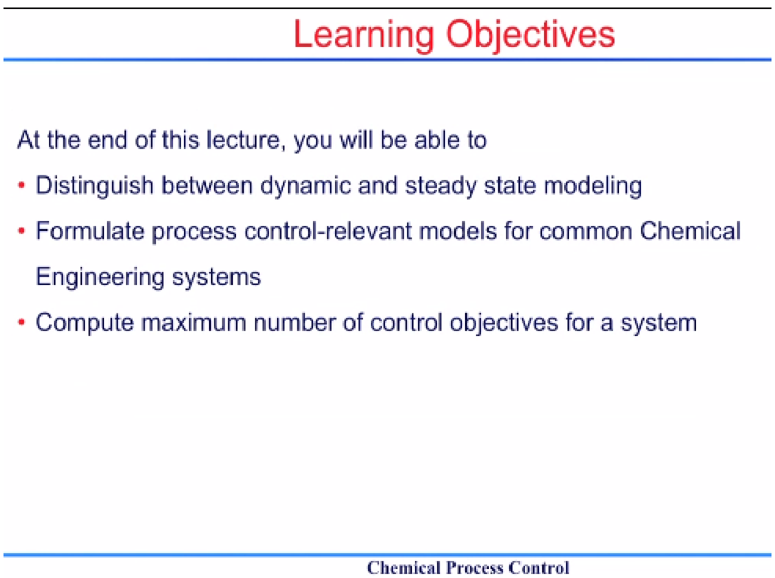
Chemical Process Control
Prof. Sujit S. Jogwar
Department of Chemical Engineering
Indian Institute of Technology-Bombay

Lecture - 05
Introduction to Process Dynamics

Hello students. In this part of the lecture, we will focus on process dynamics. We will see what process dynamics are and what is the importance of process dynamics when we look at process control.

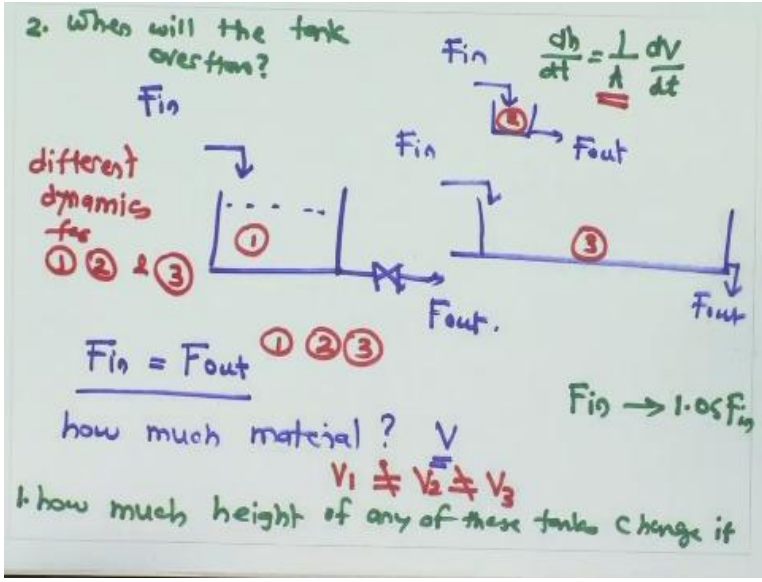
The learning objectives are outlined below.



At the end of this lecture, you would be able to distinguish between steady state modeling and dynamic modeling. You would be able to formulate dynamic models for relevant chemical engineering processes. You will be able to formulate process control relevant models for common chemical engineering process systems. Lastly, you would be able to compute what is the maximum number of control objectives which can be satisfied in a given system.

So let me begin with the distinction between steady state and dynamics. Most of the courses in Chemical engineering curriculum you might have done steady state modeling. Even in the previous lecture, I had talked about the design of a chemical engineering equipment. Even that is done at a steady state. When we talk about steady state, it tells me where the process is currently at. Let us take an example of the stirred tank.

(Refer to Slide Time: 01:57)



So when I say steady state of this system or if I ask you to write steady state balance for this system, what I get is,

$$F_{in} = F_{out}.$$

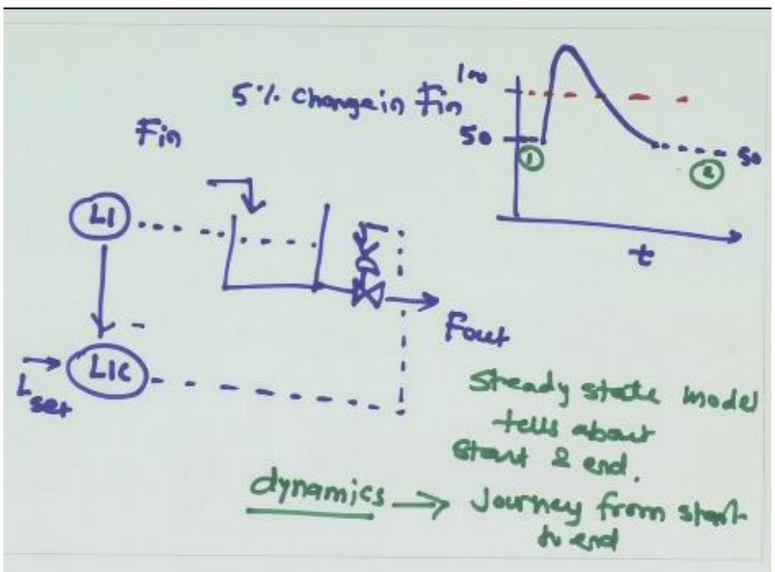
But this does not tell me, how much material is in this tank. It does not tell me what the volume of this particular tank is. The tank may be small (tank 2) and I can maintain $F_{in} = F_{out}$, the tank may be too big(tank 3) and still I can maintain the same $F_{in} = F_{out}$. In terms of steady state, all these 3 tanks are similar. But the volume of 1 is not equal to volume of 2, is not equal to volume of 3. So these 3 systems are different, but in terms of steady state they are giving me the same information. That is because steady state information is limited. It does not give you all the information about the system.

If I want to ask a question, how much height of any of these tanks change if F_{in} is increased by 5%. This is the disturbance which we had given even in the last lecture. If the inlet flow rate increases by 5%, the height would change. So in all the 3 cases, over time, the tanks would overflow. When we say how much the height of any of these tanks would change? Will it be by the same amount till all the tanks overflow? When will the tank overflow? So if I ask these questions, then you can answer by looking at what is the rate of change of height in each of these tanks.

We had derived in the last lecture that $\frac{dh}{dt}$ is $\frac{1}{A}$ times $\frac{dV}{dt}$ and this $\frac{dV}{dt}$ is related to the change in F_{in}. So this $\frac{dV}{dt}$ is same for all the three cases, 1, 2, and 3. What makes the difference for all these three cases, is the fact that all of them have different area and because of that all of these will have different rate aa t which the height will change and accordingly all of these will overflow at different times.

So we can see that each of these tanks have their own set dynamics or the way these three systems respond. Even though they have the same steady state relationship, all of them will move from one point to the other in a different fashion compared to each other. So all of them will have different dynamics.

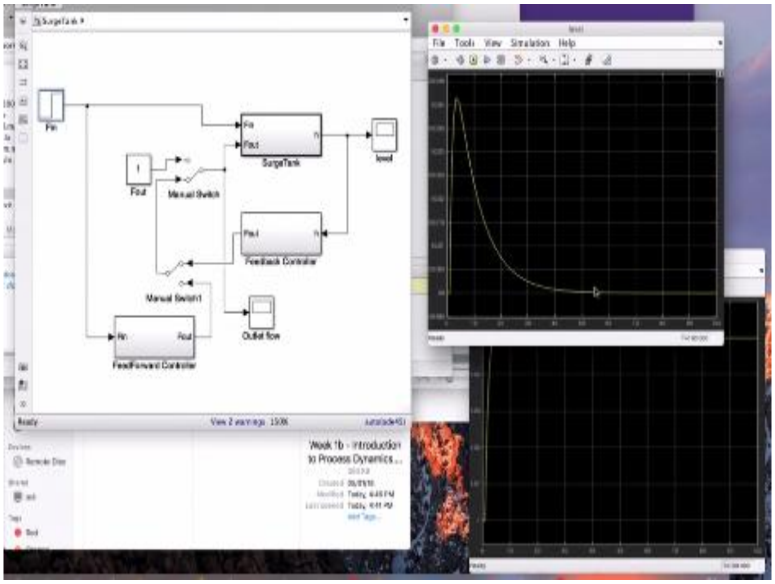
(Refer to Slide Time: 07:14)



Now let us come to the system or the example which I had shown you about the control of this particular tank. Let us say if I use a feedback control wherein we measure the level in this tank, give it to a controller which is going to know what is the set value and accordingly it is going to change the outlet flow rate. And we had seen this particular system if there was a 5% change in the inlet, the control system was able to change the outlet flow rate such that the height eventually remains the same as 50%.

So we had started with the level being 50%. There was some disturbance, and eventually the level was still 50%. So in terms of steady state F_{in} was equal to F_{out} in the beginning as well as in the end. But based on the steady state modeling can you tell me whether the height was always 50%?

(Refer to Slide Time: 08:53)



If you look at the response, you would see that the height started with 50% and ended at 50%, but it went through some increase in the level and later on followed by a drop in the height. So as a function of time, the height was not 50% all the time. So steady state model tells me only about the starting point and the end point. It does not tell me about the journey from start to end. That is given by the dynamics of the system or the dynamic model of the system.

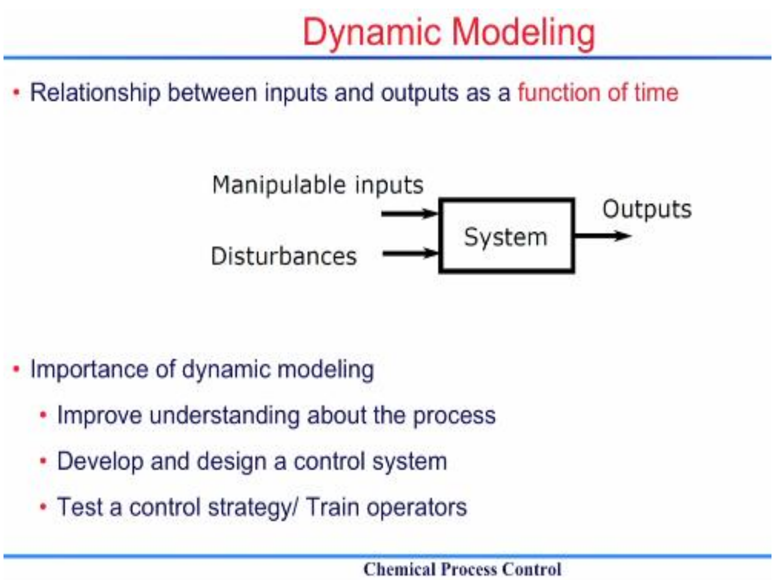
Why is that important? Because we saw that in certain cases this 50% maybe very close to the overflow limit. In this case, the controller causes your height to go beyond 100%. So let us say if this was the limit, then this controller is not good because it is causing the height to go beyond the overflow condition and it is not physically meaningful. This response, in that case, is physically non meaningful.

So when you talk about control, it is very important not only to know what is the start point and end point but also what path the system takes from start point to the end point and that is why the dynamic model is important compared to steady state model when we talk about process control. For all the other courses in chemical engineering steady state model is sufficient to capture most of the relevant details of the system but not in the case of process control. We have seen that dynamic modeling gives us additional information than steady state modeling. Specifically it tells you additional system variables, for example, volume of the tank which was not apparent from the steady state modeling and the second thing it also tells you the speed of response of the system.

When I ask the question what time would any of those tanks take to overflow, the answer would be the tank 2 would be the first which would overflow followed by tank 1 and lastly tank 3, because the rate of change of height is the smallest in time 3 and it is highest in tank 2. So dynamic modeling gives us additional information about the system, and thus it is that additional information itself is required when you design a control system for that particular process.

So what exactly is dynamic modeling?

(Refer to Slide Time: 12:21)



The dynamic model is the relationship between input and output as a function of time. Those last three words "function of time" is the key difference between dynamic modeling and a steady state modeling. Steady state model also gives us the relationship between input and output, but it is at the end point. It does not give you how that relationship or the effect changes as a function of time. In terms of process control what you can see is that there are two types of inputs.

We have seen that in the last lecture, any input can be manipulable input which affects the output or it can be a disturbance input, and those inputs would have an effect on the output. Now how a dynamic model will capture this effect as a function of time? When we talk about a feed-forward control strategy, in that case, the dynamic model between disturbance and the output will help you predict what the effect of disturbance on the output is. Similarly, the dynamic model between manipulated input and output or the inverse of that would help us to identify how the manipulated input should change so that I can negate the effect of disturbance on the output. So that way these two functions, the functional relationship between disturbance output and manipulated input-output would help us design a control strategy so that the disturbance can be rejected.

In addition to the above, the dynamic model gives you an additional improved understanding of the process. Like we saw for the stirred tank system it tells you about what is the speed of response of that particular system. It also tells you about the size or capacity of the system and thus as it tells you how the system behaves as a response to inputs, it is also helpful or it helps you in terms of developing and designing a control system.

And nowadays, the dynamic model is also used to train operators in a very safe environment. Rather than asking the new operator to operate a live plant where a small wrong action can also result in unsafe conditions, they are trained in safe environments wherein a dynamic model of the system which captures the essence of the real plant is simulated on a computer, and then the new operator is trained in a very safe environment. So dynamic model also has advantages other than process control wherein it is now used as a training tool. Thank you.