Process Control and Instrumentation
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Lecture - 1
Introduction to Process Control

The name of this course is Process Control and Instrumentation. Initially, we will cover the process control and then the instrumentation course.

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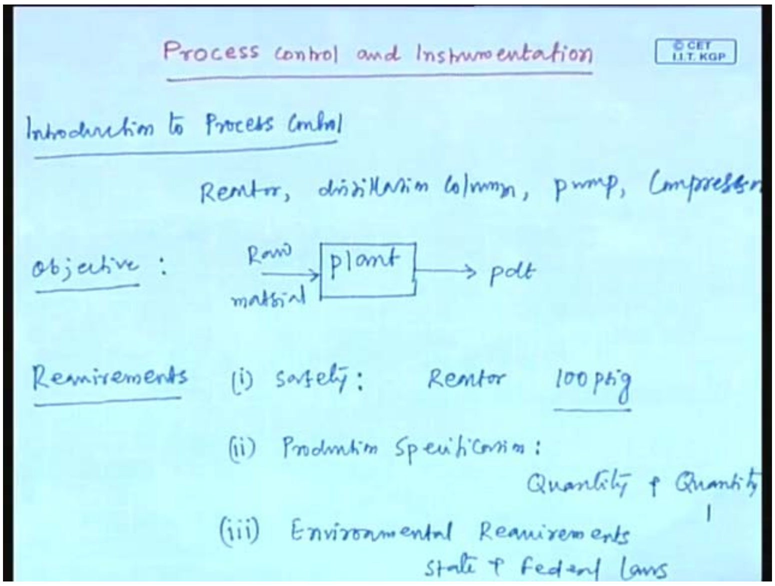

So, the first topic is introduction to process control, this topic we will cover first. Now, in chemical engineering, we have a number of chemical units; for example reactors, for example distillation column, like pump, compressor, etcetera, these are the different units which are extensively used in chemical engineering. Now, to constitute a chemical plant, we need to assemble few of these units if we assemble few of these units then we can constitute a chemical plant.

Now, what is the objective of a chemical plant suppose, we have a plant now, it receives raw material so input to this plant is, raw material and output is product. So, basically, the plant receives raw material using different available sources of energy, the plant produces products in the most economical way, this is a objective of a plant. It receives raw material, it uses available sources of energy then it produces product in the most economical way, this is the objective.

Now, to meet this objectives, we need to meet some requirements porter these requirements, the primary requirement is safety, say for example, a reactor which is design to operate within 100 psig pressure. We have one reactor, which is designed to operate within 100 psig pressure, now to maintain this pressure, we need some external intervention so that, the reactor operates below this limit, this is the first requirement that is, safety.

Second one is the production specifications, a process must produce desired amounts of product and desired quality of product. So, first one is quality and second one is quantity, this the product specifications, we need to maintain the quantity as well as the quality, that is a product specification. Third important point is environmental requirements so there are a number of state and federal laws, which enforce to maintain say for example, the concentration of chemicals.

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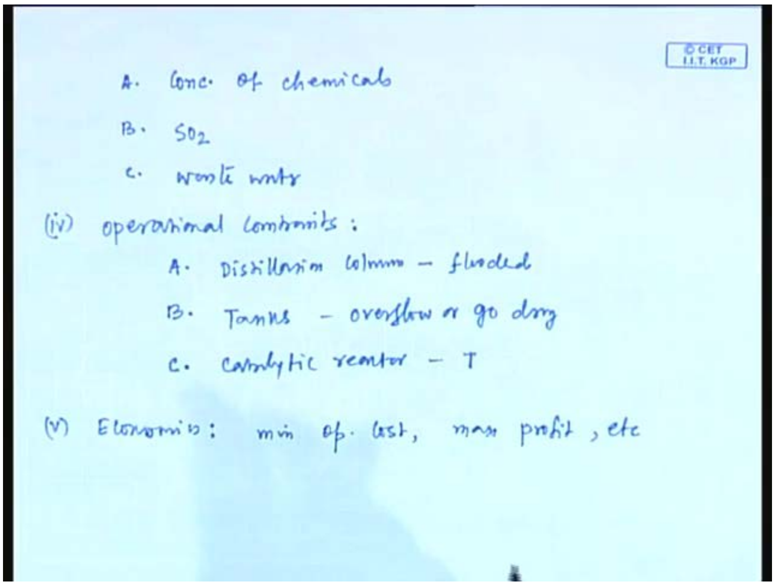

Say for example, it is require to maintain the concentration of chemicals in the effluent stream now, another example is sulphur dioxide concentration in the stream, which is rejected to the atmosphere. Second environmental requirement is, to maintain the sulphur dioxide concentration, this is example which is rejected to the atmosphere. And third example is the waste water which is retained to the river or lake, these are three examples under the environmental regulations.

Next important requirement is operational constraints now, the plant have certain constraints inherent to the operation say for example, the distillation column, this is the first example. The distillation column should not be flooded, this is one operational constraints second example is, tanks should not overflow or go dry. Third example is, the temperature in a catalytic reactor should not exceed the upper limit, if we consider a catalytic reactor.

So, the temperature should not exceed the upper limit because, if the temperature is higher than the upper limit, the catalyst may be destroyed so this is all about the operational constraints. Fifth one is the economics so it is require to control the operating conditions at given optimum level of minimum operating cost, maximum profit, etcetera.

Say for example, we need to judiciously use the raw materials, the energy used in the process the human level so that, we can minimize the operating cost and maximize the profit so these are all about the requirements to meet the plant of ((Refer Time: 09:08)). Now, it is very obvious from this discussion, that to maintain all these requirements, there is some external intervention is required and that external intervention is nothing but, the control system so to maintain, to meet all these requirements, we need to devise a control system.

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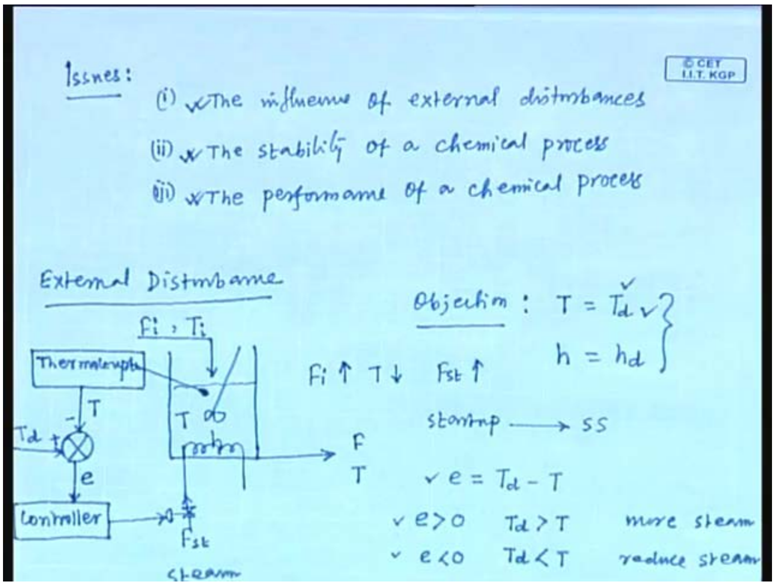

Next, we will discuss three important issues which can dealt by the control system, what are these issues. First issue is, the influence of the external disturbances, this is the first issue second one is, the stability of a chemical process, this is the second issue and third one is, the performance of a chemical process. So, these are the three important issues which should be dealt by the control system.

Now, the basic aim of a controller is, to separates the influence of external disturbances, second one is to ensure the stability of a chemical process and third one is, to optimize the performance of a chemical process. So, we need to device a control system, which separates the influence of external disturbances, it ensure the stability of a chemical process and it can optimize the performance of a chemical process. We will discuss all these three issues in brief with the help of control system.

So, first we will discuss the external disturbance so to discuss this external disturbance, we will consider a simple example that is, a tank heating system. The schematic of the tank heating system is something like this, this is a tank, a liquid steam which is entering this tank with a flow rate of F suffix i, temperature of this inlet steam is T suffix i. Now, this liquid is while stared, the outlet steam flow rate is F and temperature is T now, the liquid in this tank has the height of h definitely, the temperature is also T because, we were considering starrer.

Now, to heat up this process, we need to introduce one coil, through which steam is going with a flow rate of F suffix s t. So, this is a heating tank system, a liquid is entering the process with flow rate F i and temperature T i, the outlet flow rate has the rate of F and temperature T, one coil is introduce for heating the liquid and through the coil, steam is passing with a flow rate of F s t.

Now, what is the objective of the this process, that we need to mention first, first objective is, to maintain the liquid temperature T at it is desired value, that desired value is suppose, T suffix d this is the first objective. The temperature of the liquid should be maintained at it is desired temperature that is, T d. Similarly, the second objective of this process is, we need to maintain the height of liquid in the tank at it is desired value that is, h suffix d so these are the two objectives.

Now initially, what are the steps we need to follow for any chemical process, first is, we have to follow the startup procedure of a process. After starting of the process, it reaches at steady state, we are presenting that by ss so after starting up the process, it reaches at steady state. Now, suppose, the process is at steady state and if there is no external intervention I mean, if there is no change of F I, there is no change of T i, there is no change of F s t, the process remains at steady state all the times.

So, if there is no change of any input variables then the process remains at steady state so there is no need of any control system but, this is not the case in practice. Usually, the input variables may change with time, not regularly but, maybe in some interval say, for example this heat, inlet flow rate which is coming from one upstream unit. So, we do not have any control on F i and T i exactly so this is the practical case where, the input variables may change with time and that is why, we need to devise a control system.

Now question is, how we can devise that control system and how, we can keep this objectives say, for example, we are considering the first objective I mean, we need to maintain the temperature at it is desired value, how we can maintain that. First of all, we have to measure this temperature of this liquid steam, we can measure the temperature using one thermocouple say, this is a thermocouple employing, which we can measure the temperature of this liquid.

And suppose, the thermocouple outlet I mean, the temperature which is measured by the thermocouple, that is exactly the liquid temperature T. Now, this temperature is then compared with the desired value that is T d, this input T d is given by the person who is in charge of operation or you can say, value of this T d is specified by the control engineer. Now, we compare this T d and T, and the outlet of this comparator is e, that is nothing but, the error and that error is T d minus T.

So, we can do one thing, we can put here positive sign and here negative sign, this error signal goes to a controller, this error signal is the input to the controller then this controller produce or calculates control actions and that control action is implemented through this control valve. So, this is a heating tank system, we are considering only the first objective that is, we need to maintain the temperature at it is desired value. We are not considering the second case so initially, we need to measure the liquid temperature using one temperature sensor that is, thermocouple.

We have assume, that the thermocouple outlet temperature is exactly equal to the liquid tank temperature then this temperature is compared with the desired temperature that is, Td. So, we have used one variable that is, error which is represented by e, e equals to T d minus T then this error signal goes to the controller, controller calculates and that calculated action is implemented through this valve. Now suppose, error is greater than 0 this is the first case, error is greater than 0 it means, T d is greater than T that means, the desired temperature is higher than the temperature exist in the liquid system. So, what is require to do for the controller?

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Yes, the controller will increase the F st so it is require to increase the steam flow rate that means, more steam is required to flow through the control valve, this is one case. Similarly, if error is less than 0 in that case, the situation is just opposite I mean, T d is less than T that means, the control should reduce the stem flow rate. Now, we have to introduce this fact in terms of the disturbance, here the disturbance is basically, the feed flow rate and temperature.

Suppose, feed flow rate has been increased, this F i feed flow rate increases now, there is no change of the inlet steam flow rate, only change is in F i. If F i increases and F st remains same then what happens, temperature increases or decreases, temperature decreases. So, in this situation, what the controller will do, the controller will increase the steam flow rate that means, the controller will increase this F s t. So, this is description in terms of external disturbance so it is very clear from this discussion that, the controller which separates the effect of external disturbance.

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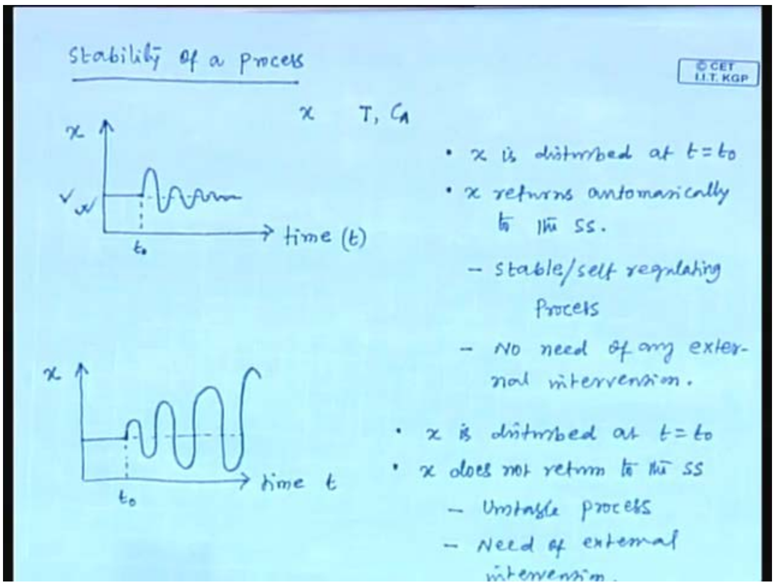

Next, we will discuss the stability of a chemical process so we will first draw a plot, we will make a plot, this is x and this is time t. This x may be temperature, x may be concentration now, s i mention that, initially the process is at steady state. Now, at time t equals to t naught, the x is disturbed, this is the steady state value of x. Now, first x is disturbed at t equals t naught now as a result, the x show this type of response that means, x returns automatically to the steady state.

If this is the case, this type of process is called stable or self regulating process, x returns automatically to the steady state value and this type of process is called stable process or self regulating process. So, for this case, there is no need of any external intervention I mean, no need of any controller for this stable system. We will consider another case which is unstable so this is x versus time that is t, initially the process is at steady state and x is disturbed at time t equals to t naught.

Now, in this case, the response is like this so this figure indicates that, x does not return to the steady state, this figure clearly indicates that x does not return to the steady state and this type of processes are called unstable process. And for this process, there is a need of external intervention I mean, there is a need of controller. Now, from this discussion, we cannot control that for this stable process, there is no need of controller, we cannot conclude that.

Because, we have mention three important issues so this is only one issue, for other two issues like the separation of external disturbance and third one is the optimum performance of the process, for those two issues, we may need the controller. Not only that, even for this stable process to reach at steady state with a short period of time, we may need a controller. So, we can say that, here also the need of controller we realize, next issue is the performance of a chemical process.

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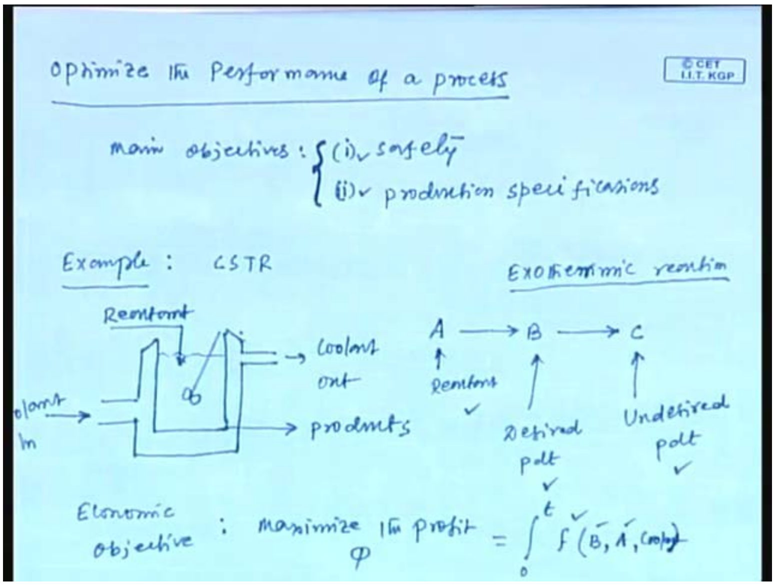

Or optimize the performance of a process this is a third issue now, the main operational objectives, main objectives are, first one is the safety and second objective is production specifications, this is the second objective. Once these are achieved, once these two objectives are achieved, the next goal is to make the operation more profitable. Now, in that direction, we will consider one example that is, continuous stared tank reactor.

Suppose, this is a jacketed reactor, this is a schematic of a reactor reactants enter the process, this is the reactant and this is the product. Now, in this process, two consecutive reactions A to B and then B to C occur, this is two consecutive exothermic reaction occur. A is the reactant, B is the desired product and C is the undesired product so this is basically products, A is the reactant, B is the desired product and C is the undesired product.

Now, what is the economic objective, the economic objective for this process is to maximize the profit. Now, the profit function is phi and this is integration of 0 to t, t is nothing but, the operational time and here, one function will be there, this function is in terms of revenue from the sales of the product B then it includes the cost of reactant A and then the cost of coolant. Basically, if this is the exothermic reaction, we need to introduce here coolant to take out the exothermic heat and this is coolant in, this is coolant out.

So, the profit function which includes the revenue from the sales of product B, cost of reactant A and the cost of coolant then we need to maximize the profit. And then we can maximize the performance we can say so these are all about the three issues, which can be dealt by the control system. Next, we will discuss the classification of variables, the variables which are extensively used in process controlled course, that we will discuss in the next.

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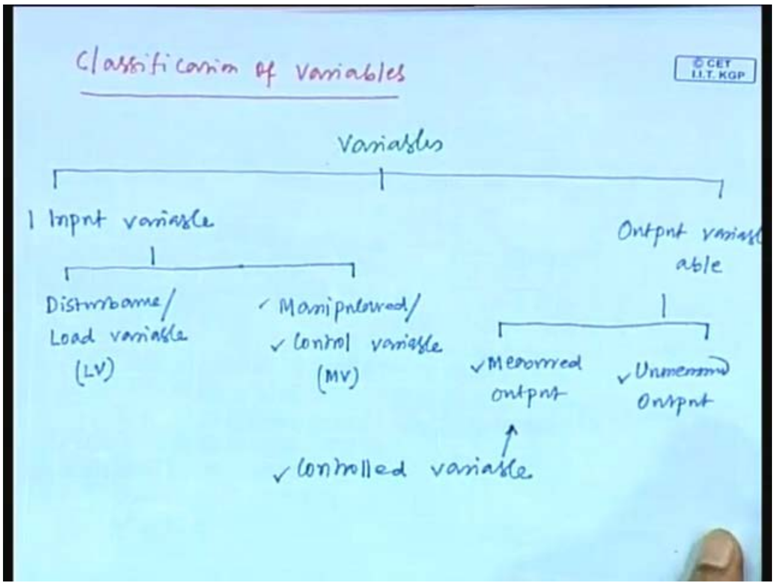

So, next topic is classification of variables, the variables is usually 2 types, one is input variable and second one is output variable. Now, input variable is again 2 types, first one is disturbance or load variable and it is conventionally represented by LV, second input variable is manipulated or adjustable variable or some time it is called control variable. So, input variable is 2 types, one is disturbance or load variable and second one is manipulated variable or control variable, this we can represent by MV.

Similarly, the output variable again 2 types, one is measured output and second one is unmeasured output, another variable is also used that is, controlled variable. So, do not confuse with this controlled variable, controlled variable is manipulated variable and controlled variable we will discuss that. But at this point, I can say, that the controlled variables are usually the measured output. Sometimes this is also unmeasured output so this the controlled variable so these are all about the variables. Now, we will take different examples and we will select the different variables for that specific example so we will start with a simple liquid tank system.

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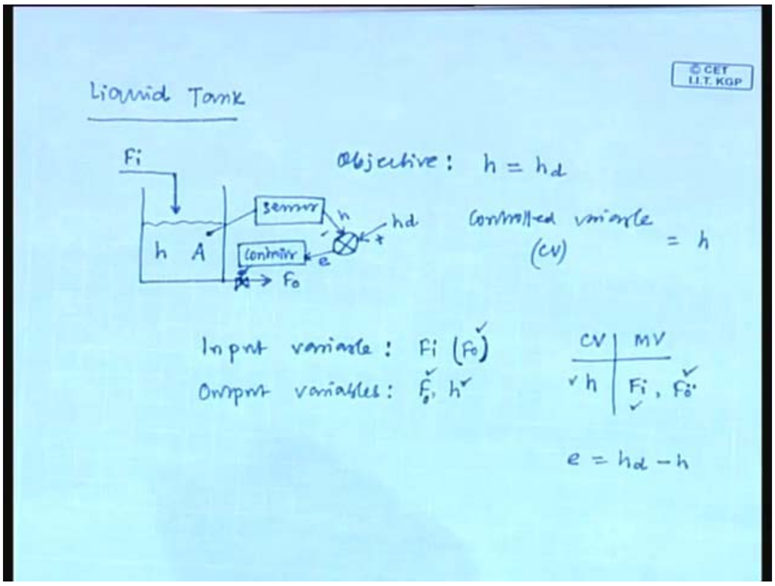

We will first start with a liquid tank so this is a liquid tank system, the input to this process is the input steam, has a flow rate of F i, outlet flow rate is suppose, F naught. The liquid in this tank has the height of h and the cross sectional area of tank is A now, this is a simple liquid tank system. So, what is the objective of this process? The objective of this process is, to maintain the liquid height in the tank at it is desired value h d ,this is the objective of this tank system now here, the control variable is height.

The controlled variable we will represent by CV, the controlled variable CV here is liquid height. Now, if we considered this process so can you classify the variables so which one is the input variable for this process? F i. Input variable is F i, what are the output variables, one is F and another one is liquid height, the output variables are one is outlet flow rate F and second one is liquid height. Now, for this example system, can you make a pair in between controlled variable and manipulated variable, we have decided that, for this particular system, liquid height in the tank h is the controlled variable.

So, what will be the corresponding manipulated variable I mean, to maintain this liquid height, which variable we can adjust F i or F o? ((Refer Time: 40:20))

I think both we can do, F i and F naught. I am just making one controlled configuration suppose, this F naught is the manipulated variable corresponding to liquid height h so what will be the control configuration, as we have drawn for the heating tank system. So, first of all, we need to measure this height by level sensor so here a level sensor we can place, which can measure the liquid height.

Suppose, this is height then it is compared with the desired value h d, this carries positive sign and this is negative sign. Now, the output of this comparator is error, error is basically desired height minus height then this error signal goes to controller and this control action is implemented here, this is a control valve. So, F naught is the manipulated variable in this control configuration now, can you tell me, F naught is input variable or output variable? ((Refer Time: 42:13))

You see the classification, manipulated variable is under input variable or output variable? Input variable. So, if we consider F naught as the manipulate variable then F naught is input variable. In this example, it is clear that, if F naught is manipulated variable then that is input variable, not output variable. Because, manipulated variable is one type of input variable that is why, you write within bracket F naught but, if we consider F i is the manipulated variable in that case, F naught is output variable. Next we will take another example, to know about all these variables.

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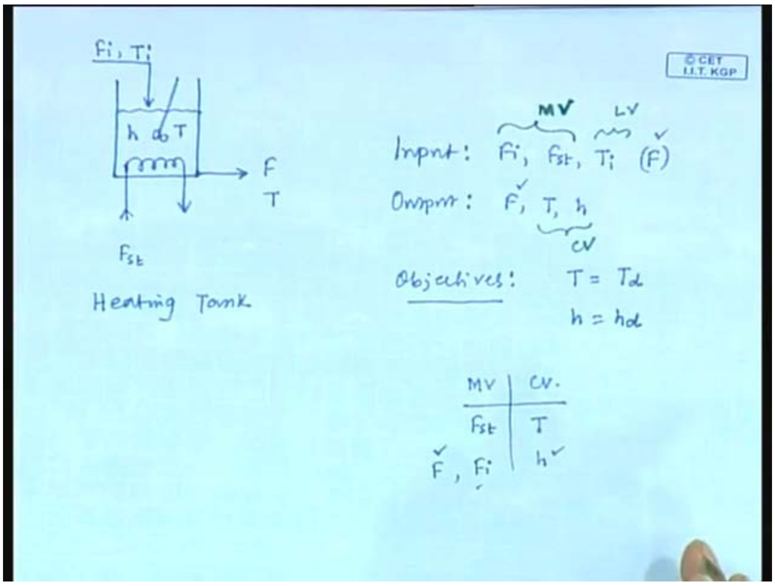

That example we have consider heating tank system so this is if heating tank system, the inlet steam has flow rate F i, temperature T i and it has the outlet flow rate of F and T, steam is introduced through this coil, it has the flow rate of F st and liquid height here h, temperature T so this is the heating tank system. Now, what are the inputs in this case, F i, F st, T i these are the inputs and what about F, may be input and what about the outputs F, T and h.

We have mentioned the objectives of this process, first objective is to maintain T at it is desired value and second is we need to maintain height at it is desired temperature. Can you classify the, can you make the control pairs I mean, manipulated variable and corresponding controlled variable pairs. So, one controlled variable is temperature because, that is our objective, second control variable is height, how you can maintain this temperature, by adjusting F st and for the case of height, how we can maintain the height, by adjusting F i and F naught, F i and F.

If F is the manipulated variable, as we discuss for the previous example then F will be one input variable, if F i is the manipulated variable in that case, F will be output variable. So, F i and F st, these two are suppose for this case, manipulated variable and this T and height, these two are controlled variable. So, which one is disturbance variable or load variable, inputs variables are 2 types, one is manipulated variable and another one is loaded variable, F i and F st they are manipulated variable so rest is T i so this is load variable. So, these are all about to the variables, different variables next, we will discuss the controlled configurations. Although we did not discuss the control configurations in details but, before that, we want to know the different configurations.

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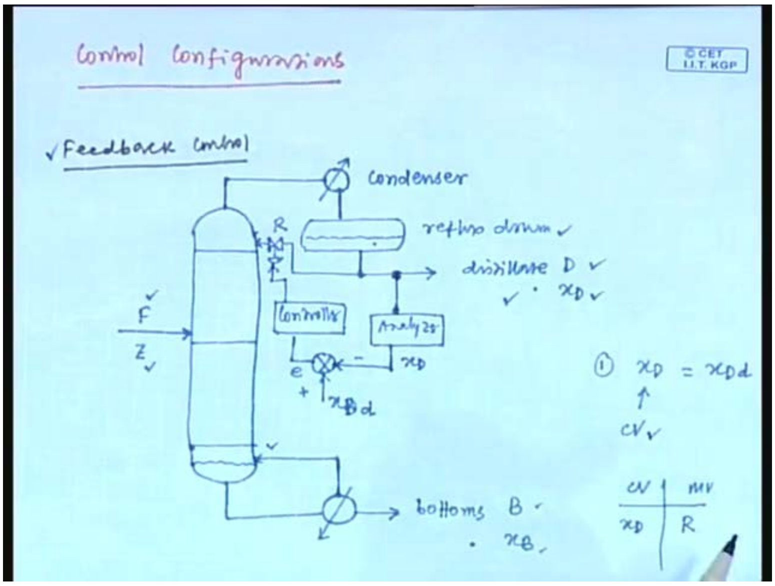

Control configurations, we will consider the distillation example, which is quite complex compare to this liquid tank and heating tank system. Now, first we will consider one control scheme that is, the feedback control scheme. So, distillation column, this is the tower of a distillation column, feed is introduced here with flow rate F and composition Z, the overhead vapor which leaves the top tram is condensed in this condenser, this is a condenser. Then, the condensed liquid is accumulated in a drum, which is the reflux drum, this is also called reflux accumulator.

A part of this liquid is recycled back to the top section of the column and a part is withdrawn as distillate with flow rate D and composition x D, composition means here mold fraction. Similarly at the bottom, the liquid is withdrawn and it is subjected to a reboiler, the produced vapor is recycle back to the bottom tray and some amount of liquid is taken out as bottoms with flow rate B and composition x B. So, feed is introduced with flow rate F, composition Z, this is a feed tray, this is the top tray, this is the bottom tray.

Now, the overhead vapor goes to a condenser, condensation occurs then the condensed liquid is accumulated in this reflux drum and part of this liquid is recycle to the top tray as reflux, this is called reflux rate, reflux flow, reflux steam. And another part, a part of this accumulated liquid is withdrawn as distillate with flow rate D and composition or you can say mold fraction x D.

Similarly at the bottom, this liquid which is coming from the bottom tray, it goes to a reboiler, the produced vapor is recycle back just below the bottom tray, this is bottom tray. And some amount of liquid is withdrawn as bottom product or bottoms, with flow rate B and composition x B. First we have to know, what is the control objective of this process, there are basically 2 product, one is distillate another one is bottoms, we will consider presently the top product.

So, what is the objective, objective is to maintain the top product composition at it is desired value, this is the objective if you consider the top section only, we need to maintain the top product composition x D at it is desired value. So, what will be the control configuration for this case, if this is our control objective that means, this is the controlled variable so controlled variable manipulated variable pair we have to make. If x D is the controlled variable then corresponding manipulated variable is reflux flow rate R.

Can you make the control configuration now, yes we can make it suppose here, the liquid has composition of x D so we need one composition analyzer to measure x D. Then, this analyzer gives the value of x D then that x D is compared in this comparator, this is negative and this is x D, this is capital D desired this is positive then we get the error signal. This error signal goes to the composition controller then the control action is implemented through this valve so this is the control configuration.

So, this is basically the feedback control scheme, in the feedback control scheme, the controlled variable is measured. Anyway, today we do not have time so in the next class, we will discuss other two control schemes, they are feed forward control scheme and inference sale control scheme, along with other topics.