# Chemical Process Control
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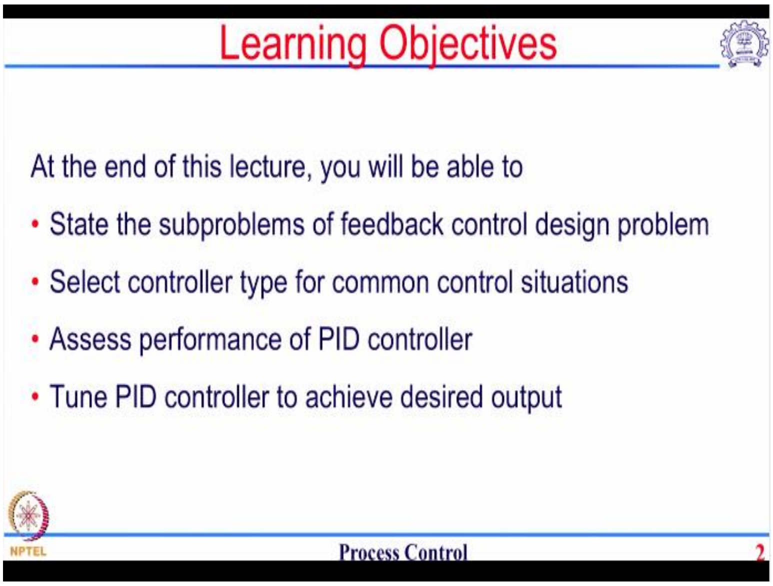
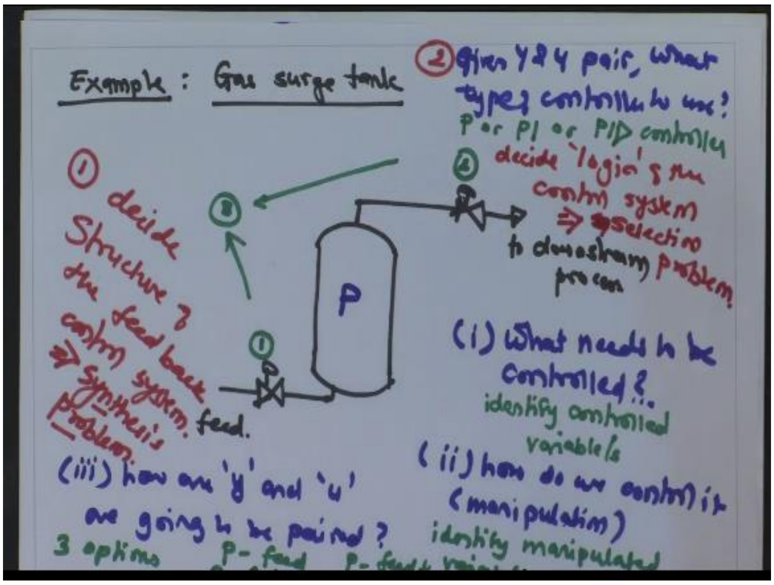
## Lecture - 32
## Synthesis Problem

Hello students. This week will focus on how to design a feedback control system for any chemical engineering equipment. In the last couple of weeks, we have seen what is feedback control, we have seen how PID controller works, we have also seen what are the extreme values of the controller parameters which can be used so as to ensure the stability of a system. So we will kind of use all these information which we have obtained so far, and applying it to real life chemical engineering examples.




Here is the list of objectives for this particular week and we will see that this design of a feedback control system is done in 3 different steps. We will call them as subproblems and we will tackle each of those problems in this week. As we have only seen PID controller so far, we will be focusing most of our analysis based on the use of PID controllers; wherever it is very customary or very common to use advanced controller, I will make some remarks about that connection.

Let us get started. In this week what we will be seeing is if you are given any chemical engineering equipment, how do we go about designing feedback control on that particular process.




Let us take an example of a simple gas surge tank. Most of the times we have seen liquid surge tank, this time just for a change we will take a gas surge tank which means it is a day tank. Lot of times whenever you have gas as a raw material, you would have a day tank where the feed gas will come from the storage or from a customer pipeline. So the feed flow is as shown in the figure and then it will go to downstream process.

Let us say this is a very simple system which we have to consider and how do we go about designing a feedback control system. We will see what sort of questions do we need to ask. The first question, the fundamental question which we have to ask is what needs to be controlled. This is the primary question which you have to ask whenever you are given with any process that what is the controlled variable?

The answer to this is to identify the controlled variable or variables. For this particular system, we know that it is a surge tank, the state variable or the reason why we have kept this particular tank is to maintain a certain pressure of the gas which is going to go to the downstream process unit. So the controlled variable in such a tank is typically a pressure of the stream which leaves this tank which is more or less the same as the pressure inside this tank.

The first question we have to ask is what is the controlled variable and a lot of times, there are different types of controlled variables. As we go on analyzing different examples, we will come to that. But primarily what you have to see is what is the purpose of that particular equipment and it will give you an answer about what is the primary controlled variable of that particular process.

The next question we have to ask is how do we control it in terms of manipulation? If you have to really control pressure inside this vessel, what are the handles or what are the things which you can manipulate in case pressure is not equal to its set point and how do we bring it to its set point. In other words that means we have to identify manipulated variables.

Then lastly, the third question before even going forward in terms of design is how are controlled variables which we typically represent as y and u are going to be paired? Now this question is irrelevant for this particular example as there is only one control variable. We have seen that the second question is how do we manipulate it. For this particular process, there are 3 different possibilities of manipulation.

One is you can manipulate the feed flow so that if the pressure inside the tank increases you reduce the feed flow. The second option is if you want to control the pressure by using the outlet flow, so if the pressure goes above the value, the outlet wall will open and the third option is a combination of the two. You can use both inlets as well as outlet valves to control the pressure.

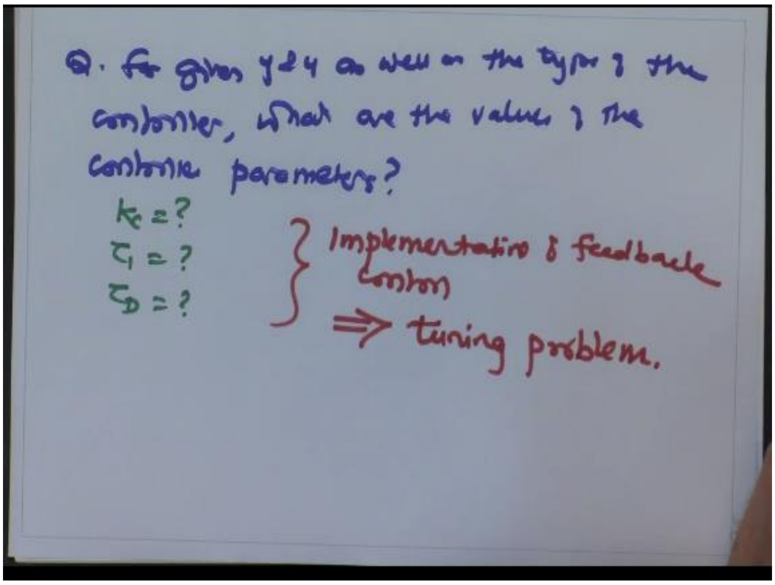
The third question, when I ask how are y and u going to be paired? There are 3 options for pairing. One is pressure with feed, other is pressure with an outlet and the third one is pressure with feed plus outlet. So before even going forward in terms of designing a control system for this process, we have to identify what is the controlled variable, what are the possible manipulated variables which will give you multiple different combinations of inputs and outputs. And eventually selecting the best one out of those, so that you will know what is the manipulated variable and what is the controlled variable on which the corresponding feedback control loop will be implemented. All these 3 questions essentially decide what is going to be the structure of the feedback control system. This particular problem is known as synthesis problem.

Now here I have given you a very simple example where there was only one controlled variable, two manipulated variables, and 3 possible ways. So that there are 3 different possibilities of inputs and outputs; however, when we go into more elaborate examples, you will see that as you have more number of controlled variables and manipulated variables, the number of options and even the different ways in which these can be paired grow exponentially. Therefore a synthesis problem becomes very tricky, it is a very active area of research and this is the first thing which you have to answer before even going into the implementation of a feedback control system. So, this first thing is the synthesis problem.

Now once you know what is going to be the manipulated variable and what is the controlled variable, the next thing which you have to do is what type of controller we will be using? Synthesis problem was problem number 1. When we talk about the second thing, then the question comes is given y and u pair, what type of controller to use? So as said, we are mostly limiting our discussion to PID controllers. So the answer to this in this context will be whether we are going to use a P controller or a PI controller or a PID controller. So we have to answer this particular question once we have decided about the inputs and outputs.

This particular section, this particular problem decides the logic of the control system. Depending on whether you have a P, PI or PID controller, they have different logic. P controller penalizes only the current error; PI controller will have current and past contributions; PID will have past, present, and future contributions. So all these will decide the logic of the control system.

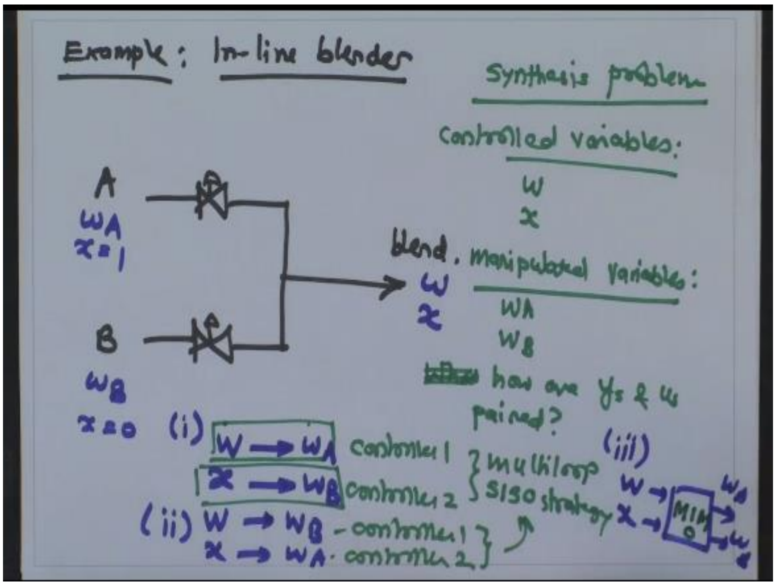
This particular problem is known as the selection problem. This is the second problem. Then lastly, once we have decided what is the input and output as well as the type of a controller, then the last task remains what are the corresponding values of the controller parameters?



The next question which we ask is for given y and u as well as the type of the controller, what are the values of the controller parameters? I mean I say what are the values, these are the best values which somebody will use. In terms of PID controller, it will be what is the value of controller gain, what is the value of the integral time constant or what is the value of the derivative time constant.

This particular subproblem or this particular question tries to answer what is the implementation of feedback control. Once we have the values of these controller parameters, you can punch those in into the control system and the final feedback control system will be ready to go. This particular problem is known as a tuning problem. So then we solve all these 3 problems. That means we have completely designed the feedback control system. Okay.

Let us start with different, so now what we are going to do is we are going to cover different example systems and we will try to focus on the first problem which is the synthesis problem.




The next example which we are going to consider is in-line blender. A lot of times in our chemical industry, we have to mix two streams and typically there is no mixer which is provided but just two lines which mix together. Let us say you have two streams A and B which you have to mix to get the final blend. So in this case, one stream comes at the flow rate of $w_A$, other comes at a flow rate of $w_B$.

Let us say this is a pure component and so these are this is a binary blending where these are the two pure streams. In terms of one of the variables, it becomes mole fraction 1, this becomes mole fraction 0. The objective of blending typically is to attain a certain blend flow and a certain blend composition. This is a fairly common example type of simple system which you will see.

Let us now try to solve the synthesis problem. So what are the different questions which we have to ask? The first question to ask is what is or what are the controlled variables? In order to answer that question, we have to ask what is the purpose of this particular unit. This particular unit is there because we want to achieve a certain blend flow and we want to achieve a certain purity of the blended material.

So that tells me there are 2 controlled variables, one is the total flow and one is the composition. Then, the next question we have to ask is what are the possible manipulated variables. So here, there are possibly 2 variables which you can change. One is you can change the flow of stream A and you can change the flow of stream B. So there are 2 manipulated variables. One is $w_A$ and the other is $w_B$.

Then the last question which we have to ask is how are these two y's and u’s paired. So I would ask you to figure out if these are the two controlled variables and these are the two manipulated variables, what are the different ways in which we can implement a controller. So hopefully, you have tried to figure out the answer to the question which I had asked earlier.

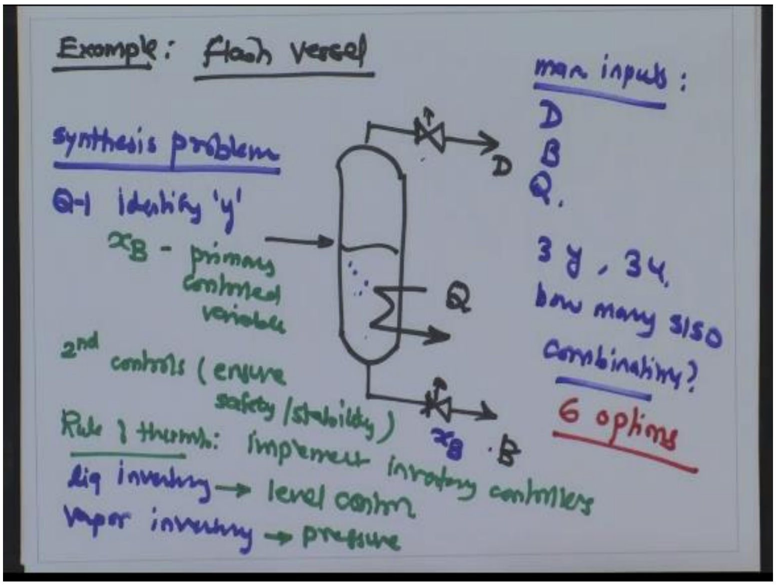
If this is the system, primarily there are 2 simple ways or options in which we can achieve this control. One is you can control w using $w_A$ and you can control x by using $w_B$. So that is one option. Similarly, there is another option that you can control w by using $w_B$ and x by $w_A$. So both these options what we are going to have is you will have this as controller 1 and this will be controller 2, again this is controller 1.

As we have 2 controlled variables, in each of those cases, we are going to use 2 separate controllers and each of those controllers will have a single output and a single input. So all these are known as multiloop single input single output strategy. Each of these individually would be similar to what we have studied so far. All we have studied was a single input single output type of a controller.

And then so this will be one such controller, this will be another such controller. However, for this system as we will see to almost in the last week of this course that such a strategy where you have different controllers which do not interact with each other, we are sort of independently in deriving these controllers. This will result in very poor performance and the performance can be improved by having a single controller. So the third option is, both these values are taken together and simultaneously they will give you what should be the manipulated variables. This type of a controller which uses multiple outputs and has multiple inputs is known as a multi-input multi-output controller or a MIMO controller.

For this particular system, there are 3 possible architectures which are possible, either you can go with two single input single output or two SISO loops wherein there are 2 possible options depending on the pairs of between outputs and inputs. Or you can have a full-blown controller which takes all the controlled variables and simultaneously obtains the values for all the manipulated variables. As it turns out this particular controller 3, the system works much better compared to these types of SISO controller pairings. So when we are talking about this synthesis problem, we have to decide about which out of these 3 configurations we are going to go ahead with.

Because all the subsequent selection and tuning problem would be dependent on the particular selected structure. Let us now consider another example.




This time we will consider a flash vessel. You have some stream which you are going to flash inside a vessel which will generate some vapor at flow rate D and certain liquid at flow rate L or B and you will also provide some heat Q. For this particular system, let us try to answer these questions again. We are trying to solve the synthesis problem. So question one was to identify the controlled variables.

Let us first ask the question about what is the primary reason for this particular piece of equipment. We are using flash vessel because the stream which we are getting probably has multiple components and we want to separate it into two phases such that each of those phases is richer in one of the components.

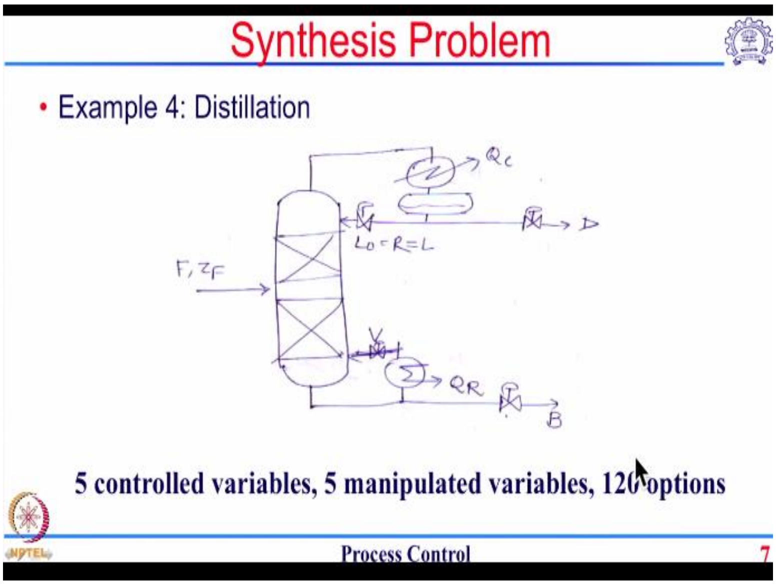
As this is a flash vessel, it is not a full-blown distillation column. This is typically used when you have a very high large difference in volatility or you want to get rid of some of the contaminants. Typically this type of vessel is implemented so that you want to knock off or vaporize some of the low boiling impurities from your product. So that what you get out as the liquid stream has a very low composition of these more volatile components.

Typically that is represented by what you get as the base purity. So the primary controlled variable here is the purity at the bottom stream. It may also in certain cases be the purity at the vapor stream. So this is the primary controlled variable. But simply having this particular controller will not going to be efficient because there are some additional controlled or controls which have to be put in into the system. These are typically known as a secondary controlled. These are there to ensure safety or stability. So again a rule of thumb is to implement inventory control. For this particular flash vessel, there are 2 types of inventories. There is a liquid inventory, how much liquid is present inside this vessel. You want to ensure that there is sufficient liquid inside this vessel. It should not go dry or it should not overflow, it should not fill in the complete vessel.

And also there is a vapor inventory which means how much vapor is present inside this vessel. As the flash vessel works on the principle of vapor-liquid equilibrium, you have to maintain a sufficient amount of vapor and a sufficient amount of liquid inside the system. So that is what this rule of thumb says, you have to have control over the inventories. So when you talk about liquid inventory, it means how much liquid is present or it will result in level control.

So level has to be controlled in this vessel. When we talk about vapor inventory, we talk about pressure. So we have added two more controlled variables, one is level and one is pressure.

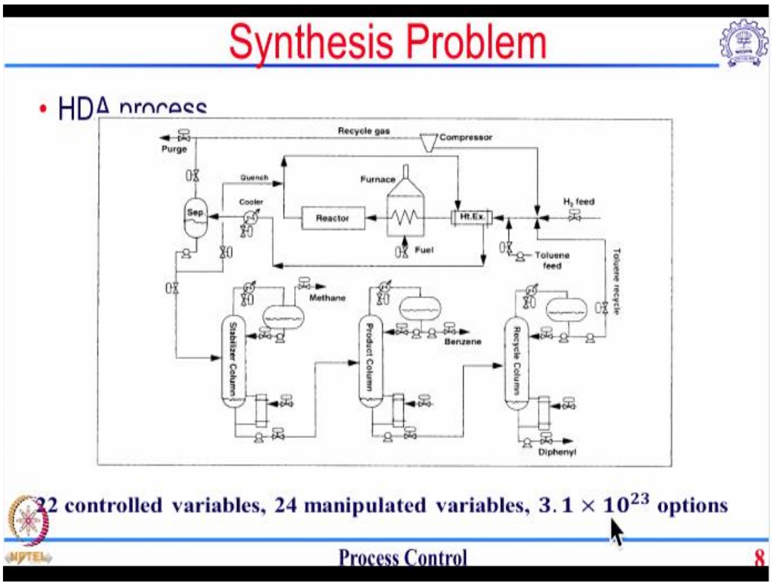
Let us look at now manipulated variables. I have shown 3 manipulated variables here. One is the vapor flow, one is the liquid flow and other is the heat duty. You have 3 outputs, 3 inputs. So how many SISO combinations are possible? There are 6 options. You have to select out of these 6 options which is the best option which you are going to go forward with. As we can do this for all sorts of example systems and what I want to drive at is so let us say if you take a distillation column such as the one shown here.




You will see that the distillation column has 5 controlled variables. If this is a binary distillation column, you will have some control of the purity here at the top, purity at the bottom. You also have 2 liquid hold-ups, 2 liquid inventories in the system. One is the reflux drum level and the other one is the reboiler or the bottom of the column level sump level. Then lastly you have to control the vapor inventory which is given by the pressure control.

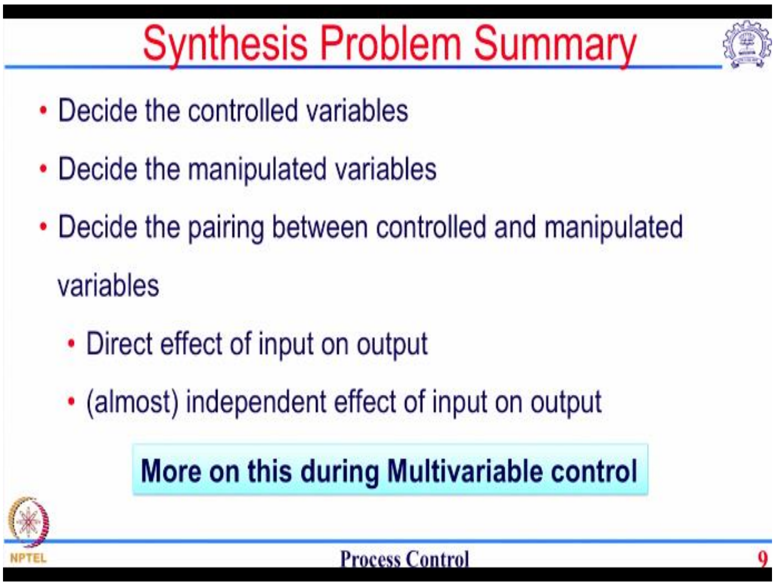
There are 5 controlled variables and there are 5 manipulated variables as well which refer to the product flow, bottom flow, condenser duty, reboiler duty, and reflux flow. So this particular system has 5 controlled variables, 5 manipulated variables and in general, there are 120 options. So even for a single distillation column, you have 120 different ways in which you can pair these 5 controlled variables with manipulated variables.

All these 120 are simple SISO pairings. We have not even looked at the multi-input multi-output controller and those will eventually increase the number of options even further.




And if you go to a real life size problem, let us say a HDA process, hydrodealkylation of toluene to get benzene. It is a very fairly commonly studied process, a benchmark process. So for this particular process, you have 22 controlled variables and 24 manipulated variables and the number of SISO pairs go to 10 raised to 23. So all I am trying to drive you at is so this synthesis problem is not a straightforward problem.

Bigger the system becomes the number of options go to a very high value, so you need a certain type of guidance in terms of how do you go about selecting the best structure. As I said this is a very active area of research and there are sometimes heuristics which are followed in order to go about the pairing and the type of controller.




Just to summarize, what we do in the synthesis problem is you decide what are the controlled variables, what are the manipulated variables and then how do you pair them. We will right now restrict only to multiloop SISO control strategy. So you have to select which particular input is used to control a particular output.

When you want to do that you typically focus on 2 particular things. One is that input should have a direct effect on the output so that that particular action is very fast and the other thing which you want to do is when you do this particular when this controller works, it should not disturb all the other variables. So the effect of that input should be exclusively on that output and when I say almost that this is not in our hand most of the time. When a variable changes, its effect on all the output is decided by the process.

All we want to do is when we select the input-output pair; it should be selected such that the effect on other variables is minimum. This is done through interaction analysis. Again, we will focus on that in the last week of this particular course and more of this will come when we talk about multivariable control. So that is what we do in the synthesis problem. We will take a short break and when we come back we will look at the selection problem. Thank you.