Chemical Process Control

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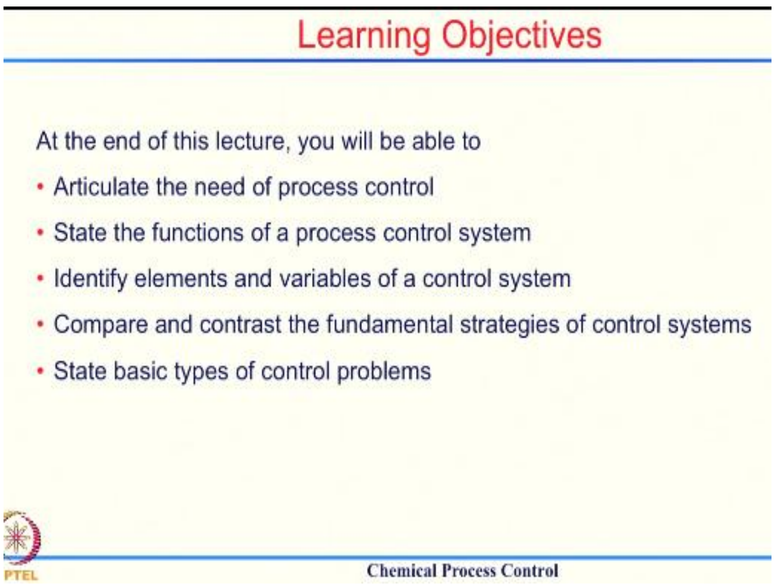
Lecture - 01
Motivation for process control

Hello students. Welcome to this course on chemical process control. The topic for this first week will be introduction to process dynamics and control. Here are the objectives for this particular part of the lecture.



What are the different types of control strategies which are possible and what are the advantages and disadvantages and lastly we will also look at what are the different types of control problems which exist in a chemical industry.

Chemical process control is one of the core courses in your chemical engineering curriculum. You also take different courses such as Heat Transfer, Reaction Engineering and other courses. In these different courses, you might have come across design of various chemical engineering equipments. Try to look back at what are the different types of assumptions which you make while designing any equipment for a chemical plant. Let us take an example from heat transfer.

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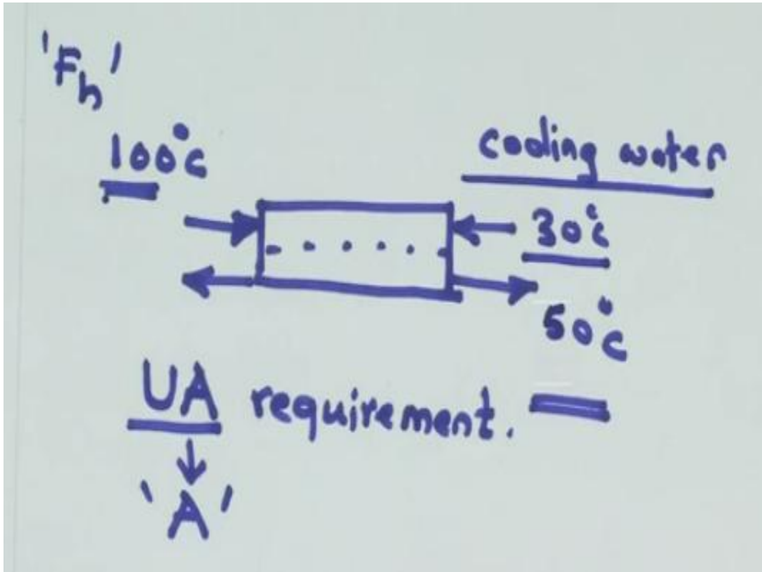


Let us consider that you are designing a heat exchanger so that you cool a process stream which is available at 100^{o}C and you have to cool it all the way up to 50^{o}C. This can be done by passing a cold fluid from the other side of the heat exchanger. So let us say you have cooling water available at 30^{o}C. You can do the calculations for this exchanger and eventually you will find out what is the UA requirement for this particular exchanger and accordingly find out what is the area of the exchanger. Now you will buy an exchanger according to that particular area as well as UA specification.

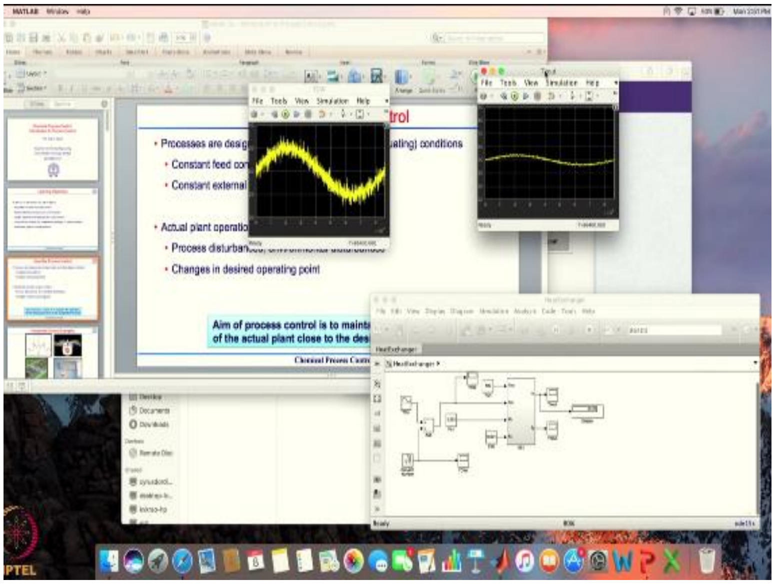
Now let us think that if you put that exchanger in the real plant, would it always give me 50^{o}C as the outlet of the hot stream? It will give you that provided,

- your hot stream enters at 100^{o}C
- your flow rate of the hot stream remain constant at the value which was designed
- your cooling water is available at 30 degree Celsius.

However all these assumptions are not always possible. It is not always possible to maintain all these assumptions when the plant is actually operated.

When you design a plant, you always design it at non-fluctuating or constant properties such as the feed conditions, speed temperature, flow rate, feed composition as well as the external parameters being constant like the cooling water temperature. However, when you operate the plant, the plant operation is quite dynamic and it is subjected to various disturbances.

Figure below shows a simple simulation highlighting what happens if you have real life cooling water temperature rather than a constant value of 30^{o}C. **(Refer Slide Time: 05:03)**



So typically cooling water comes from a cooling tower and the temperature which you get is typically dependent on the ambient temperature and you all know that during the day as well as night time ambient temperature does indeed change and here you can see that the cooling water temperature cannot be maintained exactly at 30^{o}C which was the assumption for our design and it does change throughout the day as well as night.

If such a cooling water temperature is available for the heat exchanger, the outlet which comes out from the exchanger hot side, will never be exactly equal to 50^{o}C. It will oscillate depending on the cooling water temperature and what you get at the end is an average performance which is similar to what we have designed. Hence, the local or the instantaneous temperature of the hot stream is not guaranteed to be at 50^{o}C.

So if this particular stream is going to a different unit operation, let us say it is going to a separation system which requires the inlet temperature of 50^{o}C, then we will not be able to maintain that particular inlet temperature. So the take home message is, the actual plant operation is quite dynamic because it is subjected to various process disturbances, environmental disturbances as well as instances when you have to run the plant at a different operating point even though you have designed the system at a particular operating point, due to different changes in terms of market conditions or different changes in the topology of the process you want to operate the process at a different operating condition.

You want the plant to move from one point to the other and thus there are changes in the desired operating point. So in such cases you do not go about changing the design every time because it is not always feasible to change the design of a process every now and then. So what you end up doing is, you implement a system which will ensure that irrespective of such disturbances as well as fluctuations, what you get out of the process is same as what was the original objective. This is the job which a process control system does. The aim of process control is to maintain the operation of the actual plant close to whatever is your desired point. Control is a very commonly found theme. Process control deals with control of chemical engineering processes but in general control is a very common phenomena and let me motivate it through some of the household common control examples.

The first example considers taking shower. Let us say you take shower every day and you typically try to have some feel-good temperature as well as feel-good flow rate of water when you try to take bath and you are typically provided with two sorts of nozzles or two sorts of valves so you can change the flow rate of cold water as well as hot water and accordingly you mix them such that whatever water you get out of the shower has the required temperature as well as the flow rate. Here the objective is that, you want a certain temperature as well as flow rate of the water coming out of the shower.

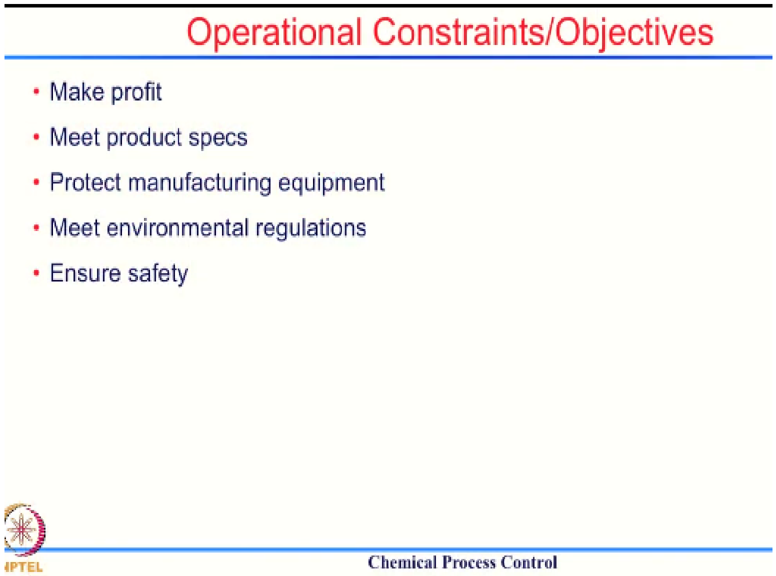
The other example is a pressure cooker. When we cook, we typically want to cook it at a higher temperature and thus we want to maintain a certain pressure inside the pressure cooker. How do we maintain that? The way a pressure cooker works is, if the pressure of the steam inside the cooker increases or reaches the value which we desire then the whistle gets blown up. As the whistle opens, the steam goes out and suddenly the pressure starts dropping. As soon as the pressure reaches the lower value, the whistle again goes back to its original position. So that way by having a manual whistle you are able to maintain pressure inside a pressure cooker.

The next example is crossing the road. When we want to cross the road, we typically have an objective that we want to go from one end of the road to the other without getting hit by any vehicle. What happens in such scenario is, we have control on how fast we can go and when we can cross the road. The disturbances here are the cars or other vehicles coming from both the sides. So we have to ensure or we have to predict whether we are able to cross the road without being hit. In this case you try to predict how fast the car/vehicle is coming, how much time would it take till it reaches you and accordingly you try to calculate whether you would be able to cross the road or not safely.

The last example concerns air-conditioning. The job of the air conditioner is to maintain the temperature inside a room that we specify. If we set a particular feel good temperature for the room then it is the job of the air conditioner to maintain that temperature irrespective of whatever is the outside temperature or how many people are inside the house. So in a way it tries to maintain that temperature by manipulating its operation.

Through all these four examples you can see that every control system has an associated objective with it. If you take the shower example, here we want to maintain the temperature and flow rate. In the case of cooker example, we want to maintain the pressure. In the case of crossing the road, we want to cross the road without getting hit or cross the road safely and in the case of air conditioner we want to maintain a constant temperature.

When we talk about process control these objectives are related to the process. For a chemical plant, the control system will be used to satisfy some of these objectives as well as some of the constraints. So If you are operating a chemical plant what are the different objectives which an operator has to maintain? First and foremost a process or a chemical plant has been setup to make money and the primary objective of operating a plant is to make profit.



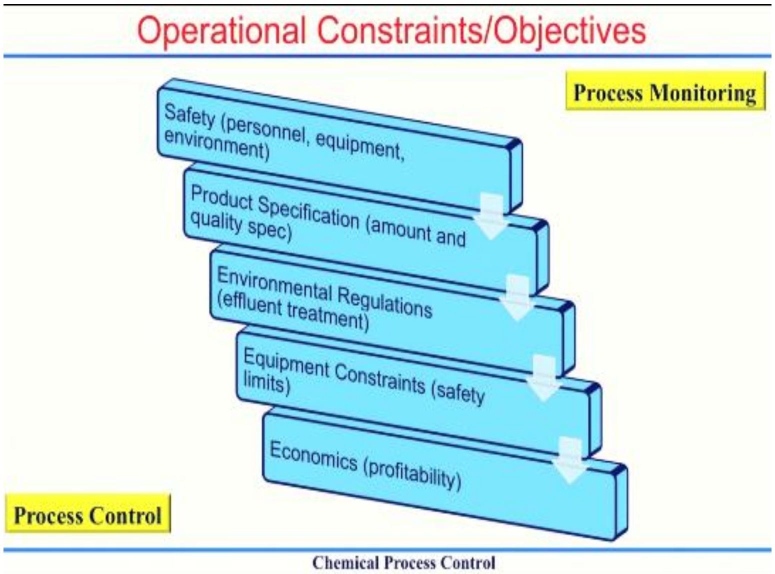
Now if you have to make profit out of a chemical plant you have to make sure that whatever the product which you are making meets the specification. If your product does not meet specifications, there is no way you can generate profit out of that plant.

Another important objective is to protect the manufacturing equipments so that equipments last their lifetime that is 10 years or 15 years. This can only happen if you take good care of your equipments. While making product out of your plant you also want to make sure that you are protecting the equipment, you are not running it towards its limit, so that you can use your machinery for a very long time.

While doing all this, you have to make sure that you are not polluting the environment because that is where eventually you are going to live in. While achieving profit as well as production specifications you also have to keep one eye towards meeting environmental regulations. The last but the most important objective is to achieve the above objectives while maintaining an safe environment for the personnel working in the plant and general public living in the nearby communities.

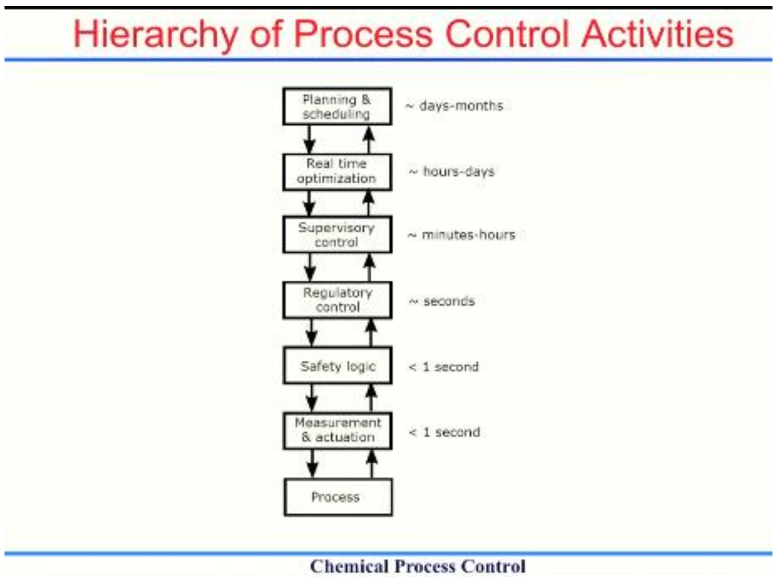
When you are operating a chemical plant, you have to ensure that these are the different operational objectives or constraints within which you have to operate. So if you connect the two slides we should have some sort of control strategies which will take care of all of these. So before moving forward let us see whether these objectives which we talked about are all taken care of in the same order or there is a special hierarchy in which these different objectives have to be satisfied.

The hierarchy in which these different decisions or constraint are to be satisfied are presented in the figure below.



First and foremost the plant operator has to ensure the safety of the personnel who are working inside the plant as well as those who are around the plant. The safety of personnel, equipment, environment always takes a prior, the first seat. Once you ensure that the plant is safe to operate, you try to make sure that the product which you are getting out is of required grade. Then you try to minimize whatever is the burden on the environment. You want to ensure these specifications while minimizing the effluents which goes to the effluent treatment. Next, you look at elongating the life of your equipment by trying to ensure that all the equipments operate within the safe limit. Once all these objectives are ensured we try to look at improving the profit. So in a way even though your primary objective of operating a plant is to make money, it typically comes as the last layer of your operational constraint.

There is always a control system associated with all these different layers. Let us say if you are a plant operator, in order to ensure whether the plant is safe or whether your product specifications are met or not, what you need to know is where are you currently standing. If you want to ensure safety you want to know how far I am away from the safety or if you want to ensure that the product specs are met or not, you want to know what are the current product spec and how far you are away from the boundary. So all that requires an eye into the system and that is done by doing what is known as process monitoring. Different instruments inside the plant will give you a measurement about how or what is the current state of the process, whether it is close to any operating constraint or it is away from the constraint and once you know where your system is at and you know what is your target performance then you can take some action and move the plant from your current point to the desired point. So that becomes the role of process control system. Figure below depicts a typical hierarchy of process control activities in a chemical plant.



At the bottom layer is your actual process and the first action is the measurement and actuation. This consists of all the instruments which are put into the system either to read value from the process or to take some action on the process. So these are the hardware elements inside the process and they will operate at a very fast rate, let us say at a second level or at the time interval of few seconds.

On top of that, the first and primary layer of control is the safety logic. This is the fall back or the primary safety which is inbuilt into the system. So irrespective of whether you have an additional control system or not, this particular safety logic will always ensure that your system does not violate any basic safety boundaries.

For example, in the example of steam pressure cooker mentioned earlier, the pressure cooker also comes with a safety valve. So if there is some problem in terms of the whistle i.e. whistle does not open or close, then there is always a rupture disc which is on top of the cooker which will open if the pressure reaches some unsafe limit. As soon as that happens irrespective of whether the whistle is working or not, the burst disc will burst and the pressure will be released.
Every chemical system will always be associated with some sort of safety logic which will ensure that even though there is no control system or the control system fails, that particular logic will ensure safety of the plant. Now on top of that is the first level of control, which is the regulatory control. These are the basic control actions which are taken at the frequency of few seconds. There are other advance control strategies which are on top of that which will subsequently ensure additional objective. In nutshell, primary regulatory control will try to ensure the product specifications, the basic objectives of the control system and then as you go above this particular hierarchy you will move towards making more profit out of the plant.

Let me explain all these hierarchies for a simple example of CSTR which is going to carry out a reaction, to generate some gaseous product along with a liquid product.

$$A \rightarrow B + C$$

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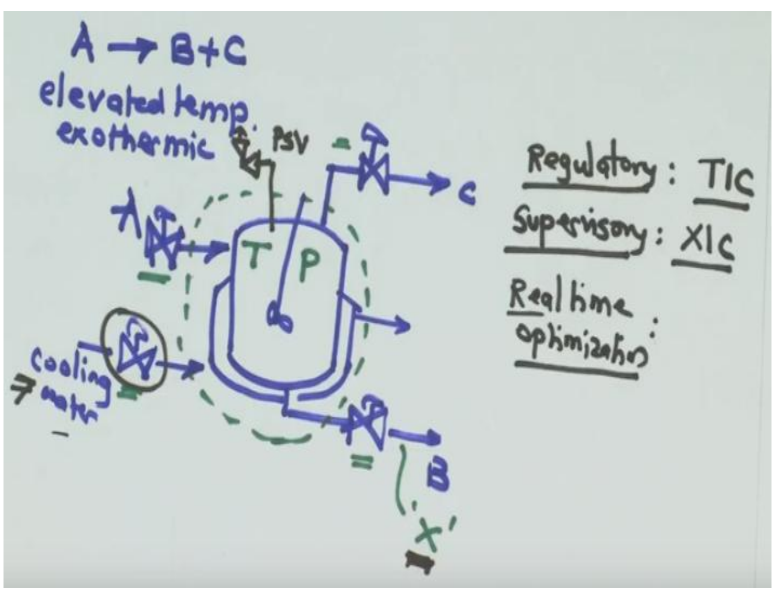

Feed A is coming in through a feed valve, reaction is carried out in the CSTR. The reaction yields B, which is liquid and a gaseous product C. There will be one product valve for B and another gas valve at the top. This is an exothermic reaction. So in order to maintain temperature you would have to have some cooling system. We will look at what are the different hierarchies of the control system for this particular system. The main process includes the reactor and the jacket. Then we will have measurement and actuation. So here the measurements would be that of the pressure and the temperature inside the reactor.

It may be composition of the product which you want to maintain. In terms of actuation, you have feed flow valve and product valves. So this is how the system can be actuated. Now the first and foremost is the safety control logic. So in this typical example, what you would want as a safety precaution is that the pressure inside the reactor should not blow up if there is excess production of C. In that case, what you want to ensure is, if the pressure inside the vessel goes to a very high value there should be some safe route and that is typically achieved by having something known as a pressure relief valve which will ensure that if the pressure inside the reactor goes to a very high value, it will open up and have a safe release of the gaseous product.

Now we move on to the regulatory layer. The regulatory layer is the basic control system which has to take decisions of maintaining the operation at a timeframe of few seconds. Typically for this particular system it will involve controlling the temperature. We typically represent it as TIC which refers to Temperature Indication and Control. So the regulatory layer will ensure that the temperature inside this reactor is maintained at a particular level. This is done by manipulating the cooling water flow rate by manipulating the valve opening. The idea here is, if I maintain a particular temperature in this reactor, then we are also somehow ensuring that if all the other conditions remain the same then the conversion or the product purity remains more or less at the same value or the desired value.

The next level of control is the supervisory control. Now even though we are controlling temperature at the regulatory level, our main objective out of this reactor is to get a product of required purity. So what we want is a particular composition to be maintained at a desired value. So your composition control will come at the supervisory level and what it will do is, it will try to dictate how the temperature controller loop change operates so as to ensure a particular value of the composition.

Now we go to the higher level. Let us say if we talk about the real time optimization it will try to find out what is the best value at which this particular composition should be maintained so that I minimize the cooling water or I maximize profit and then lastly when we talk about the planning and scheduling level, it actually looks at what are the market conditions, what is the demand, what are the raw material cost and accordingly it tries to predict at what particular time, which particular product or what particular purity has to be maintained, how much amount of product has to be produced. All that planning type of decisions are taken at the higher level. So with this simple example we could see that there are different objectives in a chemical plant and there is no single control system which maintains all these objectives.

There is always the hierarchy of decision making and hierarchy of control systems and each control system has an associated hardware with it and an objective associated with it. So we will take a short break and when we come back we will look at what are the different functions of a chemical or control system. Thank you.