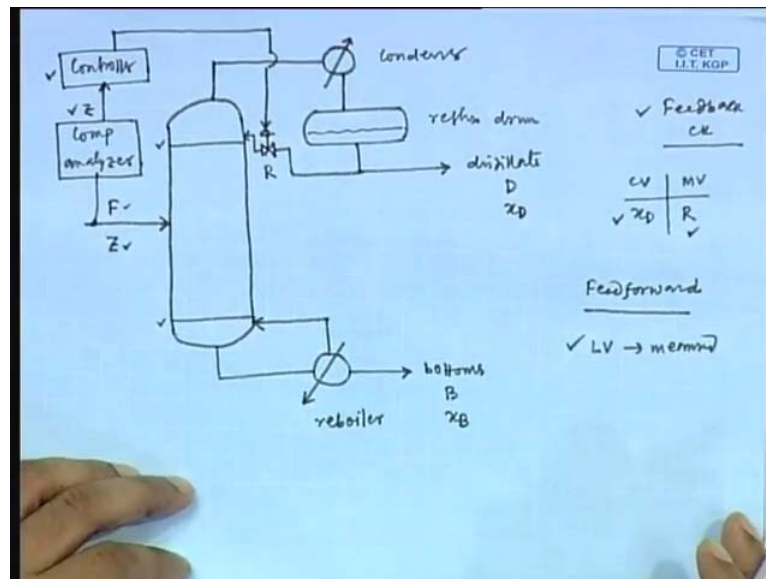


Process Control and Instrumentation
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Lecture - 2
Introduction to Process Control (contd.)

Today, we will continue our discussion with the example of distillation column.

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Again I am drawing the schematic of the distillation column, this is the tower now, feed is introduced in the feed tray. Feed flow rate is F , composition is z then, the operate vapor lifts the top tray and then, that is condensed in the operate condenser. The condense liquid is then accumulated in this reflux drum, this is the reflux drum, this is condenser then, a part of this liquid is taken out as distillate, this is the top product with flow rate D and composition x_D .

Now, another part of this accumulated liquid is recycle back to the top tray, this is the top tray so, this is the connection for the reflux rate and the bottom liquid which left the bottom tray, this is bottom tray is reboiled in the reboiler, this is the reboiler. Then, the produced vapor is recycled back just below the bottom tray and a part of the liquid is withdrawn as bottoms, this is the bottom product which has the flow rate of B and composition of x_B .

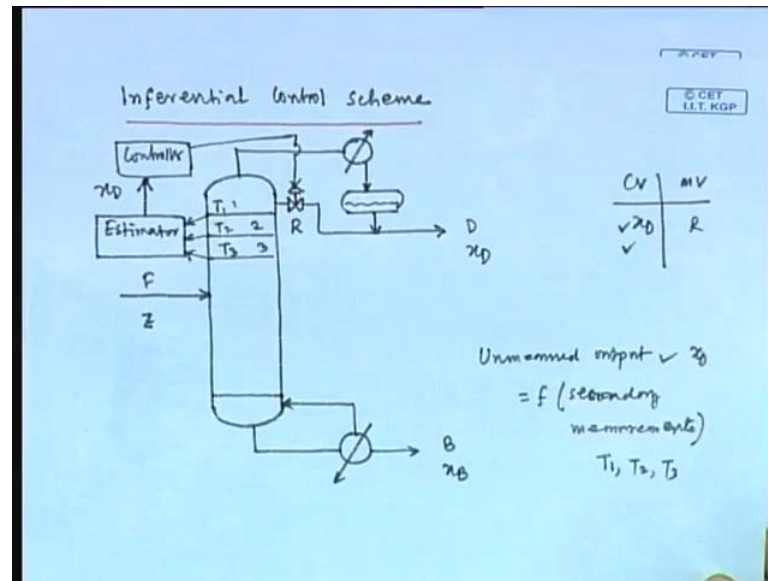
We have discussed with this example and one control configuration we have drawn in the last class, that control configuration was the feedback control configuration. That was the feedback control configuration, in that feedback control configuration, we have majored x_D basically for this particular process, the controlled variable is x_D and corresponding manipulated variable is reflux rate, this is reflux rate. We are considering only the single loop at the top, we are not presently the considering the bottom loop.

Now, in the feedback control configuration we have seen that, the controlled variable which is x_D was directly measured to manipulate the reflux rate. Today, we will consider another control scheme that is, feed forward control scheme. First, we will configure this feed forward control scheme for this distillation column, in this feed forward control scheme, the disturbance is measured. Here, disturbance is the feed composition as well as feed flow rate but, we are considering this is the majored variable.

Now, for measuring this feed composition, we need one composition analyzer, this is composition analyzer, which is measuring basically the feed composition z . We are assuming that, this composition analyzer output is exactly identical with the feed composition. Then, this information z goes to the feed forward controller, this is the block for feed forward control scheme then, these feed forward controller calculates the control action based on this feed composition and this controller action is implemented through this control valve.

For the feed forward control scheme, disturbance variable or load variable is measured using one composition analyzer then, that measured feed composition information goes to the feed forward controller. Then, the controller calculates the control action and that control action is implemented through this control valve. So, the major difference between the feedback control and feed forward control is, for the feedback control scheme, we measured directly the controlled variable and for feed forward control scheme, we measured the load variable or disturbance variable. There are many other differences, which we will discuss in the subsequent classes, another control scheme we will discuss next with this distillation example that is, inferential control scheme.

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So, we will consider the same distillation column to discuss inferential control scheme, this is a schematic of the same distillation column. Feed is introduced here then, the operate vapor is condensed and condense liquid is accumulated in the reflux drum, a part of that liquid is recycled back to the top tray as reflux stream and a part of the liquid is withdrawn as distillate. At the bottom section, we incorporate one reboiler, the vapourised stream is introduced just below the bottom tray and at the bottom, the bottom product is withdrawn.

Now, in this inferential control scheme, the x_D which is controlled variable is not directly measured, most composition analysis provide large delays in the response. Secondly, it provides high investment and maintenance cost that is why, sometimes this composition I mean, the product composition is not directly measured. In that case, we search for the secondary measurements and then, using those secondary measurements, we can infer that product composition, that is the purpose here.

So, to estimate x_D , we need to select the secondary variables for this particular example suppose, this is first tray, this is second tray, this is third tray. So, the temperature of this first tray is suppose T_1 , this is T_2 , this is T_3 it is quite easy to measure the temperature compare to the composition measurement. So, we can say that, these three tray temperatures we can consider as secondary measurements so, we will measure these three temperatures using thermocouples.

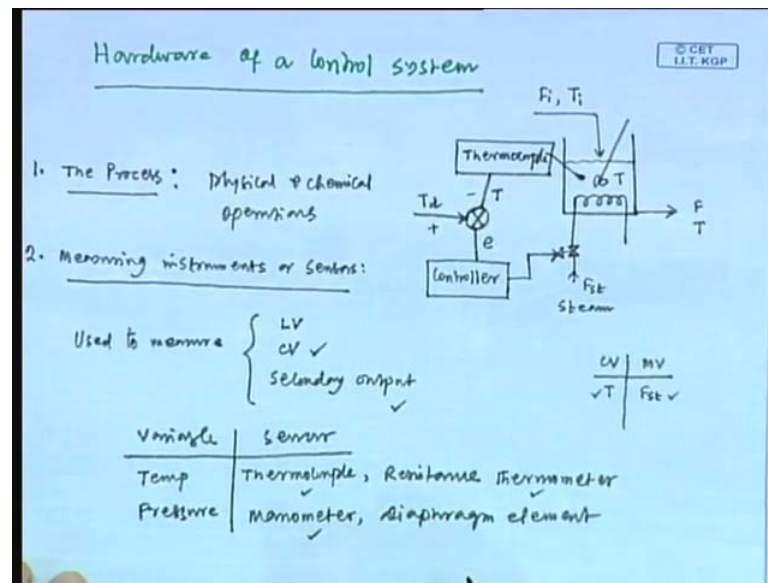
Then here, we put one block for estimator, these three temperature after measurement, the temperature information goes to this estimator, this estimator basically nothing but, one algorithm which consists of some equations and correlations. These correlations basically, calculate the x_D based on the information of the major temperature. So, here, some mathematical equations are included within this estimator and using those equations, we can directly calculate based on this measured temperature information x_D value.

Basically, this composition is inferred based on the measure temperatures then as usual, this estimated composition x_D goes to the controller and the controller calculates the action and those control actions are implemented through this control valve. Since the product composition, which is the controlled variable is inferred that is why, the controller is called inferential controller. So, we can write that, the unmeasured output basically is the function of secondary measurements.

Here, the unmeasured output is x_D and the secondary measurements are three temperatures T_1 , T_2 and T_3 . So, I have mentioned earlier that, why we prefer this control scheme, inferential control scheme because, if we directly one to measure this product composition in that case, we need composition analyser. And most composition analysis provide large delays in the response, this is the first drawback, most product composition analysers provide large delays in the response.

Second drawback is high investment and maintenance cost, this is the second drawback for the use of composition analyser. So, this is all about the different controlled configurations with the example of distillation column. In the next, we will discuss the different hardware elements of a control system.

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We will discuss different hardware of a control system, to discuss this topic it is better to take one example. We will continue the heating tank system, to discuss this topic it is better to consider one example and we will continue the heating tank system, which will be discussed in the first class. This is the heating tank system, feed is introduced with a flow rate F_i , temperature T_i and product is withdrawn with a flow rate of F and temperature T .

Now, to heat the liquid in this tank, one steam stream is introduced with a flow rate suppose, F_{st} and for this particular system, we have this control pair I mean, controlled variable and manipulated variable pair, we want to maintain the temperature through the manipulation of steam flow rate. Our control objective is to maintain the temperature of this tank and that is why, this is our controlled variable, corresponding manipulated variable is steam flow rate.

So, this is basically a close loop system I mean, this is the open loop system if we want to make it close, we need to include the controlled scheme, this is open loop now, we want to close it by introducing controlled scheme. So here, temperature is a controlled variable so, we need to first measure the temperature by using one thermocouple. This is a thermocouple then, this measured temperature T goes to the comparator, this is the comparator.

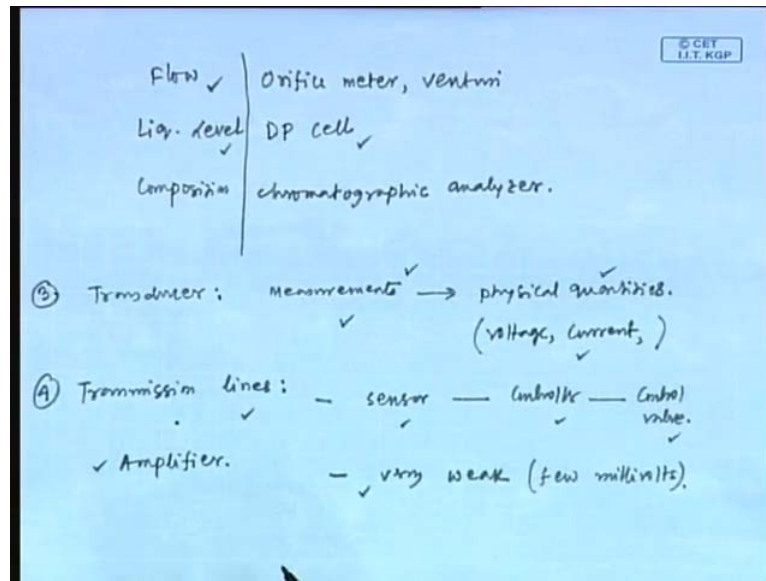
The measured temperature is compared with the desired temperature, this is positive, this is negative, output of this comparator is the error signal. Then, this error signal goes to the controller then, the controller calculates the control action and that control action is implemented through this control valve. So, this is basically the close loop system now, we will discuss what hardwares are involved in this close loop system so, first one is the process.

In this process, physical and chemical operations occur, this heating tank system is a process, this is the first hardware involved in this close loop system. Second hardware is, measuring instruments or sensors, this measuring instruments or sensors are used to measure, these are used to measure first one is load variable. These sensors are used to measure controlled variable and secondary output, third one is secondary output.

Although we have shown here, only the measurement of controlled variable but, we can measure also the disturbance variable and secondary output by the use of the measuring device or sensor. So, we will just discuss in brief what are the different measuring devices used for different variables. So, we can write them in a table form, variable and sensor used for measuring that variable like first variable is temperature say. Temperature we can measure by the use of thermocouple, we can use thermocouple, we can use resistance thermometer.

We can use thermocouple for measuring temperature, we can use resistance thermometer but, mercury thermometer is not good because, the measurement cannot be transmitted readily. Mercury thermometer is not good option because, the measurement signal cannot be readily transmitted. Next we will consider another variable that is pressure, pressure we can measure by the use of manometer, by the use of diaphragm element. For measuring the pressure, we can use manometer, we can use diaphragm element.

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Next, we can consider another variable that is a flow rate, flow rate we can measure by the use of orifice meter, flow rate we can measure by the use of venturi so, these are two measuring devices, which are extensively use for measuring the flow rate. Like, another variable is liquid level, liquid level is measured by the use of differential pressure cell, DP cell. Liquid level in the tank is measured by the use of differential pressure cell, another one is composition, composition is measured by using chromatographic analyzer.

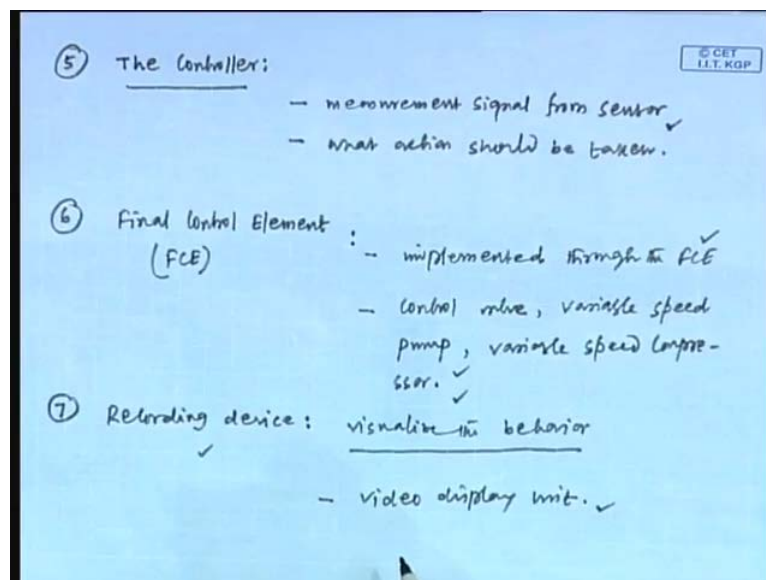
Although we have started all these things in the instrumentation part in details but, just to know, which devices can be use for different variables, we have just discussed in brief so, our second hardware was the measuring instruments or sensors. Now, third hardware is transducer now, measurement signal, measurements cannot be used for control until they are converted to physical quantities. Physical quantities say for example voltage, say for example current, say for example pneumatic signal.

So, measurements cannot be used for control until they are converted to physical quantities, which are readily transmitted, these signals we can readily transmit. And this is the purpose of the use of transducer basically, the transducer physically convert the measurement signal to the physical quantities. Next one is transmission lines, this is use to carry the measurement signal from sensor to the controller and from the controller to

the control valve. The transmission lines are used to carry the measurement signal from sensor to controller and then, from controller to control valve.

If you see the schematic representation of the close loop system, I think you can clearly understand this so, this is the usage of the transmission line. Now, measurements signal is sometimes very weak, sometimes the measurement signal is very weak say for example, in few milli volts. In that case, this transmission line is equipped with amplifier, when the measurement signal is very weak in that case, the transmission line is equipped with amplifier, this is the fourth hardware which is involved in the close loop system.

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Now, fifth hardware is the controller, this is another hardware which receives measurement signal from the sensor. The controller basically receives measurement signal from sensor and then, it decides, what action should be taken based on the major values. So, the controller basically receives the measurement signal from the measuring device in the next step, the controller calculates the control action based on the measured signal comparing with the desired value of that control variable.

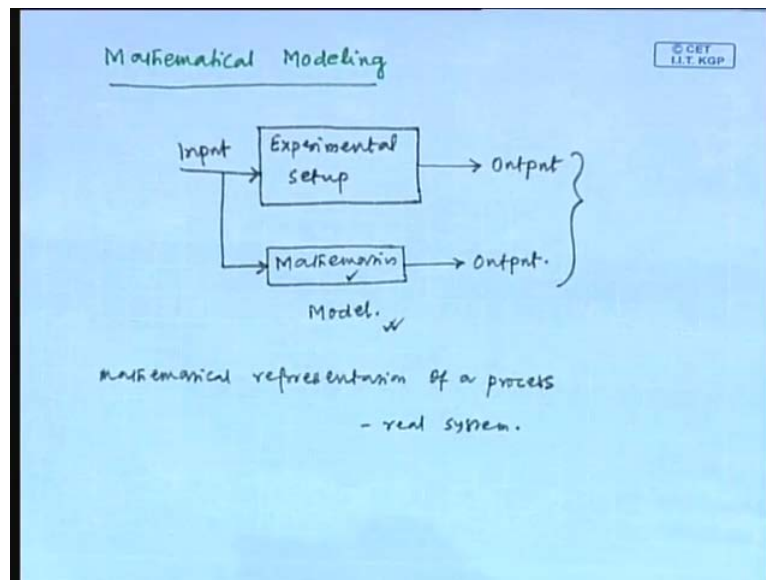
Sixth hardware is the final control element now, for the case of controller I told, that the controller basically calculates the control actions. Now, that control action is implemented through the final control element so, the control action, which is calculated and produced by the controller that is, physically implemented through this final control

element. Can you give any example of the final control element, yes first example is say, control valve, another example is variable speed pump, variable speed compressor.

Why variable speed, if the speed is fixed then, that cannot be changed that is why, variable speed pump and variable speed compressor. Now, next hardware element is a recording device, this is used to visualize the plant behavior through the measurement signals. If we used to visualize the plant behavior at different situations, we need one recording device and that realization we can achieve through the measured values. And for this purpose, we can use video display unit, which is usually accommodated in the control room.

Video display unit can be used for this recording purpose, which is usually accommodated in the control room. So, these are about the hardware elements for a particular process so far we have discussed, the first topic that is, introduction to process control. In the next, we will discuss the second topic that is, the mathematical modeling and the use of mathematical modeling in process control.

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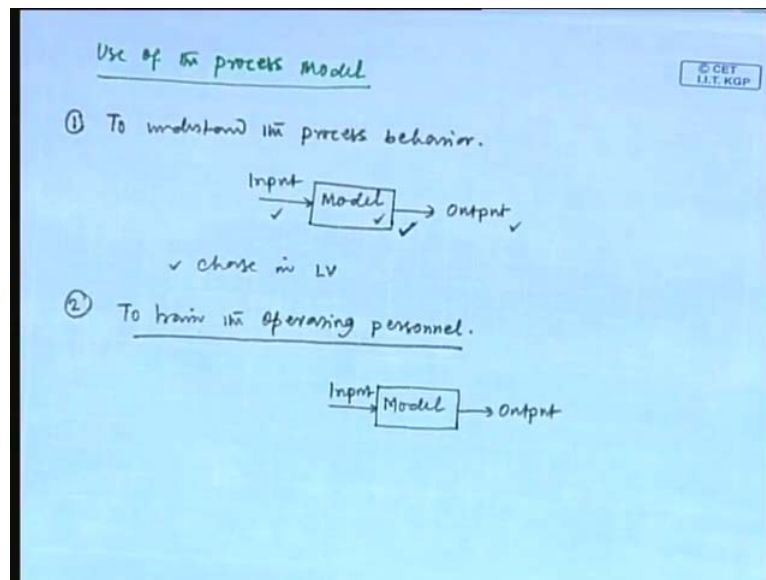
So, we will start to discuss the second topic that is, mathematical modeling first we will know in brief, what is the mathematical model. Suppose, we have one experimental setup so, we will represent the experimental setup, we will use one block to represent the experimental set up. Now, to this experimental setup, the input is introduced I mean,

input is introduced to the setup and if we run the setup, we get output this is a common thing in our laboratory which happened.

So, what is basically the model, can we represent this experimental setup by some mathematical equations or correlations we can? We can represent this mathematical setup by some mathematical correlations or equation. So, suppose, some mathematics are involved then, we are giving the same input to this block, we will get some output. Now, this block is the representation of the model, we are just representing this experimental setup by mathematical correlation.

Now, if these two outputs are close enough then, we can say that, this model is a good model so, model is the mathematical representation of a process, intended to promote understanding of the real system. A real system, we can represent by using some mathematical equations and correlations so, this is the definition of model. And next, we will discuss about, what is the use of this model, why we will develop the model, what is the use of mathematical modeling in process control, that we will cover in the next.

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So, use of the process model, first we can write to understand the process behavior suppose, we have the model and we have the solution of this model, also we are giving some input to this model, we can get the output only if, we have the solution otherwise, we cannot get the output. We have develop the model structure for a particular process,

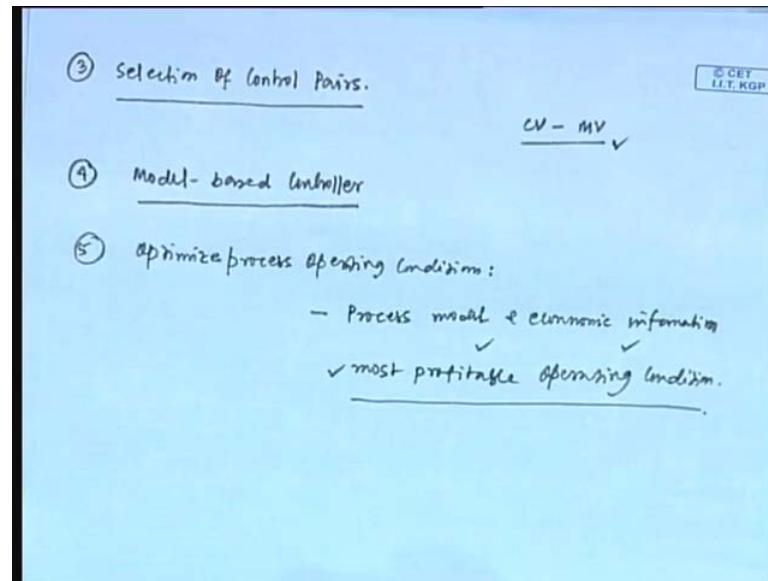
we are giving some input information to the model basically, the input information is specified and then, if we solve the model then, we can get some output.

Now, suppose, the model initially is at steady state I mean, after start of we can reach at steady state. Now, at steady state, we are giving some change in this disturbance variable then, the process will shift from steady state to another state. Basically, if we change in load variable, we will get some transient response and that transient response we can get by performing this simulation of this model without performing experiment, is not it. So, we can understand the process behavior by some change in load variable, to understand the transient behavior without performing the experimental setup.

So, this is the first purpose of the model secondly, to train the operating personnel, the model we can use for training purpose, without running the experimental setup or without running the plant. Suppose, we have the model structure same thing which we have drawn earlier, we have some input, we have output. Now, some situations can be irritated using this model like, the feed is introduced to a particular process here, we are directly using some value for the feed flow rate.

Now, suppose, the pump is not delivering the feed to the process what will happen, suppose in the distillation column, we have some minimum reflux rate. If we consider lower than that minimum reflux rate, what will happen so, these types of emergency situations, we can irritate by the use of this model, without disturbing the process. Or even some situations cannot be permitted to irritate in the real process so, to train the operating personnel, we can also use the simulated model.

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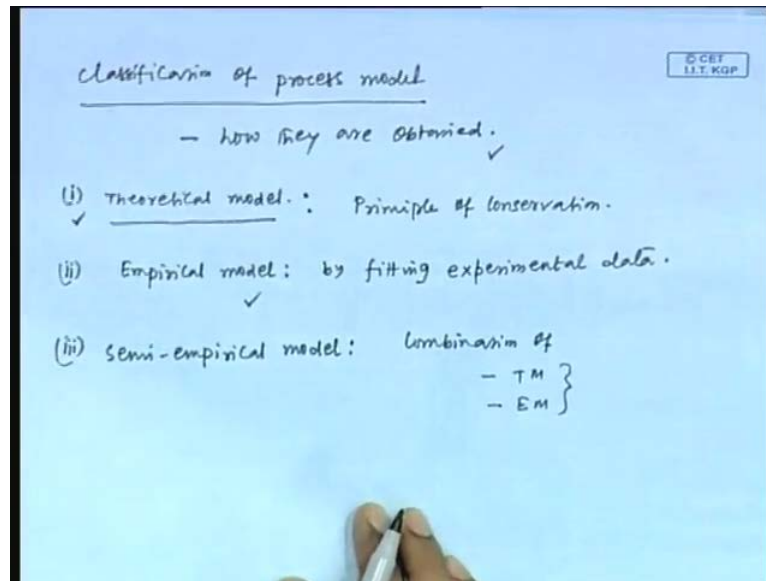


The next purpose is selection of control pairs, we have taken few examples and we have discussed the controlled variable and manipulated variable pair. But, this controlled variable and manipulated variable pairs, we can select by knowing the model of that particular process. So, if we know the model of a particular process, we can determine the pair between controlled variable and manipulated variable so, for this purpose also, we need the process model.

Fourth purpose is, to develop the model based controller, you know most of the advanced controllers are model based controller and the name clearly suggests that, the controller which consists of or which includes the process model, those controllers are basically model based controller. So, most of these advanced controllers, use the process model so, in that sense we can say that, we need the process model for the development of advanced controllers.

Fifth one is, optimize the process operating conditions, to determine the most profitable operating condition, we need the process model and economic information. So, we need process model and some economic information to determine the most profitable operating condition. So, we need the process model, we need some economic information to determine the most profitable operating condition. So, these are the issues, for which we need the process model next, we will discuss the classification of process model.

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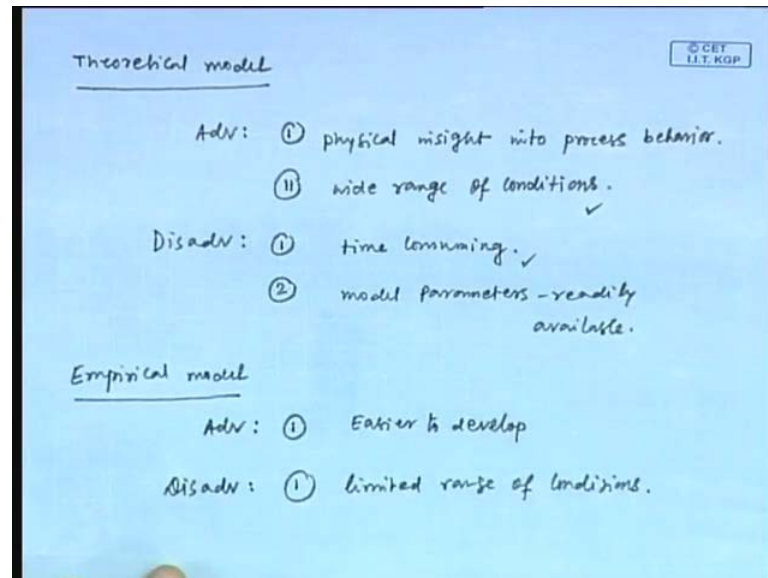
There are different ways to classify the process model but here, we will discuss the classification of process model based on, how they are obtained. There are three different models I mean, we can classify in three different ways, three different models are there, first one is theoretical model. The theoretical model is basically developed based on principles of conservation, this is developed based on the principle of conservation.

So, first type of model that is, theoretical model and this model is develop principle of conservation, I think you know the principle of conservation like, mass conservation, energy conservation, momentum conservation. And another type of model that is empirical model, this model is obtained by fitting experimental data, the second type of model that is empirical model, this empirical model we can obtain by fitting experimental data.

Basically, if we have the experimental setup, we have different sets of input output data now, if we have the input output data by fitting those experimental data, we can determine the coefficients. By that way, we can construct a model and that is the empirical model. Third one is just the combination of these two, theoretical and empirical model, that is called semi empirical model, sometimes this is also called hybrid model.

Semi empirical model is the combination of theoretical model and empirical model, semi empirical model is the combination of these two. Next, we will discuss in brief, what are the advantages and disadvantages of this models.

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So, first is the theoretical model, which is developed based on the conservation principle so, what is the advantage of this model. First advantage is, it provides physical insight into process behavior, this is the first advantage. Second advantage is, it is applicable for a wide range of conditions, this is the second advantage. Similarly, what are the disadvantages, it is time consuming to develop so, it leads to be time consuming to develop because, particularly for the complex systems, the theoretical model is too large.

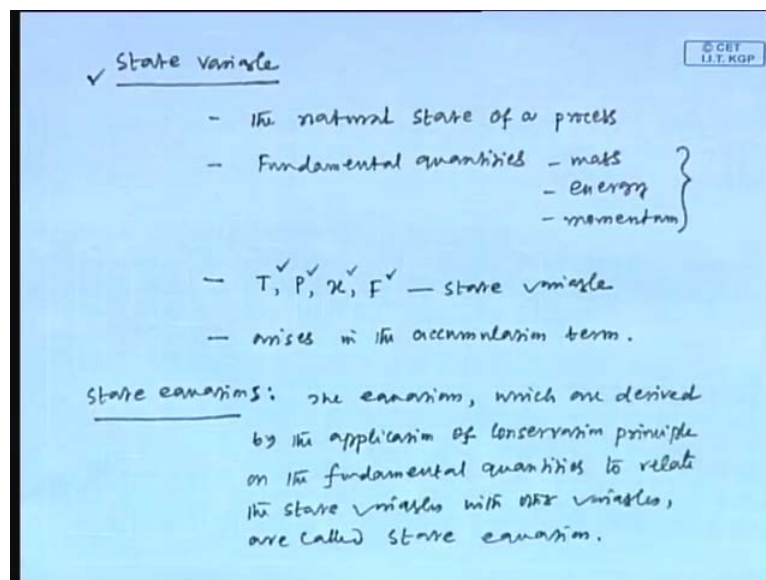
So, in that sense we can say that, this is time consuming and another drawback is, some model parameters are not readily available, some model parameters for example, reaction rate coefficient, overall heat transfer coefficient, these are not readily available. In that case, we have to follow the empirical technique so, these are basically, the two drawbacks and two advantages of the theoretical model. Now, what about the empirical model, I think we can say something for this empirical model, based on the discussion of this theoretical model.

So, what is the advantage, it is easier to develop, this is the advantage because, if you have the input output data set then, we can feed some correlations or equations using those input output data set. So, for complex process, we do not have so many equations

like theoretical model so, this is only the advantage for this case. And what are the disadvantages, this is applicable for a narrow range of conditions, this is applicable for a limited range of conditions.

So, this is the advantage and this is the disadvantage for the empirical model similarly, I think you can find, what are the advantages and disadvantages of the semi empirical model. Now, for the process control, we have discussed earlier different variables I mean, input variables, output variables then, input variables are again 2 types manipulated variable and load variable, and output variables are 2 types majored output and unmajored output. At this time, we will discuss another variable which is extensively used in process control that is, state variable that we will discuss now.

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State variable basically describes the natural state of a process now, there are basically 3 fundamental quantities. What are these quantities mass, energy and momentum, these are three fundamental quantities. Now, these fundamental quantities are usually not directly measured, these three fundamental quantities are not directly and conveniently measured. And these three fundamental quantities are usually characterized by say, temperature, by pressure, by composition, by flow rates, etcetera.

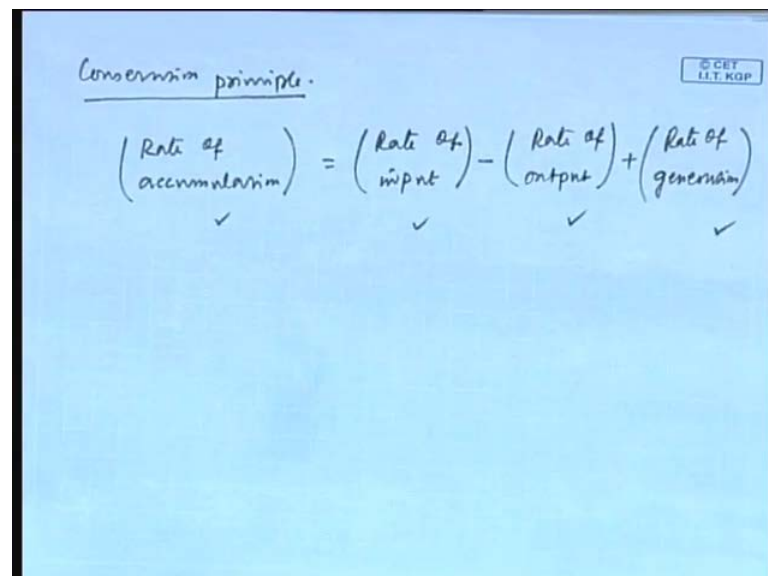
There are 3 fundamental quantities mass, energy and momentum, these three fundamental quantities are not directly and conveniently measured and they are characterized by these variables temperature, pressure, composition, flow rate and these

variables are called state variable because, they describe the natural state of the system. So, these are called state variable and it arises naturally in the accumulation term, we will discuss in the next, the conservation principle and there we will see that, the state variables usually present within the accumulation term so, it arises in the accumulation term.

Within the accumulation term the state variable is present and since we have discussed the state variable, in the next we will discuss state equations. These equations basically derived by the application of conservation principle on the fundamental quantities to relate the state variables with other variables are called state equations. The state equations are derived by the application of conservation principle on the fundamental quantities to related the state variables with other variables including other state variables are called state equations.

These are about the state variable and state equations and how, we can see the state variable within the state equation. I mean, first we will go for the development of state equation then, we will see which one is the state variable within that state equation. Now, for that purpose, we have to know the conservation principle.

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Conservation principle.

$$\left(\begin{array}{c} \text{Rate of} \\ \text{accumulation} \end{array} \right) = \left(\begin{array}{c} \text{Rate of} \\ \text{input} \end{array} \right) - \left(\begin{array}{c} \text{Rate of} \\ \text{output} \end{array} \right) + \left(\begin{array}{c} \text{Rate of} \\ \text{generation} \end{array} \right)$$

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The conservation principle, we can represent in general form like rate of accumulation equals to rate of input minus rate of output plus rate of generation, this is the general form of the conservation principle. Now, I told about the three fundamental quantities

mass, energy and momentum so, if we include here rate of mass accumulation equals to rate of mass input minus rate of mass output, that is the conservation of mass.

For the case of conservation of mass, there is no existence of this rate of generation term and for the energy conservation similarly, we can write rate of energy accumulation equals to rate of energy input minus rate of energy output plus rate of energy generation. So, this is about the conservation principle and the state equations, state variable, the description on that I mean, by the derivation of the state equation, we will know which one is the state variable, this thing we discuss in the next class.

Thank you.