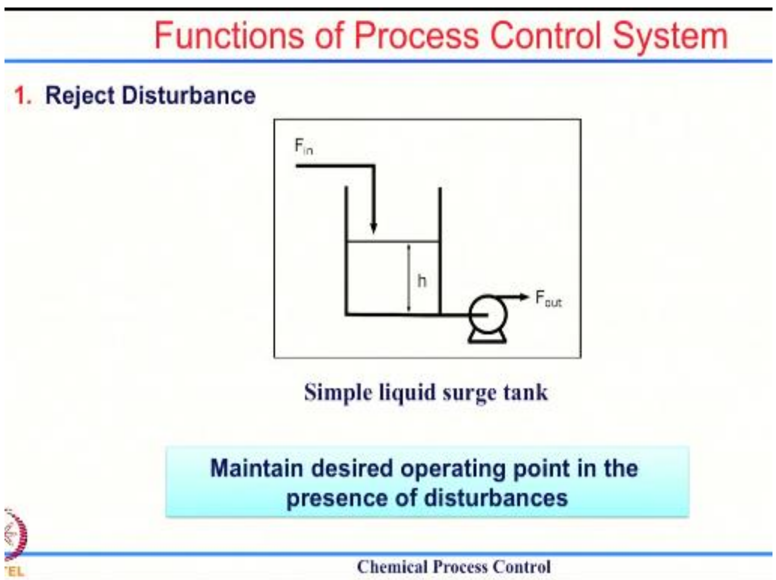
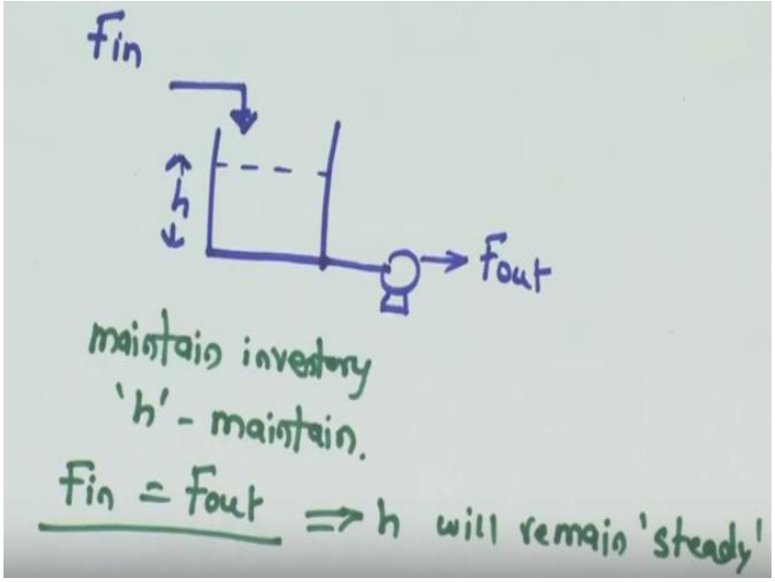
Chemical Process Control
Prof. Sujit S. Jogwar
Department of Chemical Engineering
Indian Institute of Technology-Bombay

Lecture - 02
Functions of Process Control System

Okay, welcome back. Let us now look at when will you install a control system, what sort of function does control systems satisfies or what is the function which it is supposed to perform. Most of the control systems when you implement, the primary job of that control system is to reject a disturbance or if you want to clarify, it should actually reject the effect of a disturbance. So to motivate that, let us consider an example of a liquid surge tank.



It is a very simple example and most of the time we will be resorting to this example when we try to explain a particular concept. So let me explain this particular system to you.

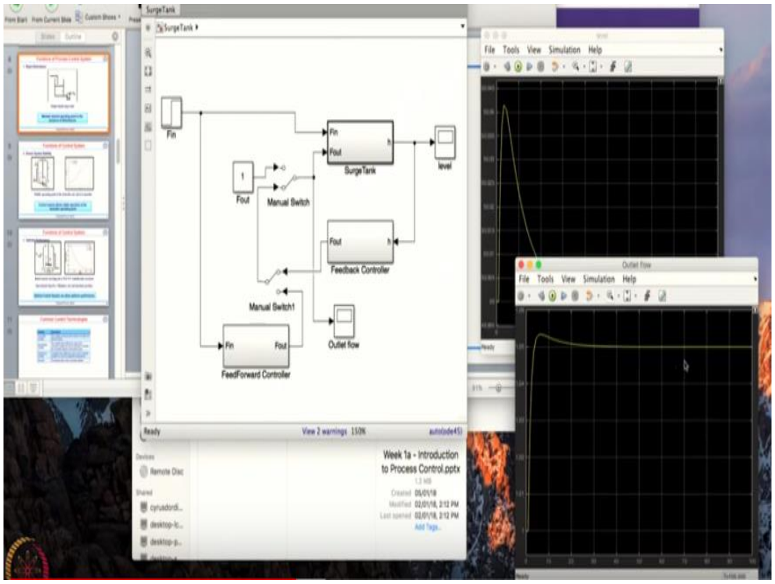


The liquid surge tank is a tank which has liquid coming in at a certain flow rate, let us say a Fin and liquid goes out at Fout. So you maintain a certain amount of liquid inside this tank, let us say a particular height and either using a pump or having an outlet valve there is a way to take out the liquid from this particular tank and it is used to temporarily store some amount of liquid inside this particular tank.

When you have such a tank, typically the objective is to maintain certain inventory inside the tank which means you have to maintain the height inside the tank. And from your basic material balance, you can know that as long as I maintain a Fin = Fout, your height will be maintained which we will also call as steady. So now for such a system typically what happens is there is no control over what comes in into this particular system.

Here there is no way you can manipulate a Fin. So in order to maintain this, let us say if there is some disturbance in the Fin and we do not do anything about the outlet flow rate, then the tank will either overflow or it will drain out as a function of time. So typically if you want to maintain a particular height in this particular tank then you have to take certain action.

The control system has to ensure that if it has to maintain the height, it has to somehow change the outlet flow rate such that it becomes equal to the inlet flow rate so that you can maintain particular height inside the tank. So let me explain that using a small simulation.



Here is the model for this particular surge tank and if the Fin or the inlet flow rate remains constant and if I run it for a long time, you can see that the height inside the tank also remains constant at the desired value which is 50. But there is no control over a Fin and the inlet flow rate may increase or decrease beyond this value. So let us say, the inlet flow rate increases by 5% and we do not take any control action. What would happen?

As a function of time, the level inside the tank will keep on increasing, in this case linearly because it is a very simple tank and what will happen is after that level reaches 100%, the tank will overflow. The same thing will be true if a Fin is less than a Fout. In that case, your tank will drain out.

But if you have some control system, so if I start the control system which is measuring the height inside the tank and accordingly changing the outlet flow rate in response to the changes in height and if I run this system what you can see is even though the inlet flow rate has changed by

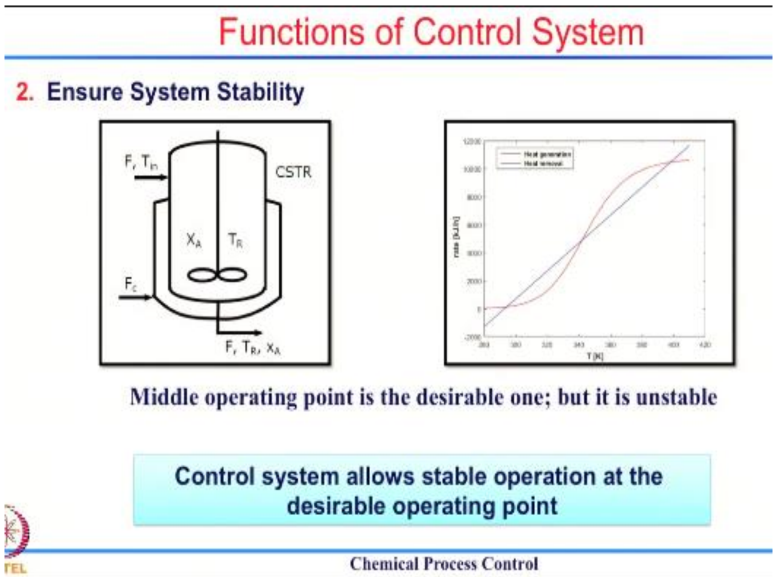
5%, the control system is able to maintain the height at the original design value of 50% and this is done by accordingly increasing the outlet flow rate also by 5%.

So, by implementing a control system, we have been able to reject the effect of disturbance. The effect of disturbance was to either make the tank overflow or drain out and that effect has been rejected by implementing a control system. So most of the control systems which you would see, their primary job is to reject the effect of a disturbance. Now sometimes the control system is also implemented to stabilize an unstable operating point.

Now before going forward let me explain to you what do I mean by stability. Let us take an example of a pendulum. Let us say if this is a pendulum and then there are two possibilities where this particular pendulum can remain steady. Either it is in the down position or it can remain stable at exactly a vertical position. Now if I consider this downward position of a pendulum and give a small perturbation, eventually it will oscillate and again come back to the original point.

In that way, what we call it as a stable operating point. So when the pendulum is vertically down then it is a stable steady state for the pendulum. But the same cannot be said about the exact opposite point of the pendulum. If there is a small perturbation, then it goes back to the stable steady state. So this particular operating point of the pendulum is called as unsteady because a small perturbation does not bring the system back to its original point.

Similarly, even chemical systems can sometimes be unstable and the job of a control system is to stabilize that particular unstable operating point. Example of such a system is an exothermic CSTR which you might have studied in your reaction engineering course.

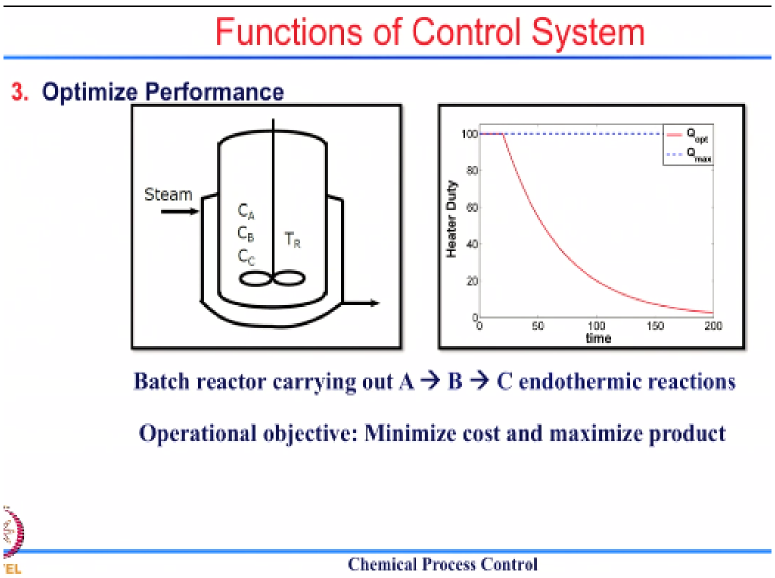


You can see that it is exothermic CSTR and therefore in order to maintain the temperature inside the reactor, you have to have some sort of cooling mechanism. Now if you look at the evolution or the comparison of how heat is generated inside the reactor, you would get a sigmoidal curve as a function of reactor temperature. But if you look at how the heat gets removed from the system, it is a linear function of temperature.

So wherever these two curves intersect that is where you have a rate of generation is equal to the rate of removal of heat. These are the three points at which your CSTR can operate. Now as it turns out, this middle operating point is the only one which is unstable. So if there is a small disturbance in this particular operating point, then either you will go towards the high-temperature steady state, or if there is a disturbance in this direction, then it will go to the low-temperature steady state. But as it turns out, this middle operating point is the one which is of interest because the other two are either too high to operate or too low temperature to get any conversion. So the job of a control system, in this case, is to ensure that in the case of disturbances, the system does not deviate away from this steady state but is brought back again to this same steady state.

That is done by manipulating the coolant flow rate. So in case, there is any disturbance, this controller will change FC such that the rate of generation of heat is always maintained to be equal to the rate of removal of it. So that unstable steady state can always be maintained, even though it is unstable. Sometimes the control system is also installed to ensure the stability of an unstable operating point.

And lastly, the process control system can also be installed to optimize the performance of the system. So here let us take an example of a batch reactor.



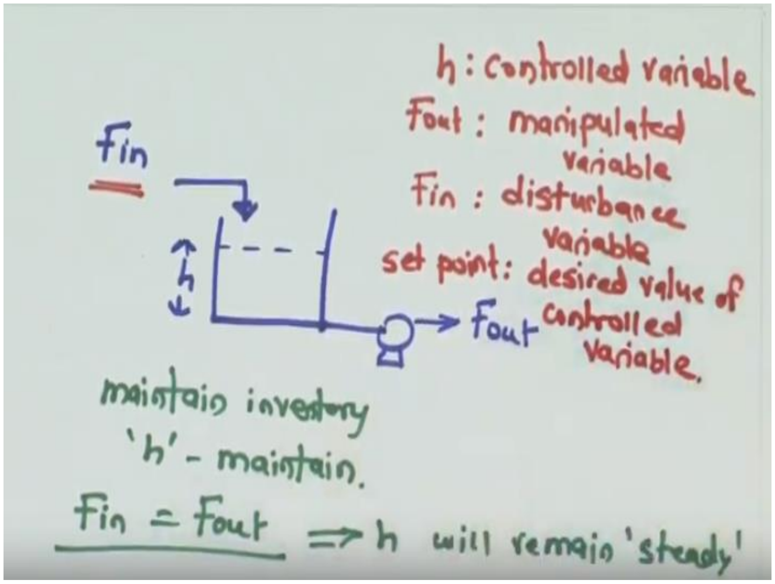
This time it is an endothermic batch reactor which is going to conduct a consecutive reaction of the form A going to B which eventually goes to C and the product of interest is B. As it is an endothermic reaction, we have to provide heat to the system. That is done by passing steam into the jacket. Now here, the objective of this operation is to maximize the production of B which is intermediate.

So you can simply think of it as if you want to optimize the performance that is to get the maximum amount of B and you want to reduce the consumption of steam, the way you can operate is as shown by this red curve. The idea is if you operate the entire operation at the highest steam duty or the heating duty, then initially you would generate a lot of product B but eventually, as all the reactions are endothermic all that B will get converted into C and your final yield of B will be less. Also, you have consumed a lot of steam.

The other extreme is you do not provide any heat. In that case, the cost of utility is very low but you are also not making any product. So the best operating policy for this case comes out to be you provide maximum heat till you get sufficient amount of product B and then slowly you keep on reducing the heat duty so that the B to C reaction gets suppressed and also you save on energy cost coming from steam.

So obtaining such kind of a profile while operating the batch is going to be the objective of the control system which in this case will be an optimal controller and it will be of the form supervisory controller or real-time optimization. So top layers, those will be the layers which will perform this particular objective of minimizing the cost of energy or maximizing the product. So this type of objective or this is the third function which a control system can perform when it is installed into a chemical system.

Let us now look at what are the different terminologies or jargons of a process control so it will help us communicate on the same ground. So I will explain this term for the same example, the surge tank example which we had considered earlier.



For this example, the objective, so when you have a control system your objective is to maintain the height inside the tank. So the variable which we want to maintain or which has to be maintained by the control system is known as the controlled variable. So, in this case, your height or level inside the tank becomes a controlled variable. Now the variable which is used to control this particular controlled variable is known as a manipulated variable.

As I had shown earlier, the outlet flow rate was used to ensure that level remains at its desired value, so it is known as a manipulated variable. So you can easily note that if a particular variable is a manipulated variable, it has to affect the controlled variable. Otherwise, it is not able to manipulate the controlled variable. Now other than that there are also some variables which will affect the controlled variable but we do not have any control on those.

For this particular example, the inlet flow rate was a variable which is going to affect the controlled variable. But we do not have any control on changing the value of the inlet flow rate. Such kind of variable is known as a disturbance variable. Lastly, there is always some set value or the desired value at which we want the controlled variable to be at. In this case, the desired value of level was around 50%. So that desired value is known as a set point value. So going forward, we will be using this nomenclature. Thank you.