**Plantwide Control of Chemical Processes**
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**Lecture - 21**
**CSTR Heat Management**

So, welcome to this next lecture. We have been looking at continuous stirred tank reactors, and just to quickly go over what we have looked at in the last lecture.

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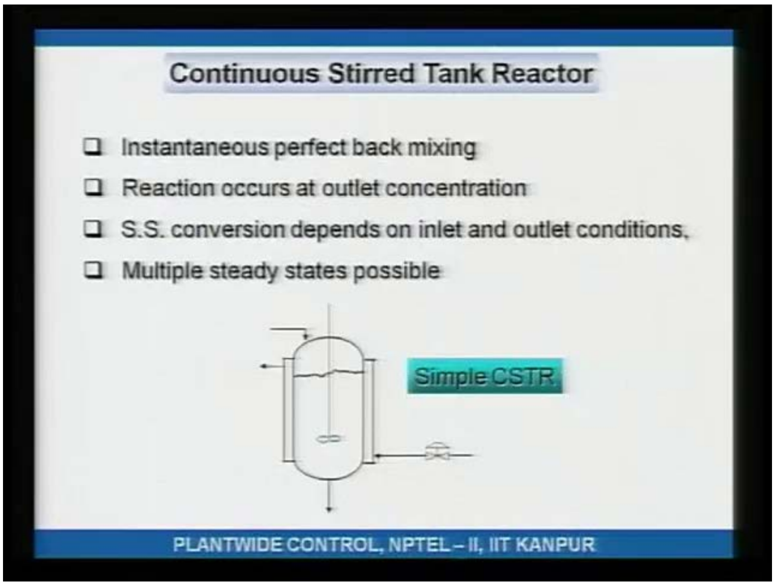


Well in a continuously stirred tank reactor well there is perfect back mixing, what that means is that the exit concentration is the same as the inlet concentration and the concentration inside the reactor concentration temperature, and all other state variables if any are the same at every location in inside the reactor.

So, that is meant by perfect back mixing, and because that is the case the concentration will be the same at the exit. So, the exit concentration temperature is the same as the reactor concentration temperature, and if you write a material and energy balance around the reactor what you will find is that, the steady state conversion depends on both the inlet and the exit conditions. It is because of this that there are there is the possibility of multiple study states. Note that in a in a in a in a plug flow reactor given the inlet condition you just integrate over the length of the reactor and you get the outlet condition.

In a CSTR the outlet condition depends, the reaction rate depends on the composition in the temperature inside the reactor. Therefore, the material balance has whatever is coming in and whatever is going out and reaction rate since, it depends on the out state. You have greater nonlinearity and because of this greater nonlinearity, there is the possibility of multiple steady states and we, I think discussed this.

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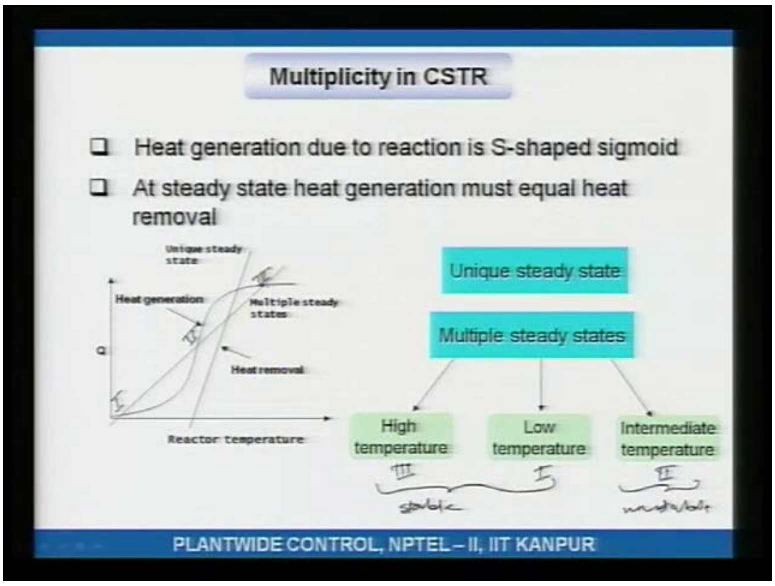


If you look at the reactor temperature and you look at the generation of heat due to reaction it is an exothermic reaction, the generation curve is an S shaped curve heat transfer. Let us say, it is a jacketed CSTR that jacket is at a temperature T C reactor is at temperature T then the heat transferred across the walls of the jacketed reactor would be u A delta T. u A T minus T C and that would be a linear curve. This linear curve may have one intersection with the S curve so that is the steady state or more often than not if the slope is lower you will have three intersection then what we saw was, that the steady state over here if I call this steady state one, steady state two, steady state three, well high temperature is steady state three low temperature is steady state one intermediate temperature is steady state two.

These two are stable and this one is unstable, we had discussed this last time and what that means is let us say if I am at steady state three, I am here if the temperature of the reactor goes up a little bit because of any reason then because the heat removal rate goes up faster than the heat generation rate, that extra heat removal will bring the temperature back down. So, a deviating temperature is brought back. Same logic will hold through in at at steady state one. At steady state two on the other hand if the temperature goes up, the the heat generation rate goes up faster than the heat removal rate therefore, the temperature will continue to increase unless you take control action to increase the heat removal rate.

So, if you do nothing and the heat heat removal rate, the jacket temperature is held constant then if the temperature at steady state two increases it will continue to increase and and your reactor temperature will end up at steady state three. Similarly, if the reactor temperature decreases the temperature will continue to decrease and you will end up at steady state one. So, steady state two is open loop unstable. If you do nothing well this temperature is bound to end up deviating to a height at the high temperature steady state or the low temperature steady state. In practice though it is usually desirable to operate at steady state number two, that is because at steady state number three the temperature is too high it will kill the catalyst, at steady state one the temperature is too low reaction rates are not fast enough.

So, for a given conversion the size of the reactor would be too too large that means the reactor cost will be too high. So, since you desire to operate at steady state two and steady state two is open loop unstable this is an example where a control loop that adjust the cooling rate so that it increases faster than the heat generation curve to bring the deviating temperature back to set point. So, control or temperature control of the reactor by adjusting the cooling duty, would stabilize this open loop unstable system. So, this is an example of a control system, stabilizing in open loop unstable system.

You see this pen it is open loop unstable right if I do nothing it will fall, but if I you know if I take control action it can be my control action. What not that good, but if I you know if it is a longer stick if I just keep moving so that the stick does not fall you know by doing appropriate control this pen or the longer stick can be controlled. So, that it does not fall right. So, this is an example of a control system stabilizing in open loop unstable system I think we had done till here.

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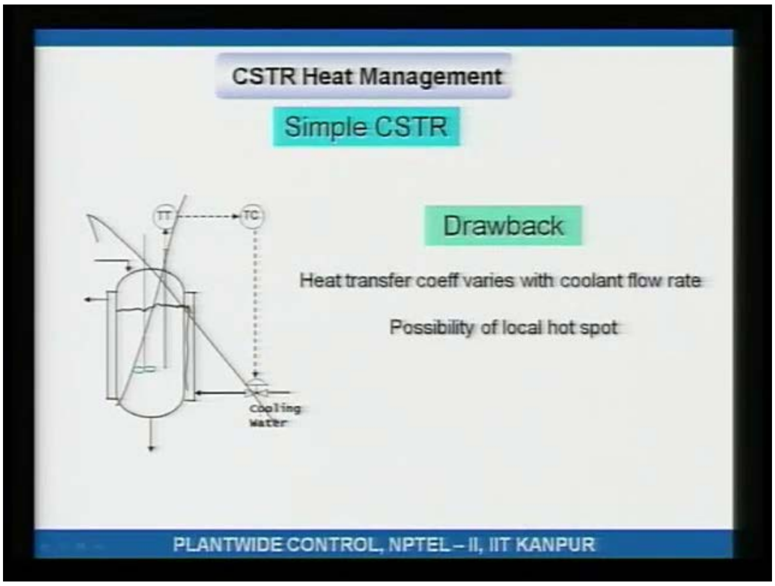


Now, well stable unstable of course, now heat management you see, most reactions are exothermic so you need to remove heat they might be mildly exothermic or they may be highly exothermic and here we have, I have drawn a simple scheme where what we have is cooling water is going in the jacket and it is exiting out here. Now, if I control the temperature inside the reactor by adjusting the cooling water flow rate, let us say the temperature has gone too low. Then what you need to do is you want you have to reduce the cooling water rate.

So, what happens here is there are some inherent disadvantage advantages, because you are controlling the temperature of the reactor by adjusting the cooling water flow and the cooling water flow can vary from low to high. You have not only the, at low flow rates there will be a significant rise in temperature of the cooling water, as it moves from the inlet to the outlet. As the water moves from here to here temperature will rise. So, the reactor would not see a constant temperature jacket. Secondly at low flow rates the heat transfer coefficient would be low, on the other hand at high flow rates the heat transfer coefficient would be high. Therefore, in this configuration, in this heat removal configuration, heat transfer coefficient varies with coolant flow rate and there is the possibility of the of a local hotspot because there is a temperature gradient in the jacket itself.

The inlet of the jacket is cold, the exit of the jacket is hot because the coolant flow is slow. So, this is even though this is what you would think confectually, this is what should be done. This is never done in the industrial practice this is never done. please note this down.

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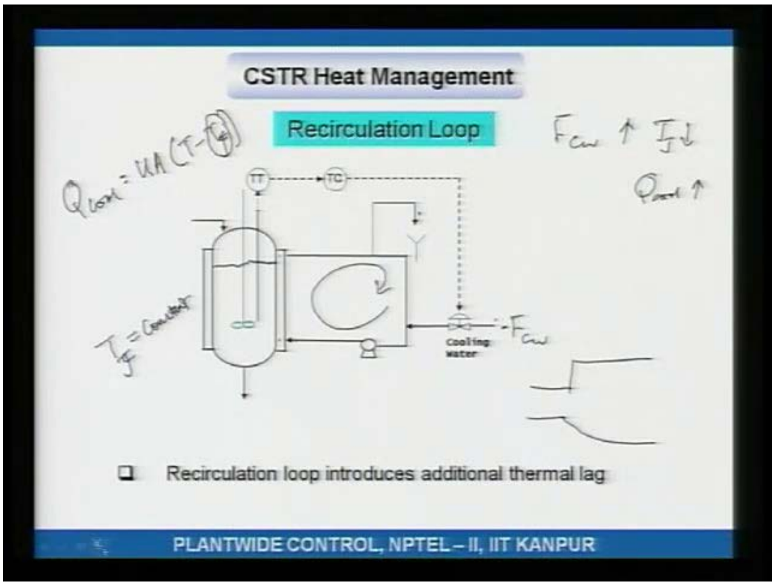


What is done, what you will find find is actually this is also not done, but the recirculation loop loop is what is done here. What is done is you got cooling water going in right here and you got a high you got a pump that is circulating the cooling water in the jacket at a high flow rate and this flow rate is the same as this flow rate. So, the out flow or the overflow from the cooling circuit is the same as the inflow of the cold cooling water. What happens here is you see this flow rate circulation rate in the in the in the in the loop is constant, and it is very high since the circulation rate is high temperature rise from here to here will be very small or negligible.

So, as far as the reactor is concerned, it is seeing a jacket which is at constant temperature alright. So, as far as the reactor is concerned T coolant is equal to constant and this is a consequence of the high recirculation rate. Then how do you vary the the amount of heating or cooling or the amount of cooling? So, you see the amount of heat removed Q cool is equal to heat transfer coefficient, into area for heat transfer times temperature of the reactor minus temperature of the coolant and the temperature or temperature I will call it temperature of the jacket. Let us call it J. T J temperature of the jacket is constant, temperature of the reactor minus temperature of the of the what of the jacket.

Now, if you add more cold cooling water that means if you open the cooling water valve since more cold water is coming in T J will go down. So, if if I call this F cooling water if F cooling water goes up T J goes down. If T J goes down Q cool the amount of heat removed goes up alright. So, the amount of heat transferred across the the wall of the reactor is adjusted by adjusting T J and T J gets adjusted by adjusting the amount of cooling water that is being put into the loop. Now, you may think that if I want to control the temperature of the reactor what I do is I measure the reactor temperature, and if the reactor temperature is increasing.

I put more cooling water, if the reactor temperature is decreasing I put less cooling water, well that is one way of doing it, but there is a better way of doing it and let us talk about by the way there is a comment here you see when you add the cooling water the temperature of the water inside the recirculation loop will decrease. So, if cooling water goes up as a step if F c w goes up, as a step then temperature of the jacket will actually go down not immediately, but slowly so the recirculation loop actually introduces an additional thermal lag and because of this additional thermal lag this control loop cannot be tuned very tight because you change the cooling water. Then the temperature of the jacket slowly goes down and once the temperature of the jacket slowly goes down heat transfer up, transferred across the wall goes down and then the reactor temperature responds to speed up the response.

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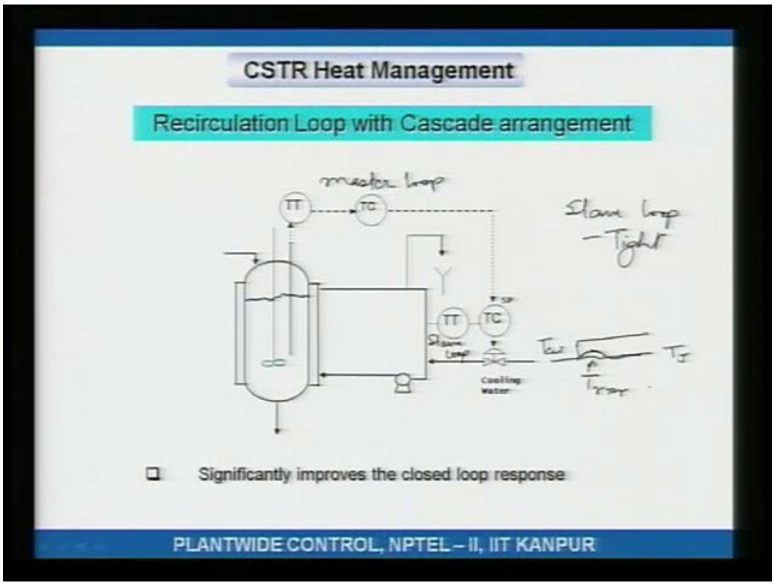


What is done in industrial practice is that you control the jacket temperature by adjusting the cooling water flow and if the reactor temperature is increasing, this master controller the reactor temperature controller which is the master controller. which is the master controller This is the master controller, this is the master loop master loop and this one is the slave loop. So, if the reactor temperature is increasing the master loop says well decrease the temperature inside the jacket the slave loop sees that the temperature set point has gone down. Therefore, it adjust the cooling water or increases the cooling water to bring down the jacket temperature.

Note that the slave loop can be tuned to be really tight and if you tuned it to be really tight, you will actually reduced the bandwidth and what that will do is as far as the master loop is concerned it sees a faster responding jacket temperature and since the this jacket temperature is responding faster relative to what we had here, the reactor temperature controller actually sees a faster response in the in the in the in the in the well it sees a faster faster well so the thermal lag is actually reduced because the slave loop is tuned tuned to be really tight. So, as far as the master loop is concerned the master loop being the reactor temperature controller. It sees an overall faster response faster response faster open loop system and faster open loop system means that you can have tighter tuning.

So, in this arrangement temperature control would be tighter. Another advantage of this system is that if there is a let us say, you know the cooling water which is coming from a cooling tower. Let us say there the cooling tower there was some upset there and the water is not as cold at it as it should be so if the cooling water temperature goes up if T cooling water if this is T cooling water if this goes up what will happen? Here is T cooling water is gone up because T cooling water is gone up jacket temperature will start to go up. Jacket temperature goes up means this slave loop will say jacket temperature is going above its set point, it will increase the cooling water flow rate and you know this deviating jacket temperature will be brought back. So, T J will go up and then it will be brought back by the action of the slave loop.

As far as the master loop is concerned because the jacket temperature is held relatively constant you will not see much of a deviation in the you know the the reactor temperature may show some deviation and comeback. So, this is let us say, maybe I should use well forget about it this is let us say T reactor.

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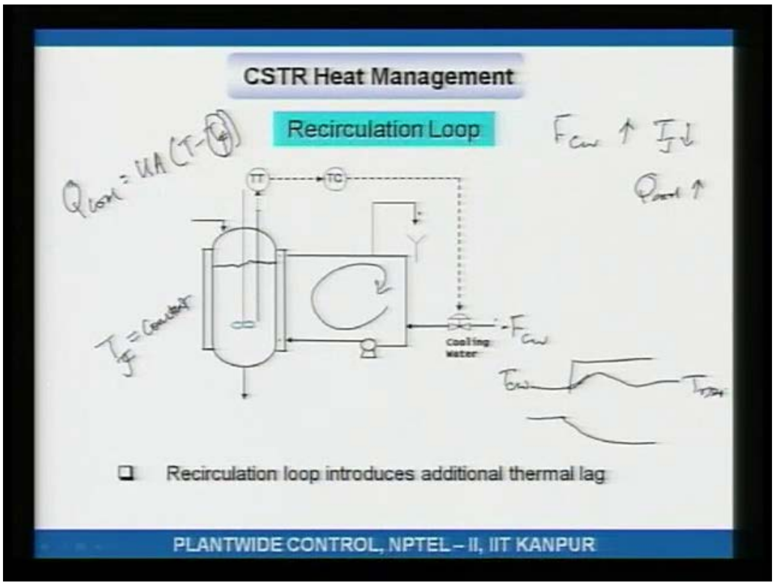


On the other hand if you did the same thing, if the same thing happened here you know T cooling water goes up as a step, well then what happens? Cooling water is hotter therefore, the jacket is hotter because the jacket is hotter less less than necessary heat gets removed across the walls of the reactor therefore, reactor temperature starts to rise. As the reactor temperature rises in response to the feedback action of this temperature controller you will add more cooling water, as you add more cooling water the jacket temperature goes down and then heat removed goes up and then the deviating temperature actually comes back.

So, in this case you will see that the T reactor actually shows a large excursion in temperature. A large excursion from the set point, where as in this case you see the a change in the cooling water temperature is a disturbance that is local to the slave loop. The slave loop removes it and you will see essentially little or no impact on the reactor temperature. So, this is this configuration is what is most commonly applied in industry.

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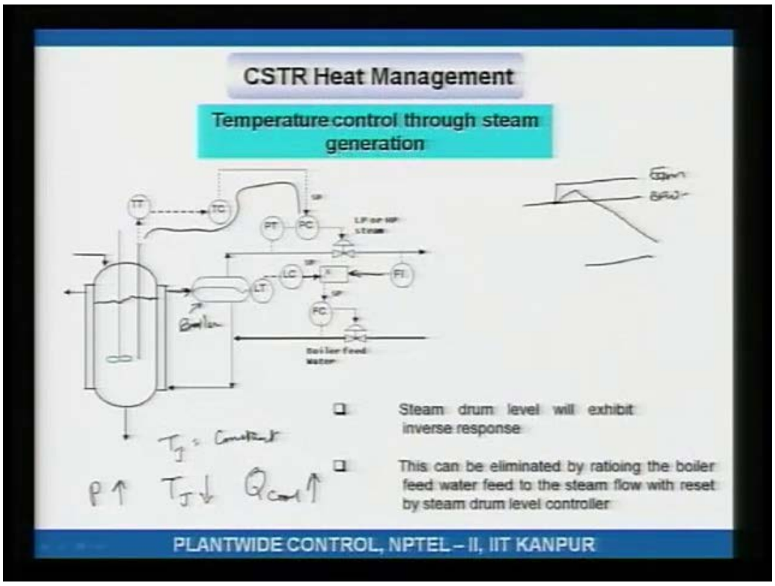


Well cooling water can be used if your reactor temperature is let us say 60, 70, 80, 90 degree Celsius, then you can use cooling water to remove the reaction heat. Let us say the operating temperature of your reaction of the reactor is supposed to be 200 degree Celsius. If if if that is the case, what is done is you still using water, but it is the the reaction heat is used to generate steam and that steam is shown here and just to describe it to you what is done here is this is a tank this is a tank or a boiler tank. It is got water in it the water the water is re-circulated in the jacket at a high speed at a high circulation rate or at a high re-circulation rate and because the re-circulation rate is high T J is constant. The jacket temperature is constant.

Now, reaction heat gets transferred across the walls and this cooling water that is coming here, it gets into this slash drum and because it is hot. See water under pressure will be liquid and when you bring it to low pressure it will flash. So, in the flash tank the water the hot water actually flashes to generate steam. So, the reaction heat is essentially recovered as steam, to generate steam. Now, because you are losing water as steam, there is make up water or boiler feed water that is put into this re circulation loop in order to hold.

The level inside the let us just call this a small boiler in order to hold the level inside the boiler constant. How so here we have, what is being done here is, if the steam withdrawal rate goes up, if the steam is increasing boiler feed water should also increase. You see what happens in boilers is level shows an inverse response. So, for example, if I open the steam valve so let us say if I open the steam valve and the flow rate of the boiler feed water is constant. So, at steady state flow rate of steam and flow rate of boiler feed water will be equal then the level will be constant. Now, let us say steam flow rate goes up and boiler feed water remains constant.

What you will find is what happens to the level is that you are removing more steam you would expect that the level should go down right, but what actually happens is the level actually goes up and then down. So, get actually an inverse response why do you get this inverse response is because if you if you would have seen milk boiling, you see when you are removing more steam when you have opened this valve more steam is being removed that means those bubbles get generated inside the liquid volume and because bubbles are getting more bubbles are getting generated inside the liquid volume, the liquid interface the the vapor liquid interface because of the entrapped bubble actually goes up. That is like milk boiling.

Of course, it goes up, but then you are removing more steam than you are putting in water. Therefore, after sometime you will you know that that that level will keep on going down, but that initial transient will be there, where if you start removing more stream or if you open the steam valve, the level actually initially will go up and then after sometime it will start to go down. So, this called that inverse response and in order to now, let us say if I did my level control without having this ratio station that shown here, If I had just simply drawn for example, a level controller that adjust the boiler feed water and none of the complexity that is that is shown here, what would happen?

Boiler feed water is going, well level is going up if level is going up it would reduce the boiler feed water. Well the steam has gone up you should actually be increasing the boiler feed water because of this inverse response what you will have is, that the boiler feed water will also go in the wrong direction. So, to avoid this or to mitigate this effect what is done is you keep the boiler feed water in ratio with the amount of steam being drawn out. So, this that ratio station. So, what you have is the flow of steam which is this guy this is the flow of steam the flow of steam is multiplied by a set point a ratio set point and that sets the flow set point for the boiler feed water.

So, the steam flow or the boiler feed water is maintained in ratio with the steam flow. The ratio set point is adjusted by the level controller so if over long time you find that the level is actually reducing than what you will do is you will increase this ratio set point. So, this arrangement essentially makes sure that inverse response in the boiler level actually does not cause the boiler feed water to go in the wrong direction. Wrong way behavior in the level does not create a deficit or too much of boiler feed water. Of course, the pressure inside the boiler is controlled by the amount of steam the is being drawn out by this by this steam wall. If you want to increase or decrease the amount of heat removed across the valves across the reactor wall, then what you do is you adjust the set point of the pressure in the boiler.

That is what this temperature controller is doing, it is adjusting the set point of the pressure in the boiler. Notice that if the pressure set point is decreased, well at a lower pressure water will boil at a lower temperature. So, the temperature so if P is increased boiler pressure is increased, temperature inside the jacket will go down. If T J goes down than u A well then Q cool, will actually if the jacket is colder amount of cooling will go up and vice versa ok So, if the reactor temperature is increasing you need to increase the cooling. The this temperature controller will reduce the pressure set point. So, I hope this is clear. So, here is the comment here, steam drum will exhibit inverse response that is what I have shown you here and this inverse response, well well the inverse response does not get eliminated please do not misunderstand.

The boiler feed water going in the wrong direction because of this inverse response in the level is eliminated or mitigated by rationing the boiler feed water. Feed water to the steam flow that is what inverse response is an inherent characteristic of the boiler that will be there, no matter what you do. All you are doing by doing this rationing is not confusing the direction of boiler feed water response. Use of an external heat exchanger sometimes let us say, the reactor temperature is I do not know 400, 450 Celsius

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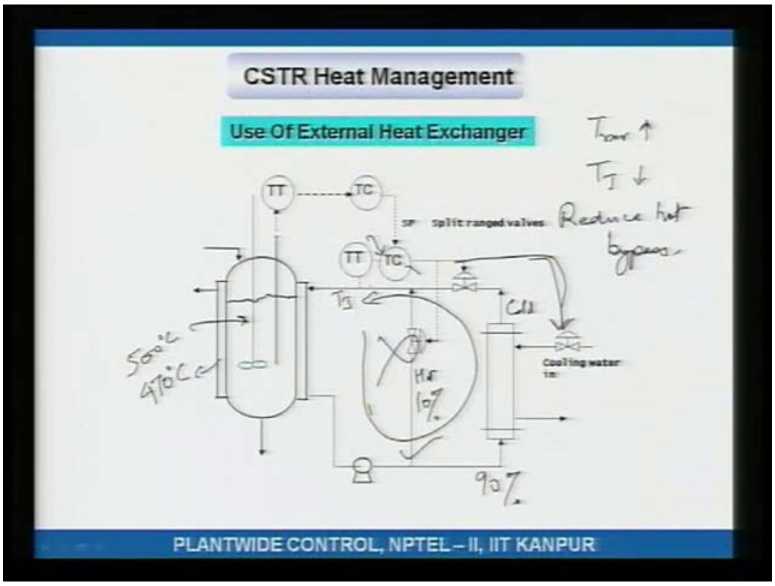


So, this reactor is suppose to be operated at a pretty high temperature 400, 500 degree Celsius and you see because 400 or 450 degree Celsius is beyond the critical temperature of water, phase change cannot occur now. Water at 450 degree Celsius is a gas. It will not undergo condensation because it is beyond the critical point. So, that being the case operating temperature of the reactor is so high that water cannot be used to remove the reaction heat and generate steam. In that case what you do is you will use one these oils for example, you use cooking oil in your cooking at in the kitchen well cooking oil is non-volatile no matter what the temperature it will not vaporize.

Something like that so those kinds of cooking oil or you know dowtherm you know there are some proprietary oils that are sold by companies, heat transfer oils special oils and then what you do is actually have that oil circulate around. You see this pump so the oil is circulating around like this and this hot oil is taken to a heat exchanger and in that heat exchanger the hot oil becomes cold and losses its heat to cooling water. So, if the reactor temperature is let us say 500 degree Celsius, that is the temperature here. You will have a jacket temperature that may be for example, 470 degree Celsius or may be 470 degree Celsius. Now, the heat, the hot oil the heat that is gained by the hot oil in the jacket is lost.

Inside this heat exchanger and what I have here is a bypass to this heat exchanger. So, let us 90 percent of the hot oil is going through this heat exchanger 10 percent is getting bypassed. Let us just say, what that means is the master temperature controller or the rector temperature controller is adjusting the set point for the temperature of the hot oil in the jacket. So, it is this is and this slave loop which is the jacket temperature controller which is this guy, this slave loop it adjusts the amount of bypassing. So, let us say reactor temperature T reactor is increasing. If T reactor is increasing I would like T J to go down so that more heat gets removed across the walls. For T J to go down you see this is hot, this is cold.

So, the hot and the cold streams mix and there give you the T J that you have here. So, if you want T J go down you would like the amount of hot stream being sent here to reduce and the amount of cold stream to to actually increase. So, to do that what you do is reduce hot bypass notice that the dynamics of this temperature slave temperature controller of the jacket temperature controller is going to be very fast, it is like mixing hot and cold water, when you take a shower hot water coming from the geezer cold water coming from the overhead tank. Well if the temperature is too hot either you reduce the hot water coming from the geezer or you increase the cold water coming from the tank. So, that is what is being done here and the moment you adjust those valves the temperature response immediately.

So, this slave loop is going to be very fast. It is almost like controlling flow. Notice that if there had been no what should I say, if there had been no bypass then what would have happened this temperature controller would have had to adjust the cooling water flow rate. Then because heat is getting transferred across a heat exchanger, then what would have happened let us say you did not have this bypass. Then what would have had happened is to maintain the jacket temperature you would have to adjust the cooling water. So, then what would have had happened is reactor temperature is going up I need to reduce the jacket temperature in order to reduce the jacket temperature I put more cooling water in. More cooling water as I put in let us say the cooling water is flowing in the tubes more cold water comes in contact with the hot tubes.

Those hot tubes cool down and as those hot tubes cool down, the hot oil that circulating on the shell side that comes in that is in contact with those colder tubes. It cools down and therefore, T J goes down. However, this will take a long time that is because there is lot of mass that those tubes have and it takes time to heat up or cool down those tubes, thermal heat capacity. So, that if if this is what had to be done what you would find is that reactor temperature control would be extremely slow and because reactor temperatures can runaway, you see if the temperature goes up reaction rate goes up exponentially that means heat released by reaction goes up exponentially and that can cause a thermal runaway.

So, it is important that reactor temperature be controlled tightly, to do that the jacket temperature must be controlled tightly, for the jacket temperature to be controlled tightly you must have this bypass. That is what gives you faster dynamics in the jack in the in the jacket temperature code control loop. It is almost like it is like mixing hot and cold streams. You can get the temperature immediately that you want right therefore, this for reactor temperature control is essential. I hope I have said enough on this.

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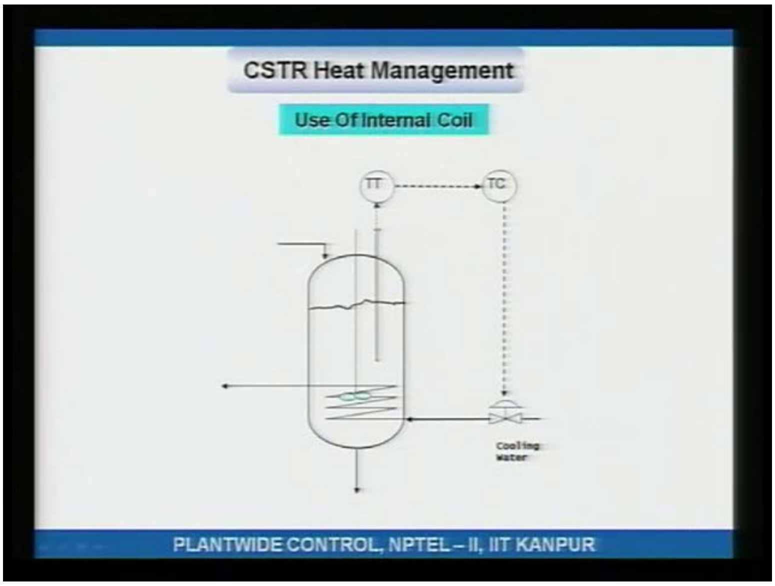


Then you see typically because you got a cylindrical tank, the amount of heat surf heat transfer surface area that you can get as a jacket is limited. It may show be that for the system that you are trying to remove heat of, it you know you just cannot remove it because there is not enough sufficient, there is not enough heat transfer area available. So, than what you have you to do is, you have to bring in design innovations or design modifications, so that the heat transfer area increases. One of the ways to do that is to use a internal cooling coil. What is a internal cooling coil?

Just cold water flowing around. In this case you know reactor temperature is controlled by adjusting the cooling water flow rate. Internal cooling coil will give you more heat transfer area, much you know certainly much more than what you will get in a jacket.

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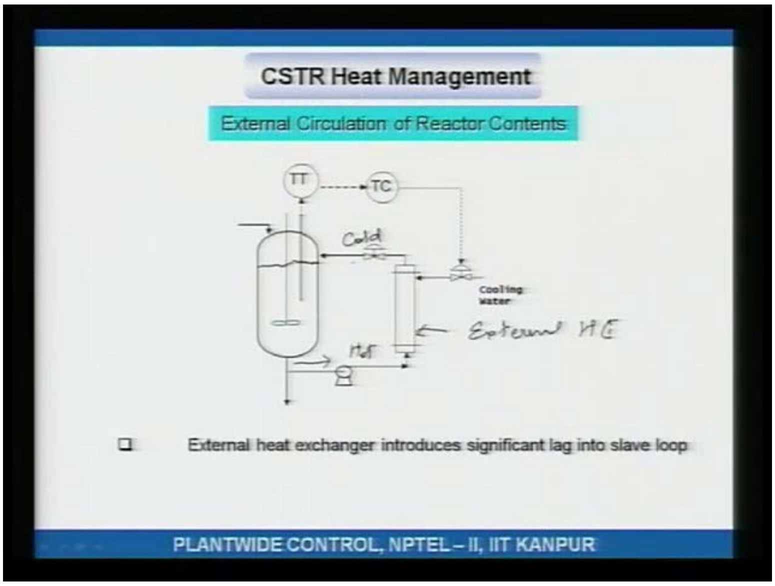


Alternately, what you can do is you take out the hot contents of the reactor that is what you are getting out here, hot contents of the reactor. They are put through an external heat exchanger. So, this is an external heat exchanger and what is happening in this external heat exchanger is, this hot reaction mixture comes in contact with let us say, cold tube the tubes who got cooling water flowing inside and this external because the hot material is losing heat to the cooling water. You know this is this cools down the reaction mixture. Notice that the amount of heat transfer, that you can the amount of heat transfer area that you can pack inside a shell in tube heat exchanger is much much much more than the amount of heat transfer area you will get in a jacket you know in a CSTR in cylindrical CSTR.

So, you take the hot stuff, circulate it through an external heat exchanger and the cold stuff goes back in. This external ex heat exchanger like I discussed previously, if you do this type of temperature control its going to be extremely slow because again the cooling water will have to cool down. The tubes the tubes have a large mass and large thermal heat capacity it takes awhile for the tubes to cool down; therefore it takes a while for for the temperature of this cooled reaction mixture to change.

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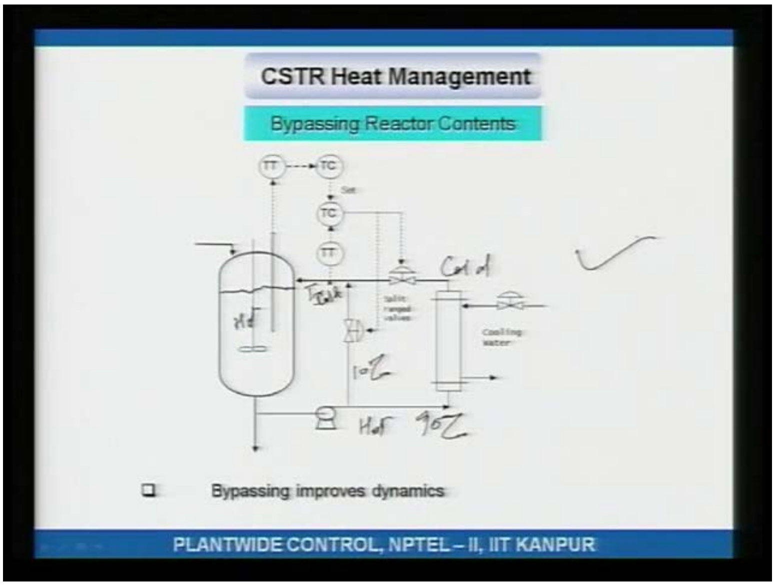


So, again that spilt range arrangement helps a lot. Now, you are just mixing. Now, a part of the hot is split, the hot and the cold streams mix and you get whatever is the jacket temperature or is this is not a jacket temperature whatever is the cold temperature that you desire. The working is extremely similar or is very similar to what we just saw couple of slides ago. This bypassing or the heat exchanger, so let us say 10 percent goes out here 90 percent goes down there. The moment you change the amount of bypass this temperature are very fast response to you see the moment this temperature changes, the it is mixing with the hot reactor, react reactor contents that mixing hot material here mixing with the cold stream here and if this colder because I changed the bypassing.

Well this hot reaction temperature will respond much, much faster than if I did it this way. Where I am putting in more cooling water and the tubes are becoming colder and then the this material is becoming colder I will take a heck of a long time. So, this is what is done this is not done.

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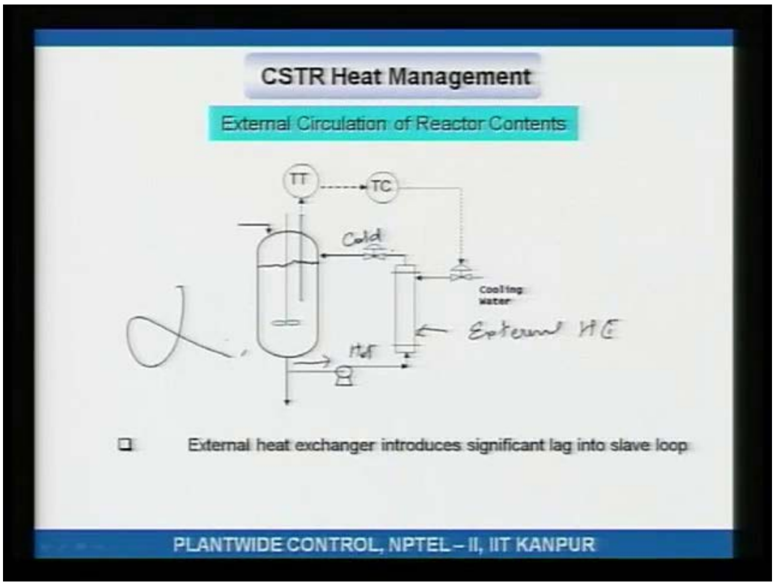


So, the comment here is bypassing improves dynamics, indeed it does.

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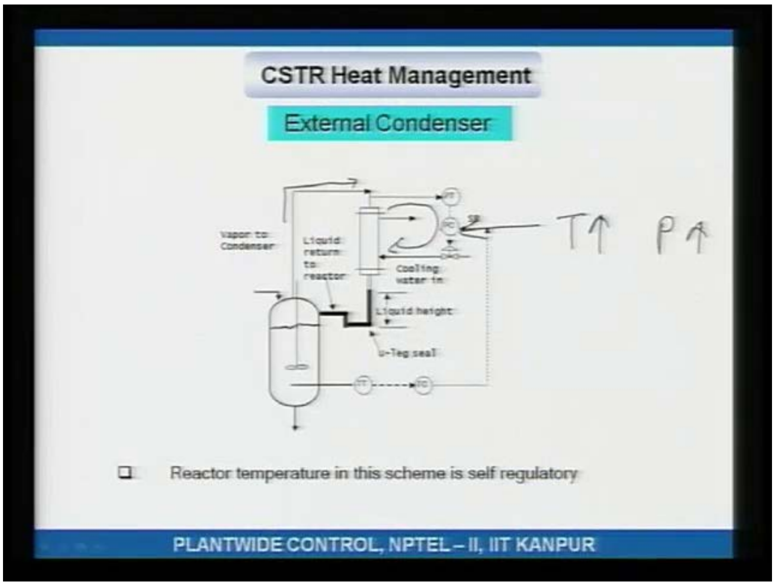


Let us see external condenser now sometimes you have got a reaction mixture which is two phase that means reaction is happening in the liquid phase, but the liquid phase is so hot the you got vapor also in equilibrium. So, what you do in that case is well this vapor is taken to a overhead condenser. In the condenser what you have is cooling water is coming in the vapor condenses on on the cold tubes and drops down and it is put back down in. In order to hold the pressure inside the reactor constant, what is done is you essential manipulate the amount of cooling water flowing in.

So, essential by adjusting the condensation rate, you see boiling is happening because reaction is exothermic heat is getting generated in the reactor and that reaction heat is calling causing boiling. So, the vapor is you know not if more reaction heat is released, well more vapor will get generated. If more vapor gets generated you have to condense more vapor. Otherwise the pressure will shoot up so that is what this this loop is doing what this loop is doing. Is essential adjusting the condensation rate to keep the pressure constant. So, what you are doing is whatever vapor gets generated because of reaction that is getting condensed in the condenser. To do that you are adjusting the cooling duty inside the condenser, that is by adjusting the cooling water flow rate. How do you adjust the temperature?

Well you adjust the set point of the pressure controller and how does this work well the higher the pressure by vapor liquid equilibrium at a higher pressure a mixture boils at a higher temperature. So, if you want a certain temperature and the temperature is increasing what you would is reduce the pressure set point and then the temperature will get back in back down. Notice that in this scheme you are not controlling both the temperature and the pressure. You are only, you are controlling the temperature by adjusting the pressure set point. So, like I was saying in this case whatever is the pressure set point this pressure set point that is what gives at that pressure whatever is the temp boiling temperature of the liquid inside the reactor, well that is the temperature that you get.

If you are not happy with that temperature and you would like a higher boiling temperature well, then you increase the pressure set point. So, if you want T to be high to increase to do that you will have to increase the P that is what this temperature controller is doing. You cannot control both the temperature and the pressure to be independent, that is because if you try to do that this system will never become once becomes you know, it will just the temperature guy will screw the the temperature will affect the pressure, the pressure will affect the temperature and there will never settle down. That is what is likely to happen. Why is that, because temperature and pressure are related thought vapor liquid equilibrium or the boiling. So, well so so so that is something that that you need to be aware of…

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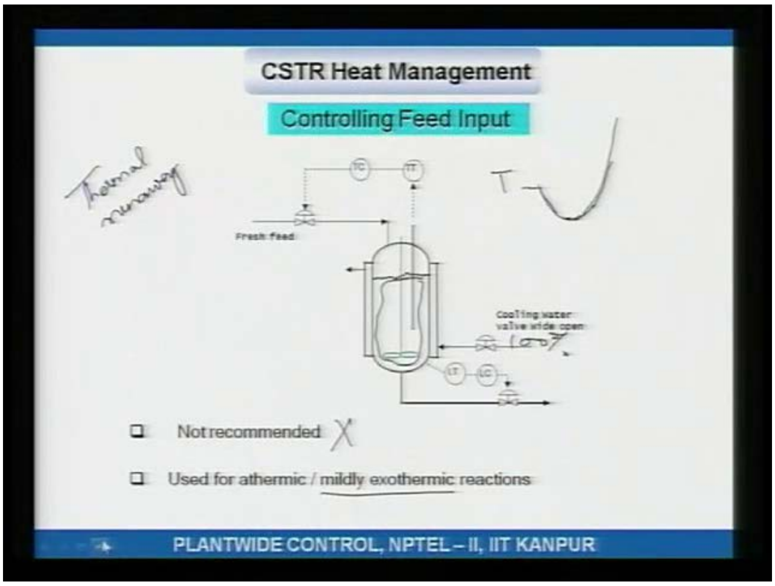


Well this is something typically production for exothermic reactions, you would like to produce as much as you can because the more you produce we have got volume driven process industry. The more you produce the more profit you make because whatever you produce gets sold in the market. So, how do you make maximum profit by by by producing as much as you can. Now, what happens is because the reaction is exothermic as I try and increase the production increasing the production means more reaction happens that how more of the product will get formed. More reaction happening means more heat gets generated in the reactor. So, as you are trying to maximize production well your ability to remove heat will becoming, will become ultimately a constraining will be a factor that constrains the amount the maximum achievable production

So, as you are increasing the the amount of feed to the reactor more and more heat gets removed and then what will happen is you will reach a state where further I mean input to the reactor cannot be increased any further because you cannot remove more heat. You have reached your maximum heat removal capacity. So, well like for plug flow reactors, we say that. Since I want my reactor to operate at maximum heat removal, what I do is this is 100 percent open, the cooling water valve is wide open. So, cooling water as much as has to be put in is getting put in fine. Then in order to control my reactor temperature what I do is, I adjust the amount of fresh feed that is going in. How does that work?

Well if the reactor temperature is increasing that means I have put in too much reactant too much reactants I need to reduce the amount of reactant being put in, that will reduce that composition of the reactants inside the reactor. Since, the composition goes down and reaction rate will typically you know if the if the reactant concentration is more, reaction rate will be more. If the reactant concentration is less reaction rate will be less. This is mostly typical. So, in that case if temperature is increasing I reduce the amount of feed reactant concentration goes down, amount of heat generation goes down deviating or increasing reactor temperature comes back. It is just that it is never done in practice and the reason why it is not done in practice is because the amount of material that stored in the in the CSTR is a large amount.

So, let us say temperature is going up. Well let us see let say temperature is gone down. Let us say temperature is going down because temperature is going down what you would do, is well temperature is going down that means I am removing more heat that means I can add more feed. So, I start adding more feed as I am adding more feed the concentration of the un reacted material inside the reactor goes up of course, because of the large mass stored in the CSTR this increase in concentration will will will happen slowly. It will not happen immediately it will happen slowly. Then because sufficient amount of material or the concentration is gone up sufficiently, what that will do is the amount of heat released will actually start to increase, because the reaction rate is increasing.

Now, because heat released increases well temperature starts to you know go up, back up. Now, as temperature starts to go up notice that as temperature goes up reaction rate goes up exponentially. What that will do is actually you know temperature will start to go up much faster and this leads to the possibility of a thermal runaway. I am not saying it will happen every time, just that there is the possibility of a thermal runaway because what is happening is when the temperature was down you allowed burnable or burnable material or fuel to accumulate. Then once the temperature starts to rise, this unreacted fuel that is there sitting inside the reactor, it can catch fire. So, to speak and what I mean by catch fire is the reaction temperature will then just shoot off and you can have a runaway.

So, this scheme is susceptible to thermal runaway. Therefore, it is not recommended. It may be used for reaction that only mildly exothermic. However, such reactions are very rare may be you will get a such reaction in the pharmaceutical industry, may be biological you know fermenters and so on so forth. Certainly not in the in the process industry certainly not in refinery and petrochemical industry. Mildly exothermic reactions in petrochemical or refining processes are very rare. Let us just put it let us just say that and leave it at that.

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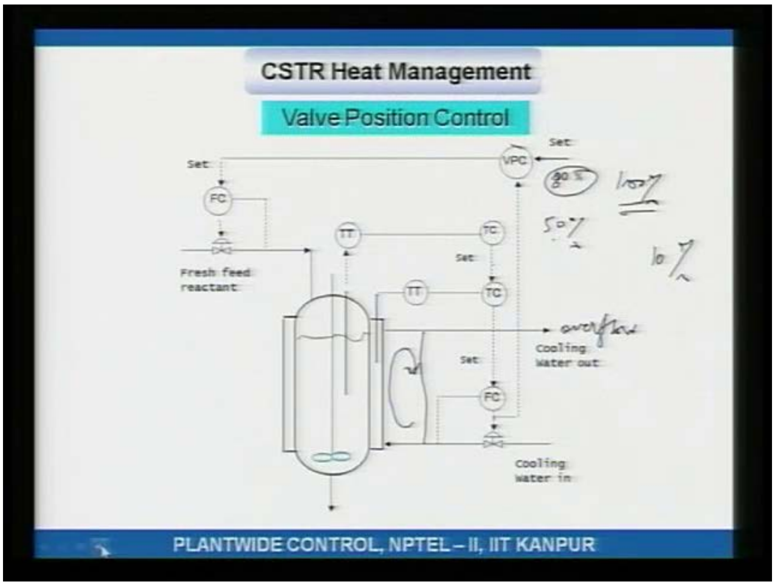


So, what is done is you apply valve positioning control. How do you do it? Well you got that standard standard thing, well what is that standard thing? Well even though I have shown it as flow controlling cooling water the what actually going on is, you know there is a recirculation loop. This is overflow and there is a large circulation rate. So, what you are doing is the jacket temperature is controlled by the amount of cooling water that you are putting in and the jacket temperature set point is coming from the reactor temperature. This is how conventional control is done.

Now, because you would like that for maximum production the cooling water valve be nearly full open. What you do is you take this cooling water vale position send it to a valve positioning controller and this valve positioning controller then adjust the feed to the reactor. Notice that let us say this cooling water valve is only 50 percent open, then what the valve positioning controller will see is cooling water is only 50 percent open, it should be 90 percent open. It will increase the set point of it will slowly increase the set point of the fresh feed to the reactor. As the fresh feed to the reactor goes up, because reactant accumulates inside the inside the reactor and the reactant composition goes up. Reactor temperature will start to go up because reaction rate has gone up so more heat is getting released.

As reaction temperature goes up the reactor temperature controller reduces the temperature of the jacket. The jacket temperature controller then increases the amount of cooling water that is been fed in what that means is this cooling water become cooling water valve becomes open. So, 50 percent will slowly become 60 percent 70 percent 80 percent until you reach 90 percent. You do not hold this at 100 percent because 10 percent or maybe 20 percent margin you want to keep and why do you want to keep? So, that margin, so that should the temperature increase when I am at when this valve is 90 per cent open. I still have that 10 percent margin to bring that deviating temperature back to set point maybe for a reactor this should be probably you know 80 percent.

So, this is how this is the, this is how it is ensured that you are processing as much feed as you can without compromising on tight reactor temperature control. You see in the previous case the temperature control had to be loose because of the because of the large lag associated with the large amount of material accumulated inside the reactor. In this case temperature is controlled is thought heat removal through the jacket and that is fast. So, this is valve positioning controller, valve positioning control for maximizing through put through the reactor maximizing the feed processed by the reactor. Why is it relevant? While you want to maximize product, that is why and to max in the effort to maximize production your heat removal in the CSTR actually limits your production.

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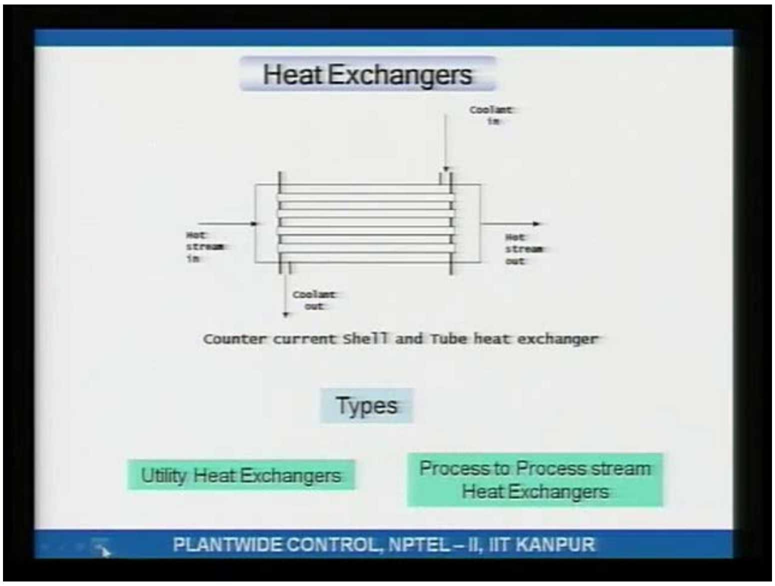


Next we will cover heat exchangers. I think I will stop today’s lecture here and will take heat exchangers next time.

Thank you.