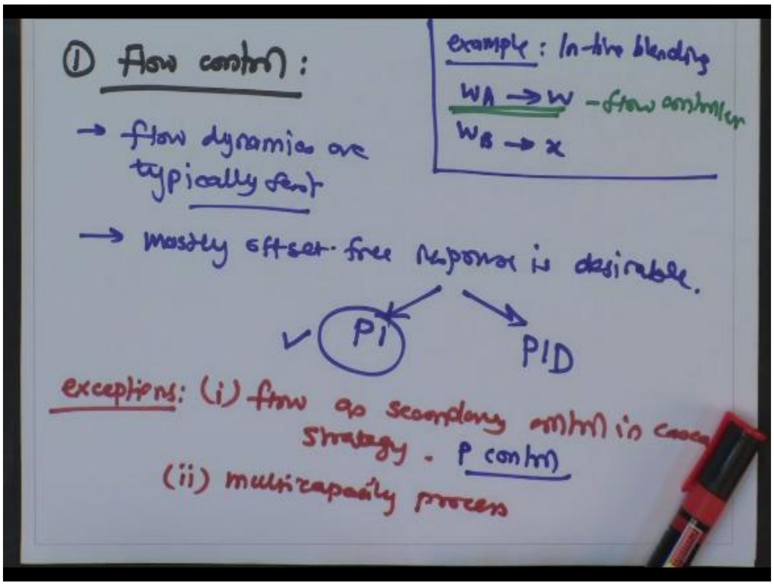

So if you try to recollect the example which we had about the in-line blending. There were 2 options, 2 SISO options. One of those was, controller 1 requires you to control the outlet flow, so this is a flow controller. So if this is the controller which we want to design further then what type of a controller we have to use. So as it turns out, flow dynamics are typically fast, and mostly you want to set a particular flow going to a piece of equipment.

So if it is a raw material flow, you want a certain flow rate going into the system. If it is the product flow, again you want a certain product to be delivered to the customer. So mostly offset free response is desirable. So based on our rule of thumb, when I say offset free response is desirable, it narrows down to 2 types of controllers, PI and PID and as the dynamics are fast, PI becomes the typical choice.

So a lot of times when you see a flow controller in a chemical plant, you will see that it will have a PI controller. Now there are 2 exceptions to this rule. So one is flow as secondary control objective in cascade strategy. Now we have not seen what is the cascade control so far, but it is a control strategy where there are two control loops which are connected together. One is a primary control loop, and other is a secondary control loop.

So when the flow is a part of a secondary control loop, typically offset is not that critical and offset is tolerable, so in such a case as to improve the speed of response, you may have proportional control. On the other hand, sometimes this flow is also part of a multicapacity process. So an example is shown here.

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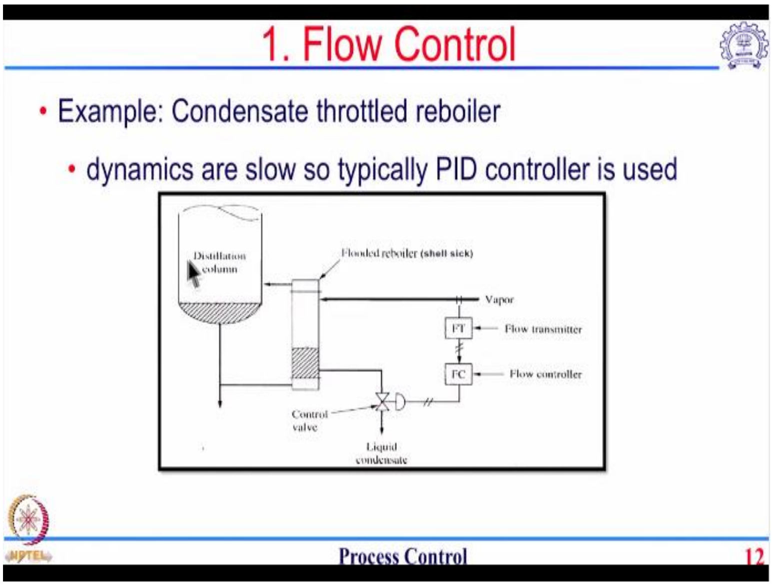

You can see that this is the bottom of the reboiler and we are trying to control the flow of steam which is going to go to the reboiler. This is known as the condensate throttling reboiler, also known as flooded reboiler where the amount of steam which goes into the reboiler is controlled by the amount of heat transfer which is going to happen. So the way this particular reboiler works is that you have this condensate flow.

So as steam condenses after giving heat, you try to control this flow of steam going into the system by changing this liquid valve. So when you open this valve, the level of the condensate goes down. As the level goes down, there is more area available for heat transfer so more amount of steam will come in. So that is how this steam flow is controlled by using this particular valve.

And what you can see is this is a multicapacity process. When you open this valve, it is first going to change this liquid flow. As you change the liquid flow, it is going to change the level. Once that level changes, the amount of area for heat transfer changes. This changes the way the steam condenses and when steam condenses this pressure goes down, so more steam is going to come in.

So it is a fairly multicapacity process. It is a very slow process. So in such a case, the flow controller will actually be a PID controller.

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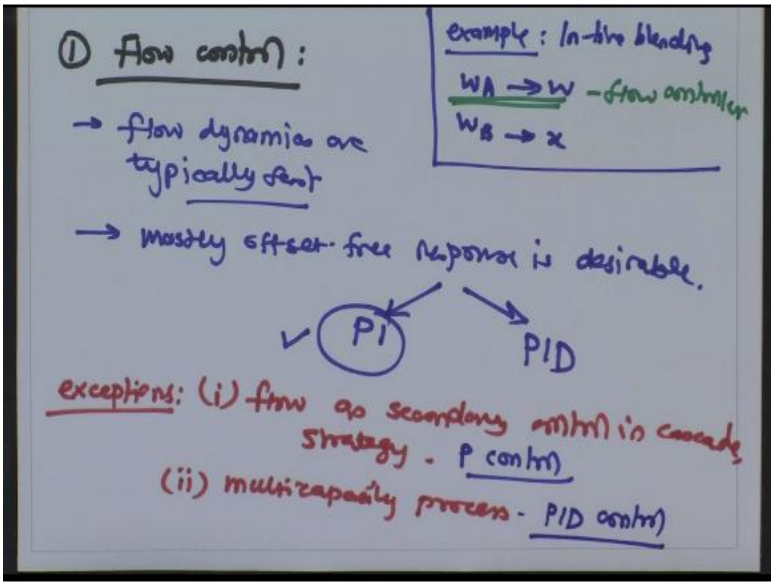

So most of the times flow control will be a PI controller. When it is part of a cascade control and a secondary control objective it will be a P controller. If it is a multicapacity process like a flooded reboiler, then it will be a PID controller. Now let us see how the control loop will look like.

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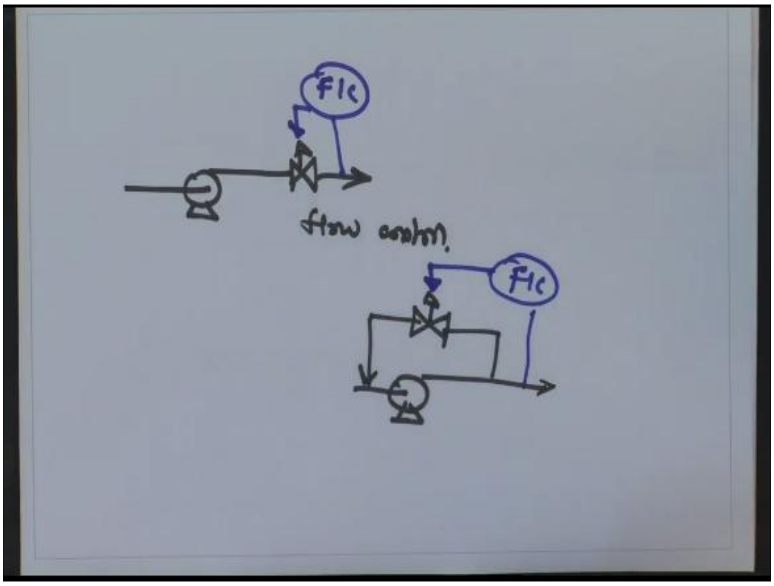

So you have a pump which is going to deliver this flow. So there are two ways in which this flow controller can be implemented. One is simply having a valve at the outlet. So you will measure the flow and then accordingly change the valve opening. If the flow is higher than the set point, you will close the valve opening. So what it does is it changes the resistance across which this pump has to do the work.

So more is the resistance, less will be the flow through the pump. So it works on that particular principle of the pump. The other way you can control this flow which has some inbuilt safety is having a recirculation loop. So in this case, you will measure the flow and accordingly change how much fluid recirculates. So here the total amount of flow which goes through the pump is sort of remains the same.

And what you do is depending on what is the requirement; you recirculate more amount of the fluid. So this particular strategy is going to have more power consumption because the amount of work which is the amount of flow which goes to the pump is higher. You also require a bigger pump. However, it has an advantage that it will ensure that the pump always has certain minimum amount of flow through the recycle.

So this way it will try to avoid the low flow regime of the pump and avoid cavitation and all those kind of any mechanical issues arising out of the low flow. So this is more robust. It has inherent safety built into it, but it will result in higher cost of operation. So these are the two simple ways in which flow control strategy can be implemented, and most of the times it will be a PI type of a controller. Let us now look at the level control.

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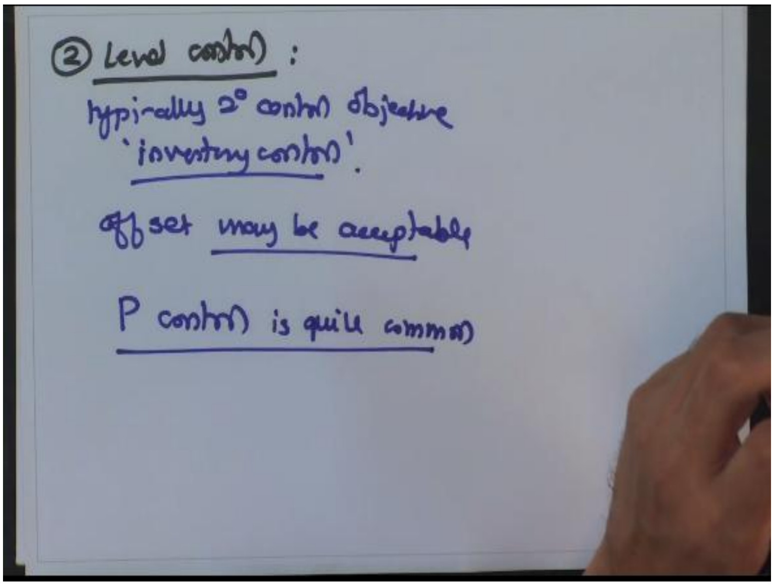

So typically as you recall the example of the flash vessel we implement level controller, not as a primary control objective but typically as a secondary control objective because you want to do some inventory control. You want to maintain a certain inventory of liquid in that particular vessel so that it does not go dry or it does not overflow. So a lot of times offset may be acceptable.

So a lot of the cases when you have a level controller you are okay with the offset, and you want a fast response so the proportional controller is quite common for level control.

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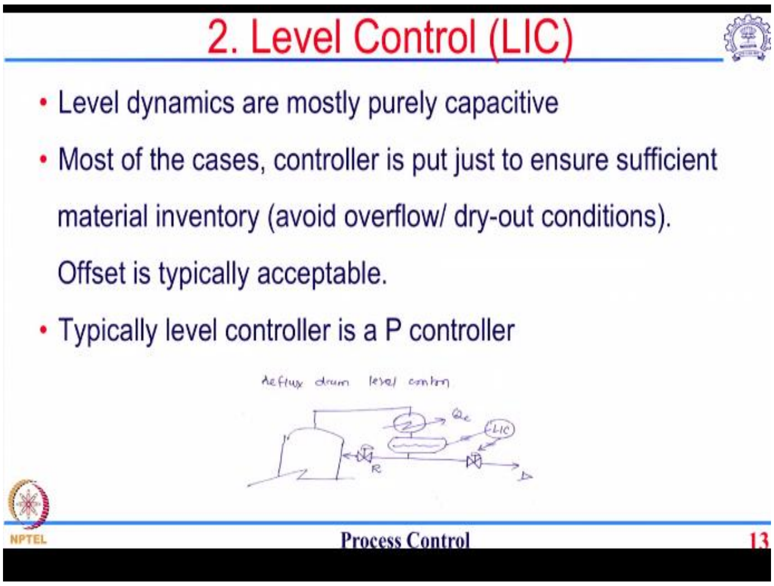

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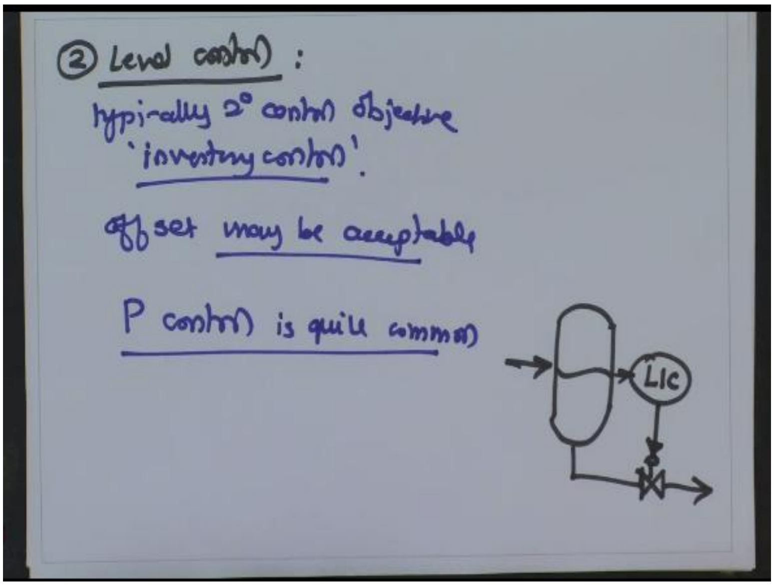

If you look at the example of the flash vessel, you will measure the level and very commonly you would try to control it by changing the outlet flow. So that is how a level controller will be implemented in a process. A lot of times you try to look at what is the outlet flow from that particular vessel and then try to control the level by using that particular flow. Next, we will go to pressure control.

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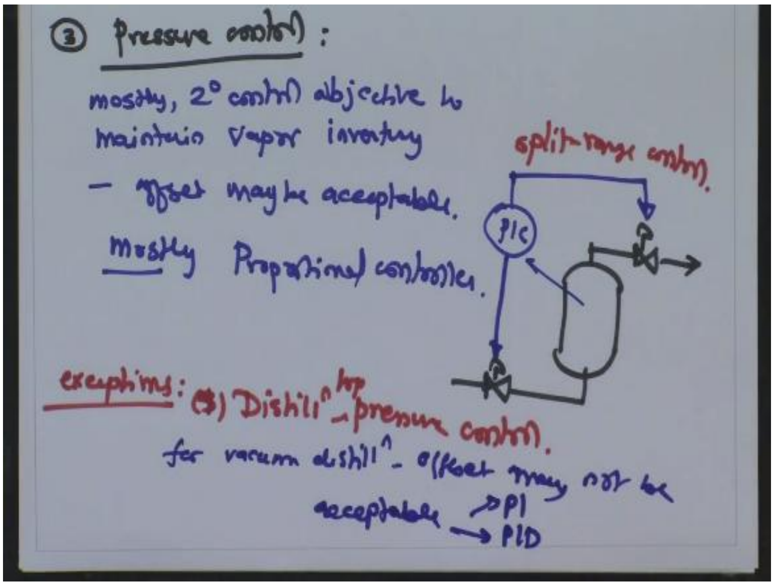

So similar to level, pressure control is also implemented as a secondary control objective to maintain vapor inventory. So offset may be desirable or may be acceptable. So mostly it is a proportional controller. So a lot of times you would have a pressure control as a proportional controller. If you see the example of a surge tank what we had, we will have a pressure measurement. Sometimes you would have the outlet flow manipulated to control the pressure. It is quite common that you also have some way to tie in the inlet flow as well. This is from a safety perspective and what we will end up having is a single pressure controller which is going to manipulate both these valves. This type of control strategy is known as split-range control.

And we will see the split-range control in more detail in the next week. So most of the times pressure will be a proportional controller, and there are two exceptions to this and both these are around distillation top pressure control. So in distillation, pressure plays a very key role apart from maintaining a certain inventory of vapor inside the column, pressure also affects the vapor-liquid equilibrium between the species.

So the extent of separation which is characterized by a relative degree, relative volatility is a strong function of pressure for many systems especially when you talk about vacuum distillation, you are talking about very low pressure, and relative volatility is very sensitive to the pressure. So in that case, even a small offset may change the performance of the column. So in that case, the offset may not be acceptable, so vacuum distillation may not be acceptable.

So that means we have to either use PI or PID control. So again depending on the type of distillation column, we may have PI or PID controls. I will give you two examples. Both are industrially relevant examples.

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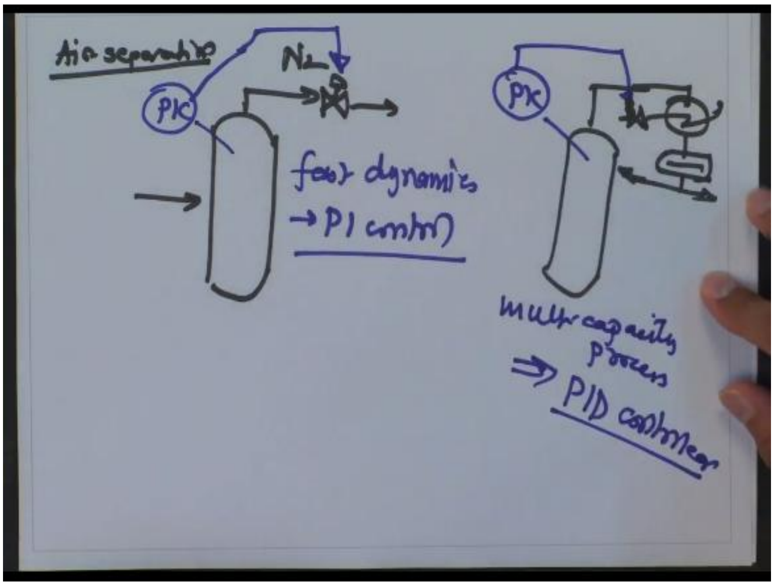

So when you talk about air separation, what you are going to get at the top of this column is nitrogen, which is gas. So the way you can control the pressure inside this column is by simply measuring the pressure and accordingly changing this valve opening. So this is a very fast dynamics, so you can use a PI control. Now this PI controller was possible because we did not have any condenser here and vapor is the product at the top.

The other type of a more conventional distillation is that you get vapor at the top, then you condense the vapor, and then the reflex goes back. So in this case, the way you control this particular pressure is that the handle which you have to control the pressure is this condenser duty. So if the pressure inside the column is high, that means enough number of vapors are not condensing.

So you have to increase the condenser duty so that more vapor will condense and the vapor inventory will go down, and the pressure will also go down. So here it is a multicapacity process. The moment you change this coolant flow, it is going to change the flow of the coolant, it is going to change how much the heat transfer inside this condenser, how much vapor is condensing.

Once that amount of vapor condenses, it is going to change the material balance at the top of the column, and the pressure is going to show its effect. So it is a fairly multi capacity process, so we will have to use a PID controller here. So having said that every distillation pressure controller will not be a PID controller because you also have to weigh in about the offset whether the offset is acceptable or not.

Lot of time high-pressure distillation, small offset in pressure is not going to affect the extent of separation, so you may even go with a simple P controller. Next, we go to temperature control.

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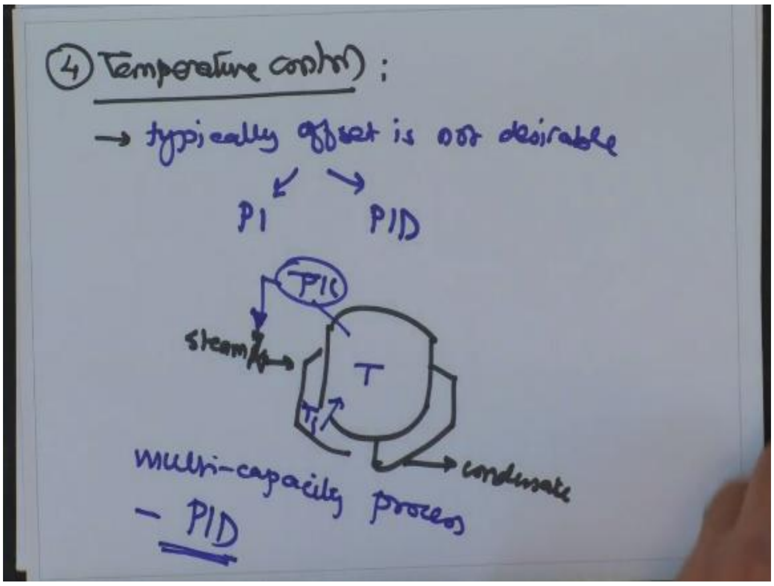
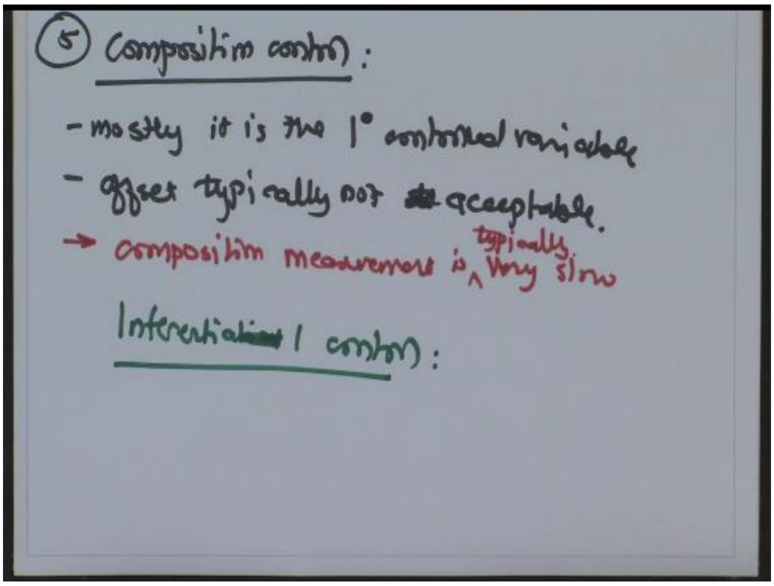


So most of the times temperature is controlled because you want to maintain a certain temperature inside a reactor, which is favoring the kinetics of the desired product. So typically offset is not desirable, so you have two options, one is PI or PID, and again we try to follow similar rules. If the inherent process is fast, you will try to go with a PI controller. If the inherent process is slow or multi-capacity, then we will go with a PID controller.

A lot of times we have the heating or cooling done through a jacket, so it becomes a multicapacity process. So if I draw a reactor in which steam is providing the heating. It is an endothermic process, and we want to control the temperature inside this reactor. So we want to control the temperature by changing the steam flow. So when you change the steam flow, it is the first valve that is going to change the amount of steam going into the jacket.

Then, it will change the jacket temperature, and then eventually it will change the reactor temperature. So it is a fairly multi-capacity process, and then most of the time this temperature controller will be a PID controller. **(Refer to Slide Time: 26:43)**



The last type of variable which we commonly want to control, is the composition control and the reason I am saying want to control is a lot of times you will not see a composition controller as a PID controller per se, so mostly it is the primary control objective. The offset is typically not acceptable, so you would typically want to think that it will be a PI or a PID controller and what happens is composition measurement is typically very slow.

And if we go back to our stability analysis lecture, you will see that the moment you have some sort of a measurement delay, it is going to severely restrict the amount of controller gain which you can put into that system and it eventually results into a very slower or poor performance of the controller. So because of that even though composition is a primary controlled variable, you will rarely see that composition is controlled as a PID controller.

What you do is something known as an inferential control. So you try to infer the composition through a secondary controlled variable, and most of the times this is temperature control. So even though we want to control a particular composition of a particular stream, we would not directly have a composition controller, but we will have a temperature controller which will ensure that if that process runs at that particular temperature, the composition control will be ensured.

And the composition control, in that case, will be part of a higher level controller also known as the supervisory controller. So let me explain that through an example. So we had this splitter.

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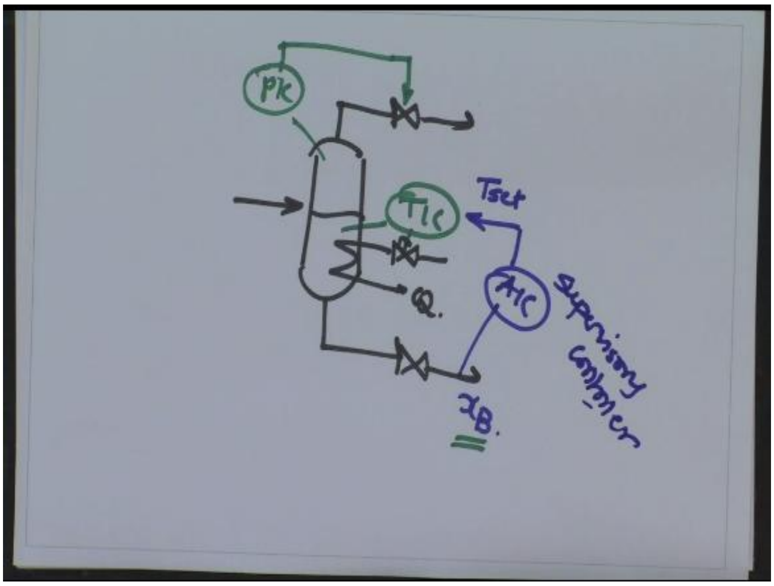

We have this flash vessel. Here we want to maintain a certain bottom purity. But we will not have a composition controller per se what we would be doing is we would have a temperature controller which is going to manipulate the amount of heating or steam which goes into this particular vessel. With the assumption that if I maintain this particular temperature because of the vapor-liquid equilibrium and having ensured that there is also a pressure controller having maintained the particular pressure at, I can ensure that the corresponding composition is also maintained. This is how indirectly we will control composition and to make this foolproof what you will also have is a secondary controller which is going to measure composition, so will have a composition controller. It is going to give the set point of this temperature.

So even though this particular temperature controller is trying to ensure this $x_B = x_{B,set}$. If there is some error in terms of VLE or the system is not behaving exactly as per that VLE or there is some identified component what this additional controller will do is, it will try to change the set point of the temperature controller, fine tune that temperature so that you ensure the desired product quality.

This would typically be a supervisory controller. So with this we have analyzed all different types of variables which you would see in any chemical plant. We have seen typically how each of those control loops will be in terms of P proportional controller, PI controller or a

PID controller and for composition controller mostly it will be some sort of a model based supervisory controller. It will rarely be a PID controller.

So we will take a break here and when we come back we will look at having now decided the type of a controller how do we go about selecting the best values of controller parameters that is the controller gain, integral time constant and the derivative time constant. Thank you.