Plantwide Control of Chemical Processes
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Lecture - 22
Heat Exchangers and Miscellaneous Systems

Welcome to this next lecture. We have looked at management of heat or the heat released in reactors. Now, we are going to look at heat exchangers. Well heat exchangers the most commonly used heat exchangers in industry are the shell and tube type heat exchangers. And why are they most commonly used, because this configuration packs a lot of surface area for heat transfer, probably the largest surface area for heat transfer in a small volume.

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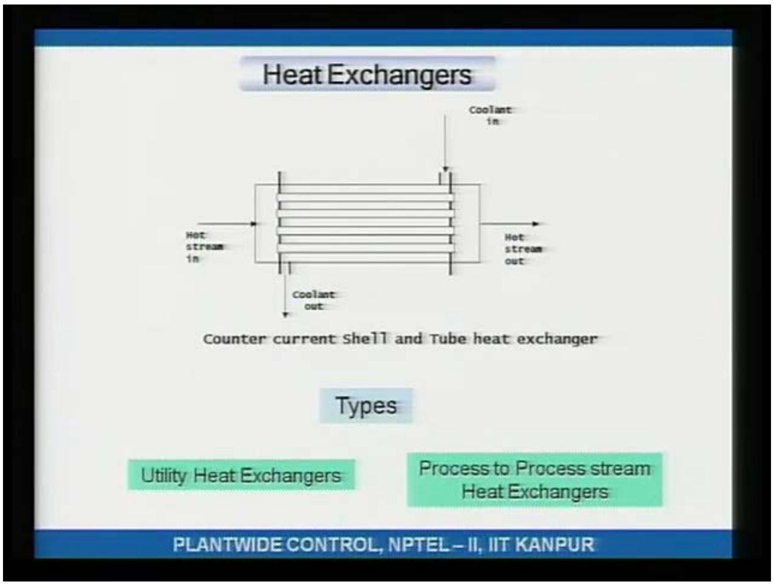

So for example, what you have here what is shown here is, there is a hot stream coming in goes into the tubes and comes out the tubes. Then you got coolant going in counter direction. So, the hot stream gets colder and the cold and the coolant gets hotter. There are two types of heat exchangers, utility heat exchangers and process to process stream heat exchangers, and we will just see what they are as we go along.

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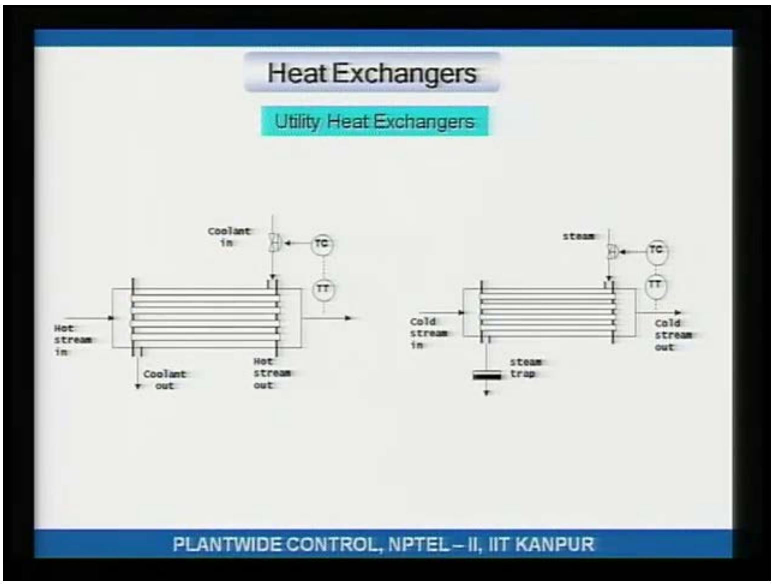

Utility heat exchangers, well utility heat exchangers use cooling water as a cooling fluid or steam as a heating fluid. So, cooling water or some other cooling utility. So for example, most common being cooling water, and the most common heating utility being steam. So, here is an example you got hot stream coming in. This hot stream is to be cooled to a certain temperature to cool it you are putting in the coolant. Well if the temperature is more than what it should be then you increase the coolant flow rate. I mean this is pretty obvious. Alternatively you got a cold stream going in and you are putting in steam and the steam is heating this cold stream to a certain temperature.

Well if you want the temperature to be at set point, let us say if the temperature is more than what it should be then you will pinch this steam valve. So, these are essentially very straight forward things that you do. So, essentially what you are doing is adjusting the heat transfer or the heat removed or added to get the desired temperature of the process stream. You are interested in the process stream having a desired temperature. By the way there is a steam trap shown here, what is the steam trap? Well a steam trap is well as the name suggests it traps steam. Suppose, this valve is open, then the you will lose precious steam steam is precious.

So, what you do is, what the what a stream trap does what a steam trap does is is essentially lets steam condense is steam looses heat. Therefore, it condenses and once sufficient amount is condensed the trap would open let out the condensate and then close again. There are various ways that gets done those are details, but what is a steam trap do it essentially keeps the steam from leaking out. It only lets the condensate out with very small amounts of steam getting out. So, essentially it keeps the stream trapped.

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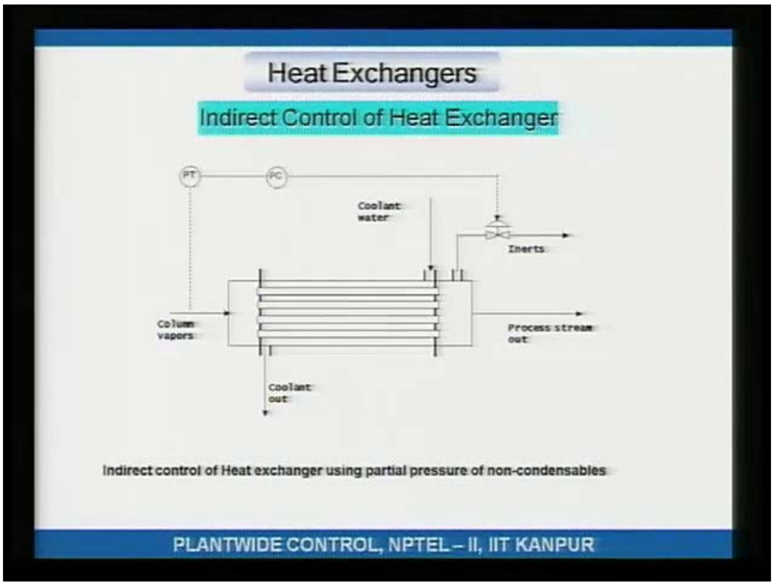

Well what the hell is this? Let us see indirect control so, here is a condenser which takes vapours from a distillation column and this vapour has got non condensables. For example, let us say it is got some nitrogen in it or let us say it is got some carbon dioxide in it, no matter how much cooling water you put the nitrogen or the carbon dioxide is not going to condense these are called inerts or non condensables. So, you are putting in the coolant and the coolant let us say, the cooling valve is fully open. How do you control the pressure of the column? You see that is by adjusting, you see the inerts or the non condensables that accumulate, you open this valve or you close this valve. How does this work? See if the pressure, well how does it work.

Well that is about it I do not think there is much to be explained here. If the pressure is building up you open the valve so, that that non condensables that have accumulated they go out and the pressure comes back. If the pressure is decreasing you close this valve so, that the pressure is maintained. By the way maintaining pressure if the composition of the vapors is fixed is equivalent to maintaining the temperature, because at a certain pressure the vapour would condense at a certain temperature which is called the due point temperature. So, this is an indirect control using well partial pressure of the non condensables.

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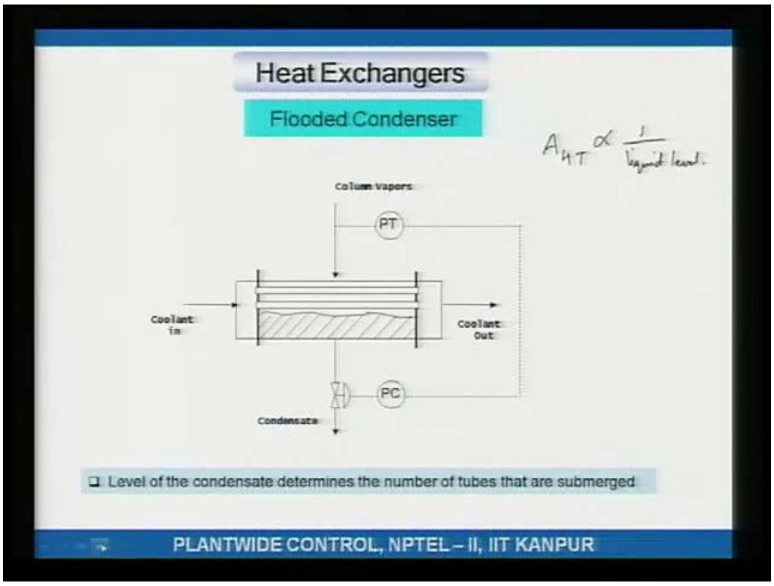

Here is another one you know a flooded condenser. What is a flooded condenser? You got column vapours coming from the column. They come in contact with tube through which let us say cooling water is flowing. Now, since cooling water is flowing through the tubes the tubes are cold so, the hot vapour comes in contact with the cold tubes and it condenses. The condensate is collected and some of the tubes depending on what is the level inside the inside the condenser, some of the tubes are submerged. So, what happens here is the area for heat transfer is proportional proportional or inversely proportional, is inversely proportional to liquid level inside the condenser.

Well you know so, the more the liquid that is accumulated more number of tubes are submerged, fewer number of cold tubes cold tubes are exposed to the vapour therefore, the heat transfer area is less therefore, the cooling duty is less. On the other hand if if the if the condensate level inside the condenser is reduced, more and more tubes will get exposed as more and more tubes get exposed well you got greater heat transfer area and therefore, more heat removal. So, in this case what is being done is you see if the pressure is increasing, if the pressure of the column is increasing that means the more vapor is coming in than is being condensed. To condense that extra vapor what would be done what the pressure controller would do is, open this valve.

As this valve gets opened the condensate leaks out now, the condensate more condensate flows out therefore, the level goes down as the level goes down more tubes get exposed as more tubes get exposed more heat gets removed. Therefore, the extra vapor that has accumulated it condenses and the pressure is brought back. So, this is how a flooded condenser works. Note that this loop will be slow because you open this valve, it takes a while for the condenser to drain. So, this is not a, the pressure here would be controlled the action of the pressure controller or rather the open loop dynamics if you change the valve position how long does it take for the pressure to respond. This would be slow that is because the level changes slowly. Therefore, heat transfer rate will change slowly and therefore, the pressure will change slowly. I hope this is clear.

So, this is the flooded condenser. If you are using a flooded condenser, note that you do not need a reflux drum. So, advantage of this unit is it is it is more compact you have the condenser as well as the surge capacity combined into one unit. On the other hand if you have a condenser followed by a reflux drum well then you got two two separate units each doing a certain task. So, here the search capacity as well as the heat exchange is combined into one unit the price that you pay for that is slow pressure dynamics. So, the pressure control will have to be loose that is because in response to a change in the level or change in the flow out of the condensate level changes slowly and therefore, pressure changes slowly. So, that is the price that you pay, you combine two units into one and the price that you paid was pressure control had to be loosened.

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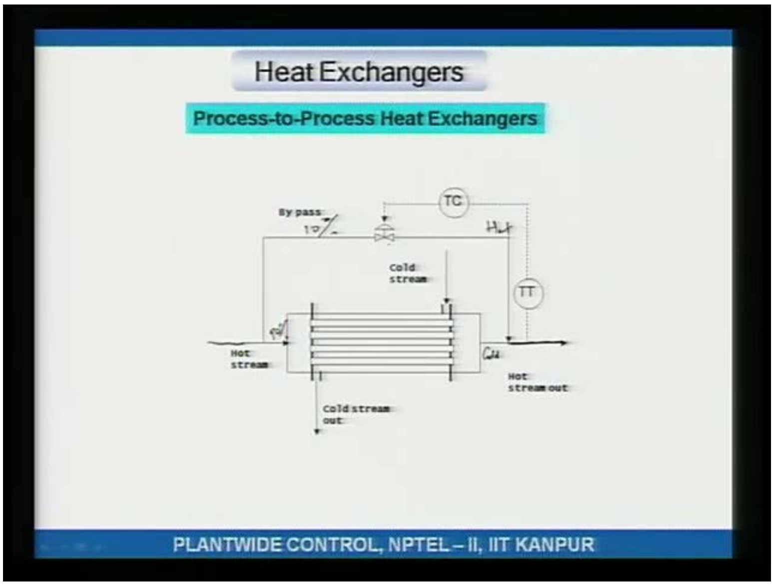

Process to process heat exchangers well process to process heat exchangers what what what essentially is being done is both the heating fluid and the and the cooling fluid are process streams and in a in a plant there are many hot streams and there are many cold streams that need to be heated, many hot streams that need to be cooled and therefore, in order to minimize steam and or cooling water consumption, what you do is you bring hot streams and cold hot process streams and cold process streams together. So, that the amount of steam consumed per kg product or the amount of cooling water consumed per kg product is reduced.

So, here is is what we have there is a hot process stream going in that is this guy and it is flowing through the tubes, coming out part of this hot stream is by passed. So, let us say 90 percent of the hot stream goes through the tubes about at base case about 10 percent is let us say bypassed. There is a cold process stream that comes which you know which becomes hot because it takes heat from the hot stream. Well to have the temperature of the hot stream at the desired value, what you are doing is you are adjusting the fraction of the hot stream that is bypassed. So, this stream is hot this stream is cold, if you mix if the fraction of the hot versus cold is adjusted this temperature will immediately respond to get back to get to where it is supposed to be.

So, this is like mixing cold water and hot water in a shower. You just at adjust the adjust the either the hot knob or the cold knob to get the temperature that you want of the shower. So, here the temperature control because of this bypass would be extremely you know the the if you change the valve position of the bypass valve, immediately the temperature would respond. So, the open loop dynamics is fast therefore, the tuning or the close loop response or or the tightness of the temperature control would also be pretty good that is because temperature responds immediately to a change in the fraction that is bypassed right. If you did not have this then we would have a problem and I think I have discussed this problem before so, I will leave that.

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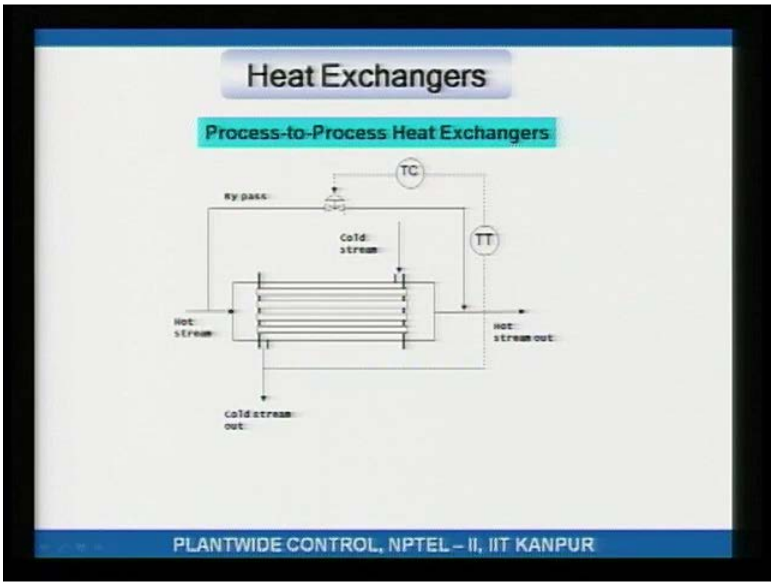

Here is a, here is an indirect way of doing it. Your bypass is on the hot side, the temperatures that needs to be controlled is that of the cold side. So, the you are interested in this temperature not in this temperature, this temperature can float. So, what what do you do? Well then what you do is essentially adjust the bypass to get the cold stream temperature that you want. Notice that in this case the dynamics of a open loop dynamics of the when you change a position of the bypass valve the temperature on the cold side will change slowly. Why does it change slowly that is because less hot stream is flowing let us say you open the bypass valve.

What that means is less hot stream is flowing through the tubes so, less heat flow through the tubes therefore, the cold stream will so, the tubes will get less hot and because the tubes are getting less hot the cold stream will get less heat and because the cold stream is getting less heat this cold stream will become hotter or colder colder because the cold stream is gaining less heat it will become colder. However, for the tubes to become hot or cold because less material less or more material is flowing through the tube, that will that will be a slow process, that will take a long time. So, the temperature control in this configuration would not be tight, would not be very tight. So, that was about heat exchangers. Now, it switch gears what do we do.

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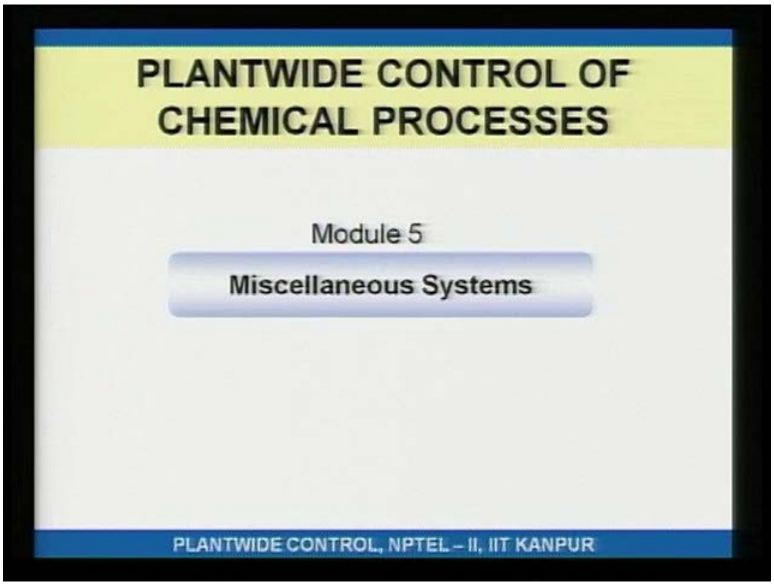

Now, we are going to go over some miscellaneous systems that are commonly encountered. Some miscellaneous systems, this is actually an interesting one.

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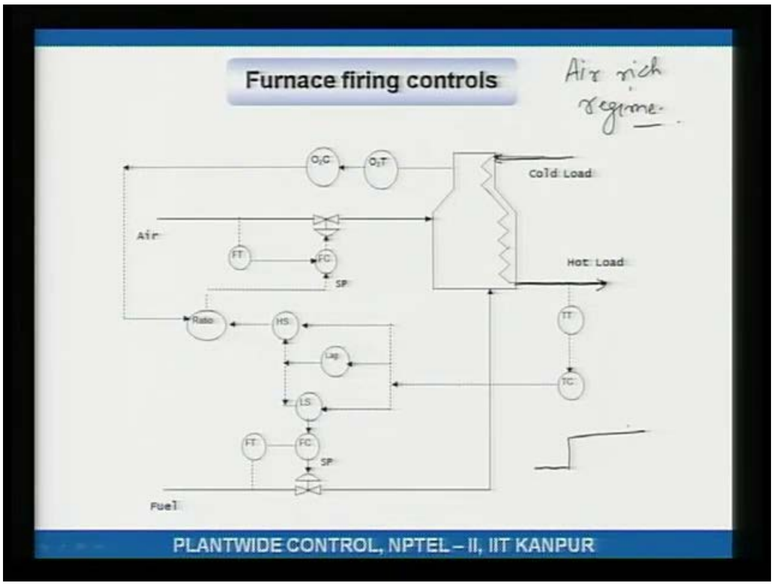

The first one will do is furnace firing controls, see here is a furnace. So, you are putting in air and fuel the fuel burns in the presence of air therefore, the tubes are really really hot. The cold process stream that is flowing through the tubes gains you know you know through those hot tubes becomes hotter and flows out. So, this is cold in this is hot out. So, this is the process stream that is being heated process stream comes in cold stream comes in flows through the extremely hot tubes and the cold stream becomes hot and goes out. Now, you would like to operate this furnace in such a way that you are always in the air rich regime. What I, what do I mean by air rich regime?

See you are putting fuel into the furnace, you are also putting air in to the furnace and there is a sparker that is you know causing that fuel to burn just like you burn burn burn gas. Once the the fuel gets in to the furnace, it must be ensured that whatever fuel enters the furnace it burns. If it does not burn that fuel will accumulate inside the furnace. Next time around when you start putting in air you think that there is no fuel there, but there is fuel unburned fuel leftover from previous operation that is inside hmm you know you can have a blast. To avoid this to ensure that all of the fuel that is been put in to the furnace gets consumed, you would always like to have sufficient supply of air.

That means you would like to have always extra air so, that all of the fuel gets burnt and none remains behind inside the furnace this is a essentially a safety requirement. What does it mean in terms of operation? In terms of operation what it means is for example, if fuel increases, if the heating load or let let us see, let us say let us say let me back up a little bit now. Let us see.

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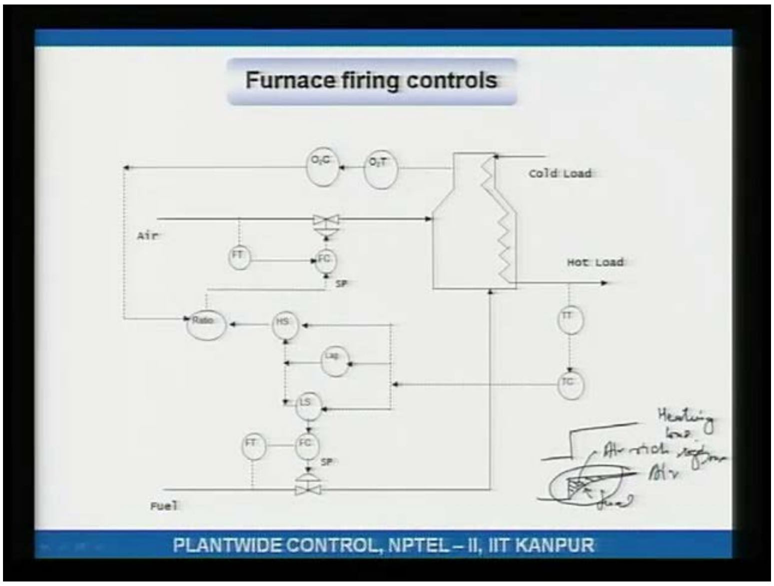

Let us say the temperature of this stream is decreasing and it is going below the set point. Since, the process stream is becoming colder that means you need to put in more fuel and more air so, that the temperature of the process stream that is decreasing because of the extra heat or the extra burning of fuel it will come back up. So, let us say so, heating load goes up that means the process stream is colder you need to heat it more so the heating load has gone up. So, this is the heating load let us say it is going up as a step just for the sake of if the heating load is gone up that means you need to add more fuel and more air. However, in order to ensure that during the transient you are always having more air than fuel.

What really needs to happen is, air should go up like a step and fuel so, air should go up like a step and the fuel should go up like a fuel should lag behind. This is fuel. What that ensures is during the transient which is this period and if you look at this hatched area, this ensures that you are always in air rich regime, air rich regime, that is what I was saying right. So, let us erase this.

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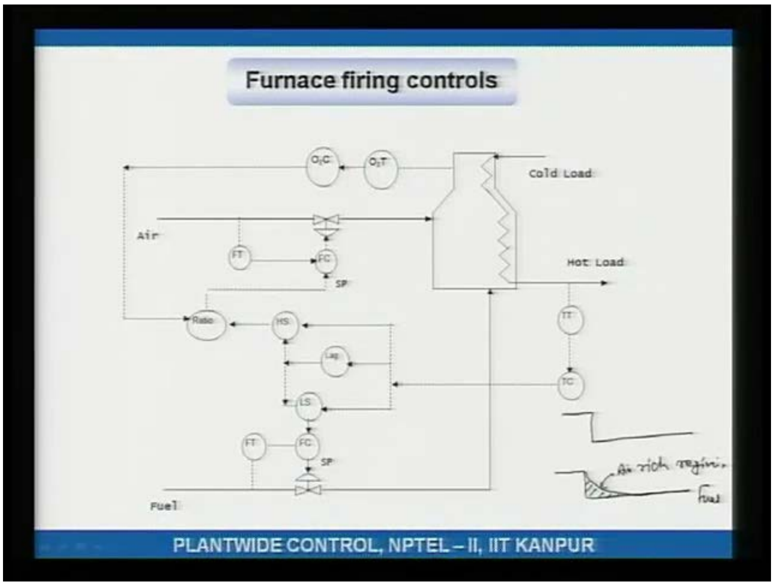

On the other hand let us say, the heating load is decreasing. What what what then you need to do is, in this case what should happen is the fuel should go down first and then the air should lag behind. Again you notice this hatched area during the transient or during the period, where things were changing from one steady state to the next during the transient period, you are getting air rich regime. You have extra air than fuel. This extra air that than than fuel ensures that whatever fuel enters the furnace it gets burnt away none of it remains and it is absolutely essential to ensure this because any un burnt fuel may lead to a disaster next time the furnace is started. So, how do we accomplish this, well it is accomplished the way it is shown here, I hope the problem is cleared to you So, let us again.

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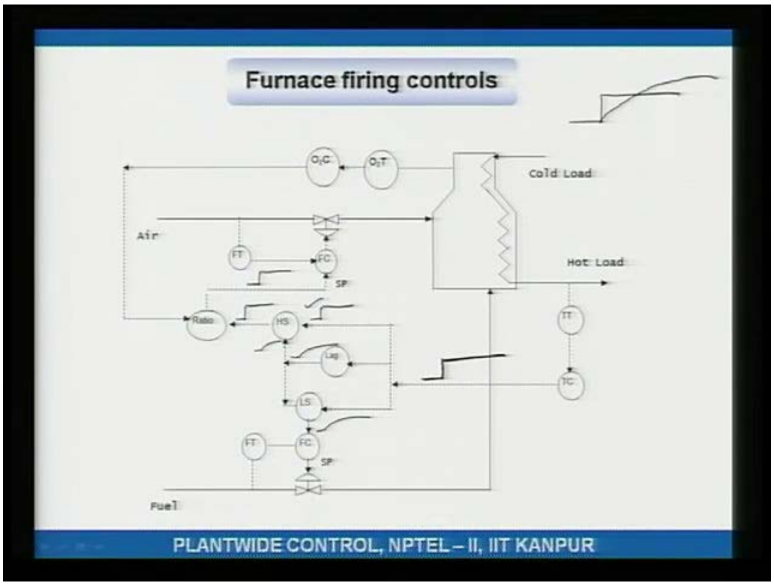

So, let us say the temperature is, temperature controller which is trying to control the temperature of the process stream, is saying that look I need to, let us say the output of this temperature controller is a step. So, the temperature controller is saying give me more heating, more heating means more air more fuel. Now, what you do is this step is sent to a lag when you send it to a lag the output of this lag would be you know something like an exponential an exponential rise. Now, what you do is this exponential rise signal is compared with a low select.

So, when you compare this exponential rise and select the low lower of the two, notice that this would be the exponential rise would be less than the step. Therefore, the output of this guy would be so, the lag will get passed through so the set point of the fuel is increasing as a lag. Let us look at what happens here, the signal here is a step, this signal is a lag. When you compare the two the higher one of the two is this guy therefore, this guy passes through therefore, this signal is this.

So, you are essentially saying increase the air flow like a step, multiplied by whatever is the set point that you want the ratio that you want the air fuel ratio that you want therefore, this goes up as a step. So, the flow set point to the airflow controller increases as a step, while the flow set point to the fuel flow controller increases as a lag. What that ensures is should the heating load demand or the heat load increase. That is what, this is the heat load is increasing you want more heating. Then the fuel lags behind the air, in that case what is happening is air goes up like this fuel goes up fuel lags behind. Notice that these two need not be equal because you will typically have, what the hell did I do or may be it will be like this, sorry.

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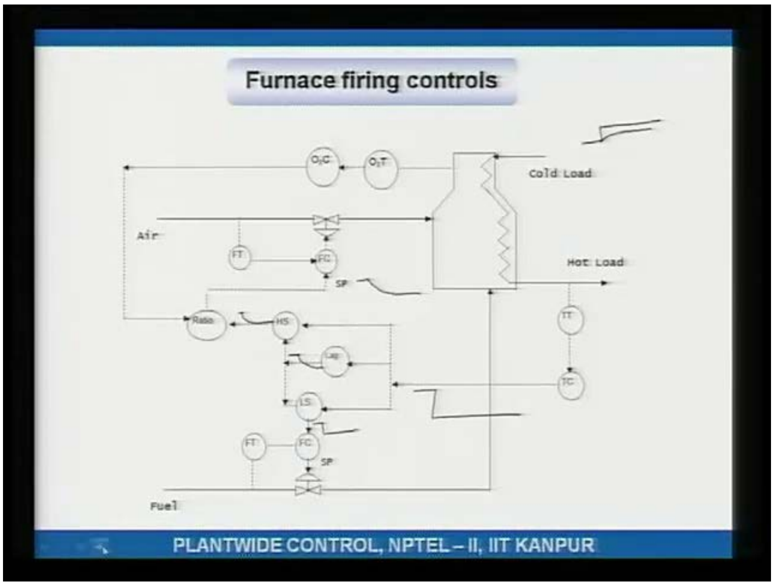

So, fuel goes up like a step and let us say the air to fuel ratio is I do not know, 5 is to 1 the fuel the air. So, fuel the air goes up like a step, the fuel will go up like an exponential. So, the fuel is always behind what behind the air so, the air increases first and the fuel lags behind. Now, let us do the other other part let us say this is a step decrease that means reduce the heating, what happens here is the lag, the lags, output of the lag would be a exponential decrease like this. When you compare this exponential decrease with this step down, well the lag is greater than the step down. Therefore, the low select will select the step down so the output of this low select will be this guy.

On the other hand the high select will select the exponential lag therefore, the set point to the airflow controller will be like this. The set point to the fuel flow controller is a step down. What that again ensures is that during the transient fuel decreases first followed by the air, that again ensures that you are always in the air rich regime during the transient. So, just a just a lag and some combination of high selects and low selects and you are able to accomplish, what you wanted to accomplish. So, this is simple control solution to to to to to to to what? To address a safety concern. What is that safety concern? You do not want any un burnt fuel to remain inside the furnace.

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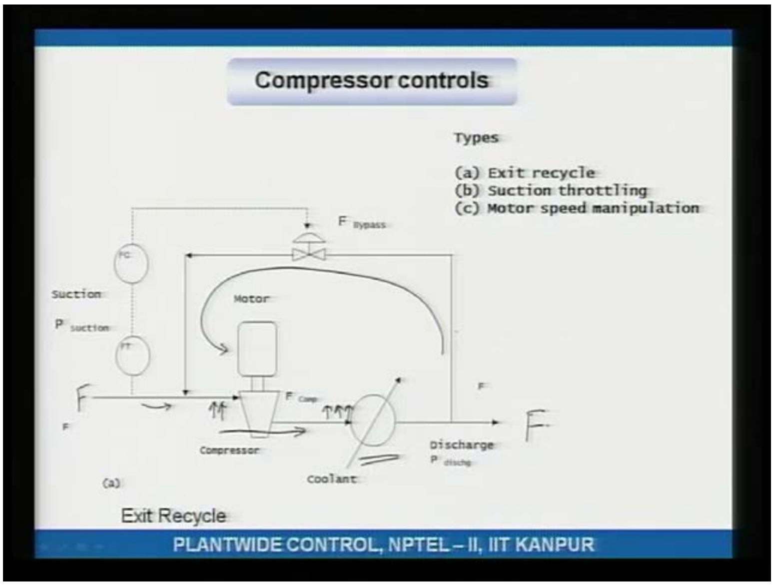

Compressors well alright, let us see what is happening here? You are getting a flow through the compressor. Now, as the gas flows through the compressor it heats up because it heats up you have this cooler which will cool this hot gas. Part of whatever is is recycled back and the other is thrown so, if this is F well this is F, and of course, you got some recycle going through. As far as the compressor is concerned, if F decreases F bypass would increase if F increases F bypass would decrease. So, as far as the total flow through the compressor is concerned that will remain constant.

It is just how much is being recycled and how much is being allowed to pass through. Notice that if you do not have this condenser or rather this this cooler and then you have this recycle arrangement what will happen? Input gas is cold, it goes through the compressor, it gets hot, part of it this hot gas mixes with this cold gas so, the temperature here is more. This temperature is more therefore, this temperature goes up. If you do not have the condenser this temperature would go up. This hotter input to the compressor will give a still hotter output from the compressor. What what I am essentially trying to say is, that temperature of the gas if you do not have this cooler will increase non stop.

If I assume that the losses are negligible, heat losses are negligible. You see there is feedback, there is energy feedback because of this recycle to break this energy feedback, this cooler is provided. So, then what happens is well this cooler essentially what you will essentially have probably is something like this, temperature controller or whatever the point is this. Cooler prevents the energy from building up so, if you want a certain flow you adjust the bypass to get that flow. I mean that is pretty clear that is how this works so, what what it essentially means is if the if the flow is more than what it should be, then increase the bypass so, more will get recycled the flow will the, the flow, the fresh feed flow or whatever what is what should we call F F will will decrease there. So, an inc if if F is increasing, increase the bypass more will get recycled. So, the F will go down if F is decreasing.

Reduce the bypass less will get recycled. Therefore, F will increase so, I hope this is clear. So, this is by adjusting the recycled rate back to the compressor you are controlling the fresh feed processed by the compressor by adjusting the recycle rate or the bypass rate.

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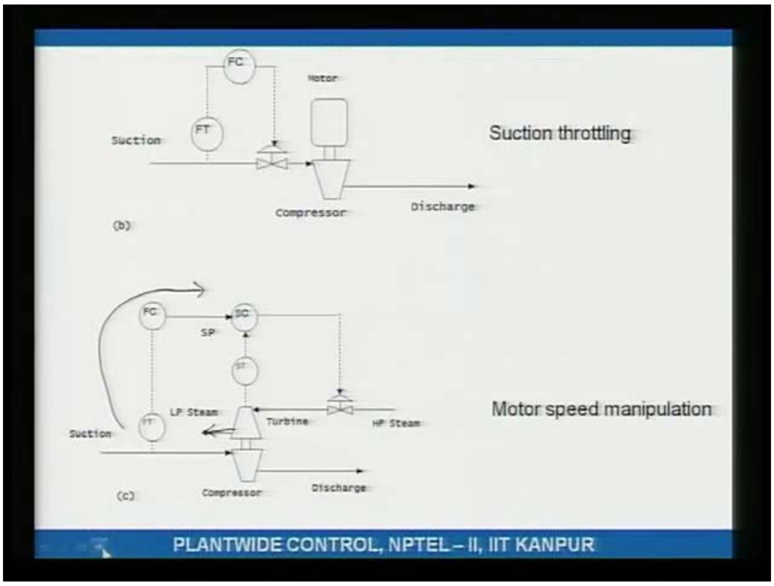

Here is another way of doing it and that is essentially by by by throttling the valve at the suction. So, you are essentially saying that if I thought, I mean if I want less flow to be processed, I will throttle this valve. If I want more flow to be processed I will open this valve. Arguably the best way of doing it, the most energy way of doing it is using motor speed manipulation which is which is shown here. What is happening here is you got a compressor and you got a turbine which is rotating the compressor. So, the cut turbine is for example, is being rotated by high pressure steam high pressure steam looses its pressure energy to create the rotation and the high pressure steam.

Then exits as low pressure steam which is here, this is the low pressure steam. Now, the more the flow of the high pressure steam the more the rotational speed, the less the flow of the high pressure steam, the less the rotational speed of the turbine. So, what is being shown here is a cascade arrangement. I have a master flow controller which is this guy, this is setting the speed of the turbine speed controller. How does this work? Well if the flow through the compressor is increasing, what that means is the compressor is compressing too much is rotating at too higher speed. So, that more material is getting processed so, what you do is the flow controller will say too much feed is being processed I need to reduce the amount of feed flow, it will reduce the set point of the speed to the speed flow controller.

This set point will go down so, as this set point goes down, the speed controller will throttle the steam valve, steam flow will decrease because the steam flow decreases that the the the the compressor will now rotate at a lower speed because it is rotating as a at a lower speed, the flow rate of whatever is passing through will become less. So, if the flow rate is increasing the rotational speed is decreased, if the flow rate is decreasing rotational speed is increased. Why is it the most efficient way of doing it, that is because you are rotating the the compressor at whatever speed it needs to be rotated at to get the flow that you want pressure inside and pressure pressure at the inlet and pressure at the outlet of course, is constant. So, no extra rotation therefore, it is the most energy efficient way of doing things.

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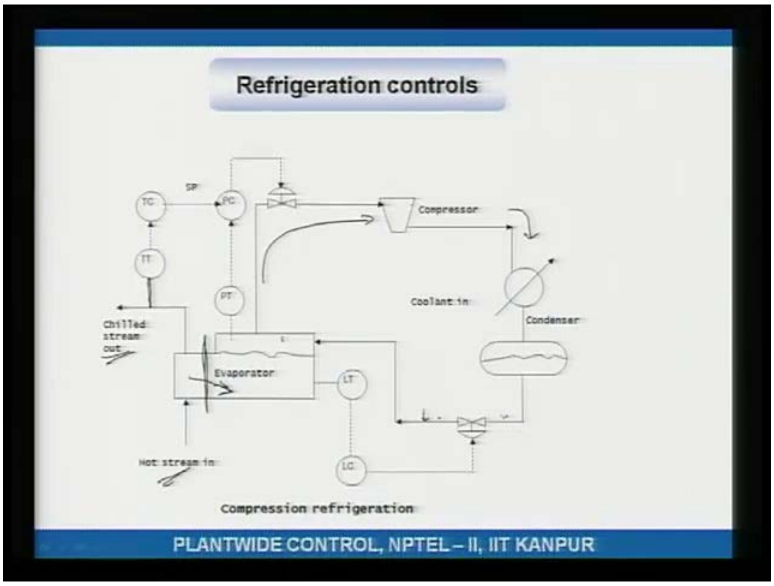

Now, let us get to some refrigeration systems. You would have seen a refrigerator, you know compressor gets on gets off consumes a lot of electricity. So, here is a hot stream which needs to be cooled to get a chilled stream out so, this is my chilled stream this is my hot stream. On the refrigeration side what I have is the refrigerant which is in contact with the hot steam because the refrigerant is extremely cold now, because the refrigerant is extremely cold the refrigerant absorbs heat from the hot side causing, this causes vaporization. The evaporated refrigerant goes to a compressor.

It is compressed it is compressed to such a high pressure so, that you can condense it or liqui at that high pressure, it can be condensed using for example, cooling water. So, this is pressurized refrigerant, then when you bring it in contact with let us say cold tubes which have cooling water you know 30 35 degree Celsius, it condenses the refrigerant condenses collects in this drum, there is a pump of course, that pumps it and I think there is a joule Thomson effect here. What what what I am saying is the following condenses collects as liquid. This liquid is fed to this tank, where evaporation is occurring and yes of course, there is a joule Thomson effect here. The idea is okay.

There is a large pressure drop across this valve. You see the evaporator is at low pressure compressor brings it to high pressure so, this is at high pressure this is at low pressure because the pressure here will be whatever is the pressure here which is the same which is which is low pressure. So, because of this large pressure drop across this valve you know the the refrigerant undergoes partial vaporization. There may also be some joule Thomson effect where, if you are if you if you if you notice you got a C O 2 cylinder and you take C O you know, you are taking out gas from the C O 2 cylinder, you will find that ice forms where that valve is from where the gas is exiting the cylinder.

So the so, so, the gas is exiting from a high pressure zone to a low pressure zone across the valve. That large pressure drop causes joule Thomson cooling and because of that you may see that know around the regulator some ice forms. This you may have observed something similar goes on here. There is a large pressure drop across the valve and as material flows across this valve, it it partially vaporizes and cools off because of the joule Thomson effect. That vapour liquid mixture accumulates in this evaporator. Now, how do we control it? Well what I am interested in is that the temperature of the chilled stream be controlled be whatever I want it to be.

Hot stream flow rate and hot stream temperature can vary regardless of variation in the flow rate of the hot stream and the temperature of the hot stream, temperature of the chilled stream should be held constant. So, I measured this temperature send it to a temperature controller and what the temperature controller is doing is adjusting the pressure set point in the evaporator. What does that do well if the temperature is increasing, that means I need to cool more.

If I need to cool more I reduce the pressure that that what will that do, that will reduce the temperature inside the evaporator because things boil at a lower temperature. If the pressure is lower so, the temperature inside the evaporator goes down. If the temperature inside the evaporator goes down, more heat gets transferred across this valve. This wall more heat gets transferred means more heat gets transferred from the hot side to the cold side. So, that is how this works. So, and what is the pressure controller doing while this the arrangement is here by throttling the suction valve to the compressor suction valve to the compressor. So, that is how this works. So, what we are essentially adjusting, is the temperature of the refrigerant increasing it or reducing it to remove less or more heat.

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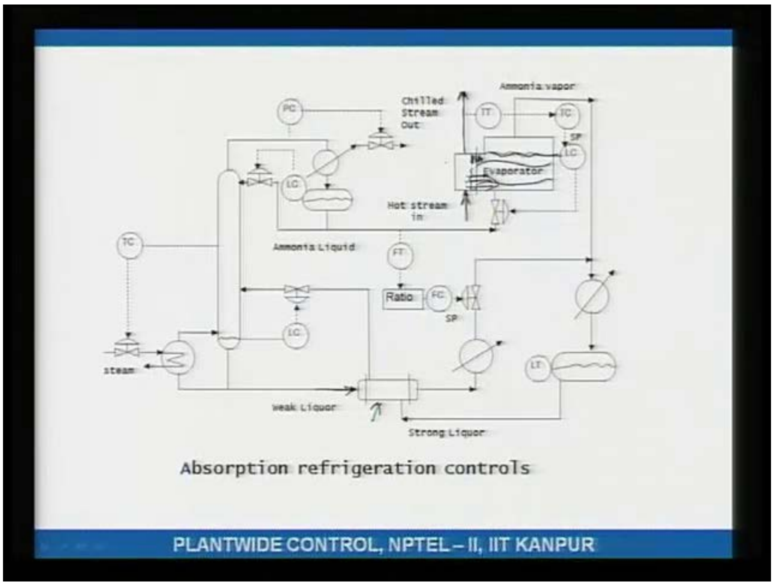

All right now, we are going to use look at another refrigeration system, which is quite commonly seen in industry and here absorption is used. See there what we had was compression and then evaporation. Here we have absorption and desorption. So, to speak or absorption and evaporation. So, let me just explain to you what is going on and then you can form your own opinions. So, here is the hot stream, which is to be chilled to a certain temperature. The hot stream is in contact or is in thermal contact with cold refrigerant, which in this case is ammonia nearly pure ammonia. The ammonia because it is getting heat from the hot stream vaporizes and this ammonia vapour is mixed with lean water. Lean meaning ammonia lean. So, it is essentially a water with a, with very small amounts of ammonia.

So, the ammonia will get absorbed in the what the ammonia will dissolve into the water and of course, this is cooled and collected so, this is actually strong liquor. Strong liquor meaning strong ammonia liquor. So, water is a lot of ammonia dissolved ammonia in it. So, this is heated and it is heated. This is a process to process heat exchanger, this guy is a process to process heat exchanger. This is a processed steam, the hot steam is also processed steam, which is the hot bottom from the distillation column, I will tell you what the distillation column is doing.

So, the strong liquor is heated and sent to a distillation column. What is happening in the distillation column is, in the distillation column ammonia being you know, when you heat it the ammonia will come out of the water and therefore, ammonia is an you may treat ammonia as as the light component.

This light component as you go up the column it becomes richer and richer in ammonia. The ammonia vapour is condensed part of it is refluxed and the other part is sent to the evaporator. Well so, I hope the process is clear to you. So, you get strong liquor it is distilled to get ammonia and weak liquor and this weak liquor is you know used to absorb the ammonia. Now, how do you control the temperature that chill stream. What we are essentially doing is the temperature transmitter or the temperature controller. So, let us say the chilled steam is becoming hotter. You know its temperature is driving that means I need to remove more heat. So, this temperature controller adjusts the level set point inside the evaporator. What that means is the level may be this or the level may be this or the level may be whatever I have drawn here you know.

What that means is as I adjust the level the cold heat you know, the heat transfer surface area actually changes. So, this would be cold for example, and not much heat will get transferred here. Why is that? Not much heat will get transferred here because because what well liquid side heat transfer co efficient will be much much higher than vapour side heat you know vapour heat side heat co efficient. So, the amount of heat transferred here will be major, amount of heat transferred here will be minor. So, the more is the liquid level, the more is the heat transfer rate. I hope this makes things reasonably clear. So, so if the temperature is decreasing for example, that means I am cooling too much. What what what should I do?

The temperature controller would reduce the level inside the evaporator and then what will happen is because the level should be less. Now, the level set point has gone down level is more this valve. This valve will be opened and this level will decrease to for example, dear erase all in consulate.

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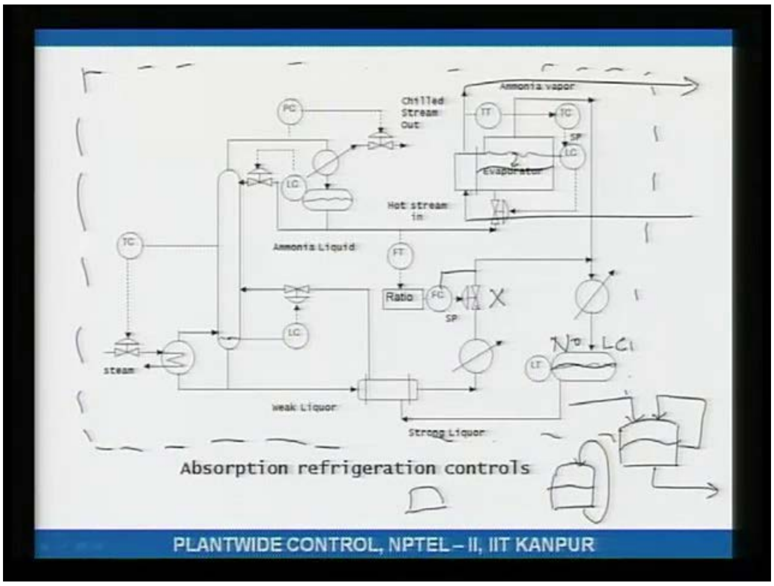

So, the level decreases comes to here and now the heat being transferred across the valve, across the wall is is reduced therefore, the temperature that was decreasing comes back up right and comes back up to set point. So, in this case the heat transfer is adjusted by the heat transfer area, not by the delta T, but by the heat transfer area. Now, well if oh shit. What did I do here? I think, I I I described the level controller wrong. See, this is the feet to the evaporator. So, if you want to reduce the level what you would do is you would pinch this valve less flow. Now, what does this ratio controller do? Well if the amount of flow here is decreasing, what that would mean is the amount of heat being transferred because the level is now lower is decreasing.

Now, since the amount of heat being transferred is decreasing therefore, less ammonia vapour will get formed, less vaporization will occur. Since, less vaporization will occur what that means is the amount of water that is needed to absorb that less ammonia should also dec you know. Let us say, it takes 2 kilograms of water to absorb 10 grams of ammonia well, because the ammonia rate is going down you should also reduce the amount of water that is going in. So, the water that is used to absorb the ammonia is maintained in ratio with the ammonia being fed to the evaporator that is what this ratio scheme is doing. Flow controller valve is this way.

Inside the distillation column you maintain a tray temperature by adjusting the steam you maintain the level at the bottoms. By the way, you maintain the, you see because you have used you have you have used up the bottoms flow rate to keep it in ratio with the distillate flow rate. Therefore, bottoms is not available for level control of the bottoms of the of the column. Therefore, the bottoms level is controlled using the feed to the column, that is because this valve is no long, no longer available. Why is it not available, because this valve is maintained or this flow rate the bottoms flow rate is maintained in ratio with the distillate flow rate the more the amount of the distillate that means more the amount of ammonia to be absorbed.

Well the water flow rate is increased in that ratio. So, if the ammonia flow rate into the evaporator is increased is 10 percent the water flow rate which is used to absorb that vaporized ammonia is increased 10 percent, that is what this ratio station is doing. Now, because this ratio is being maintained this valve is not available for level control therefore, the bottoms level is maintained by adjusting the feed to the column. Notice that the level here is not controlled. Why is that so? I mean wherever you look if there is a level it must be controlled, here is a level that is not being controlled. The explanation for that is if you look at the overall system, which is you know let me just look at the overall system.

If I look at the overall system, the process flows in and out are here is the hot stream and here is the chilled stream that goes out. As far as the water and the ammonia is concerned, none of the ammonia or the water leak out of, there is no stream of water and or ammonia that is getting out of this plant. So, if I look think of the plant as a tank well there is this hot stream coming in, there is this chilled stream going out and there is a lot of water and ammonia circulating around and that is the inventory of. Now, I can set this circulation rate at whatever I like or leaving this plant. It is like having a tank, like a, like I have drawn here it is like having a tank you have got some amount of material there water and ammonia.

You can recirculate it at whatever rate you want, you do not need to control the level. Therefore, there is no level controller here, that is why this is happening, that is why we have this. By the way this aspect I should have also shown you in the previous slide. Notice that the level, no level control here also.

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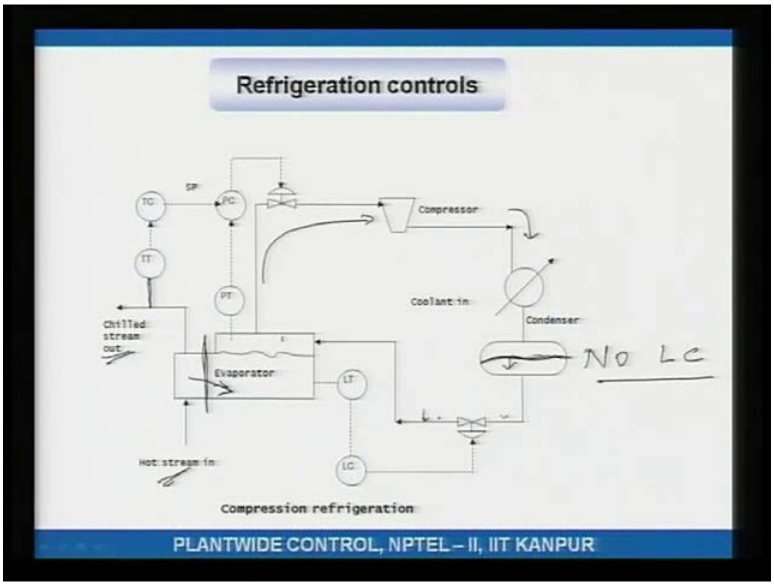

Why is that? That is because the inventory of the refrigerant which is what, this is is fixed the refrigerant can circulate around at whatever rate you want, but since no refrigerant is entering or le or or or exiting I do not need to control the level level of the of the refrigerant. Of course, some amount of leakages is always there so, this is what you do you know. Every two or three seasons you will charge the gas or the refrigerant into your car ac unit or you will charge gas into your home ac unit or you will charge gas into your refrigerator compressor or refrigerate refrigeration unit. Well of course, there are those leaks, but those leaks are taken care of by you know just after 6, 4, 6, 7, 8, 9 or you know 1 or 2 years of operation.

Just put in a little more, just just fill up the gas. Now, how how how is that indicated this level over 2, 3, 4, 5, 6 months or may be a year or 2 years of operation will continuously go down. So, once this level has gone down from say 60 percent to about 30 percent, you may decide well slowly, but surely we have lost enough refrigerant. Now, we need to charge more refrigerant. So, you charge more refrigerant, but as far as the day to day operation is concerned there is no refrigerant coming in and there is no refrigerant going out. Therefore, this level is not controlled, but of course, you monitor it once this level has gone down sufficiently because of small leaks you charge it back up.

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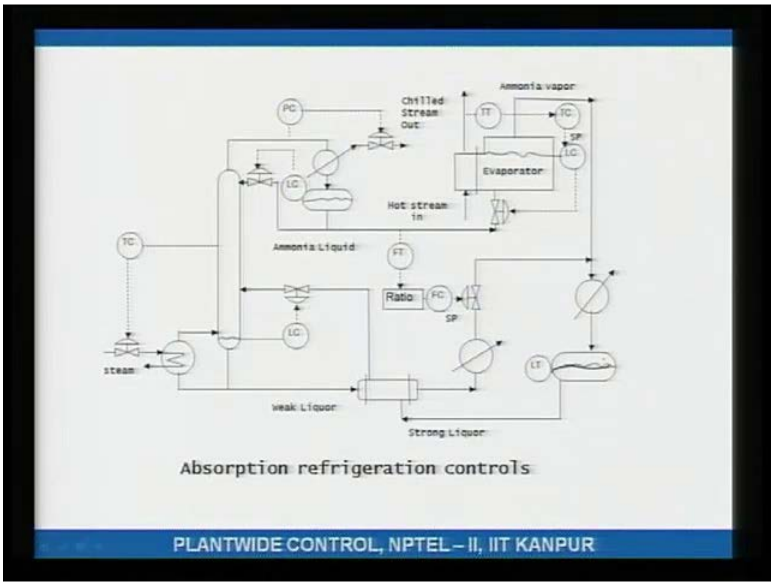

Same thing here once this this level has gone down, sufficiently you charge more water and ammonia into the system. So, that is how this is done.

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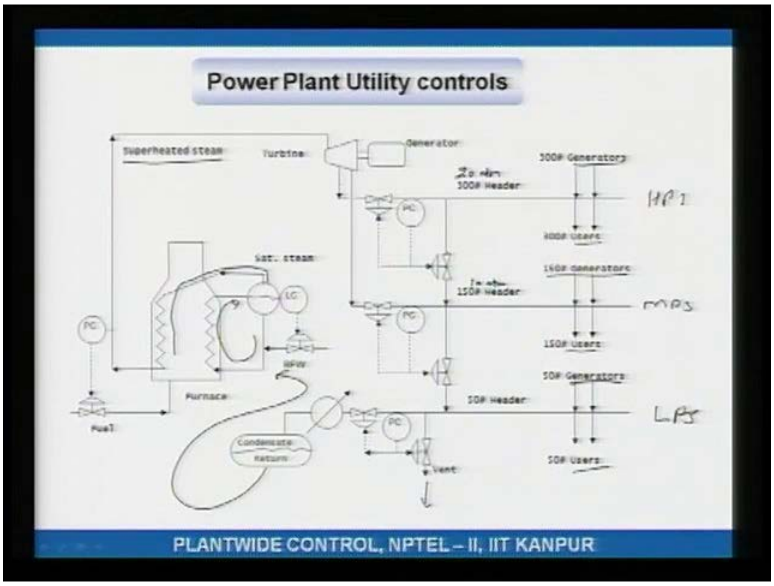

Power plant utility controls well. Why is this called power plant? Yes, because you are having that generator there. This is the steam unit in in in in a large petrochemical complex. What you have is you have got a furnace and you are let us say burning diesel or fuel gas in that furnace. Water goes into the hot tubes which are exposed to the fire in the furnace of course, sorry it is it is going like this. So, the liquid water heats up, comes here, flashes to give you steam. The steam which is saturated is further sent into the furnace.

Now, the saturated steam is further heated so, so, so what you get out here is super heated steam. This super heated steam is at a very high pressure. So, it is sent to a turbine and as it is sent to a turbine, what do you do? It is sent to a turbine to generate electricity. So, this very high pressure goes to so, from a very high pressure you go to a pressure of about 300 Psi pounds. How much is a Psi 15? So, 300 divide by 15 is how much? About 20 bars 20 21 22 kilograms per centimetre square. So, this is about 20 kgs or 20 atmospheres of that order. So, this steam which is high pressure steam is used by various plants of course, there are some plants where you know for example, reaction is generating a lot of heat. So, that hot react reaction steam is used to generate steam or the reaction heat is used to generate high pressure steam and so on so forth.

So, there are various plants that are generating high pressure steam. There are various plants that are consuming high pressure steam. So, these are the consumers these are the generators. So, that the generators are also adding their steam to this 300 pressure head 300 pound pressure header and the users are drawing stream from this 300 pounds pressure steam header. So, high pressure steam header header some of this high pressure steam here. Its pressure is reduced using this valve and then it is sent to a lower 10 10 atmospheres or medium pressures steam header. Medium pressure steam is used by many users and medium pressure steam is generated by many plants and they are supplying and consuming steam form this medium pressure steam header. This is the medium pressure steam header.

This is the high pressure steam header. Some of this medium pressure steam is again, its pressure is dropped and sent to a what a low pressure steam header and the low pressure steam is being generated by many plants, is being used by many plants and these are the generators and the users of low pressure steam. Then what some of that steam is vented out, that is this vent some of the low pressure steam is vented out, some of the what, some of the steam is condensed and probably returned to the boiler. This condensate is returned to the boiler so, let me just screen hide ink mark up.

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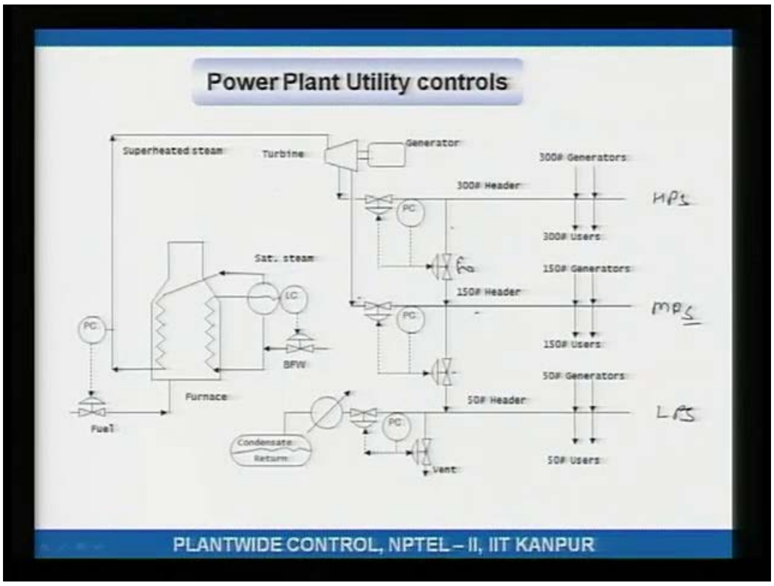

Now, what are the controls? Well if the pressure in the 300 pound are in this 20 atmosphere or if the pressure in this high pressure steam header is increasing, what do I do? I dump you see that means I am getting more you know. There is more steam coming from the generator than is being consumed therefore, the pressure is rising what do I do I open this valve and dump some of that steam into the low into the medium pressure steam header. If the pressure in the medium pressure steam header is increasing I dump some of that steam into the low pressure steam header if the pressure of this low pressure steam header is increasing, I vent that steam out.

This pressure controller is actually a split range controller so, what I am essentially doing is let us say I cannot dump any more steam here, that means this is fully open pressure is still increasing. What do you do? Well then you start throttling this valve s, that you suck in less steam. So, by venting or drawing in by by by throwing out or drawing in less oblique more steam you are maintaining the pressure in the high pressure steam header. Similarly, by by venting or taking in less steam, less or more steam you are maintaining the pressure in a medium steam pressure steam header and a similar logic also applies to the low pressure steam header. How do you maintain the pressure of the super heated steam, by putting in sufficient fuel. So, if the pressure is going down heat up more if the pressure is going up heat up less. So, this is what we have in power power plants

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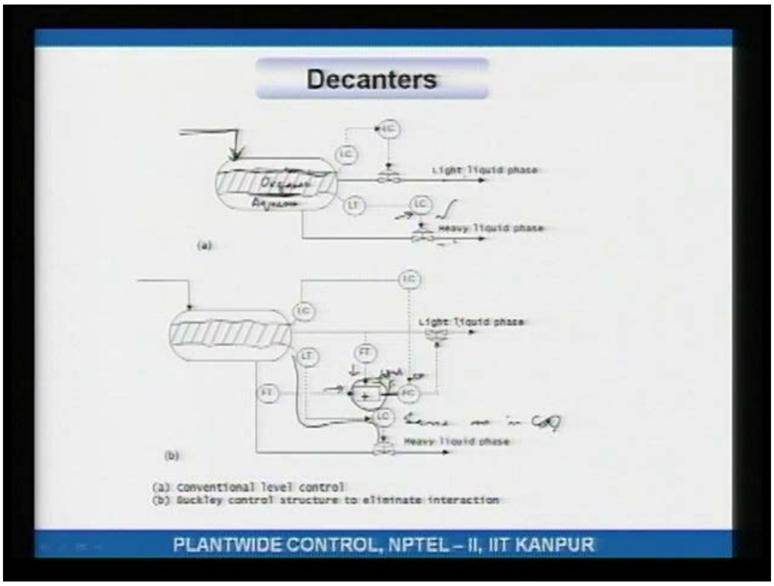

I think the last one is this decanter business. Red light has gone up, but let us see it will take may be 2, 3, 4 minutes. Decanters, so here is a liquid stream which is got, which is a mixture of organic and orga on a of an organic phase and a two immiscible liquids typically, an organic phase and a and a aquas phase. If you put it in a tank, aquas phase will be what what we have here this will be aquas and this would be organic. And and what? The water is drawn out and the organic phase is also drawn out now, you are interested in maintaining this level as well as the you know liquid liquid interface level.

So, both the levels need to be maintained. So, to do that what we are doing here is while you are maintaining the top level or or or the total level by adjusting the light liquid phase draw and the bottom of and the and the interface level is being controlled by adjusting the water draw. So, that is what this controller is doing and this controller is trying to maintain the total level. Notice that there is interaction here, why is there interaction? It is there because if you adjust this the heavy draw in you know the interface level will move and whatever is the interface level move if the if the if the light phase draw is maintained you know, the whole thing will move up or down. So, what I am saying is whatever this level controller is doing, whatever this guy is doing each action whether it is opening this valve or or closing this wall is affecting this level and therefore, disturbing the other level loop.

How do you circumvent this problem or how do you bypass this problem or how you how do you. Well notice that this level is a function of the total flow out. If the total flow in is equal to the total flow out, total flow out meaning light liquid plus heavy liquid, this level would not change. So, what is being done in solution b, that is drawn here is that the top level controller or or the total level controller. So, you have the bottom level this this is same as before. This is the same as before, same as before same as in a as in a the top level is being controlled not by adjusting the liquid phase flow, not by adjusting the top stream, but by adjusting the set point of the total flow.

So, this is the totaliser which takes in the flow of the light steam, which takes in the flow of the, so this is the, this is the heavy stream flow, this is the light stream flow. You sum it up so, this is the total flow, this is the total flow out total flow. This total flow set point is adjusted by the level controller and to keep this total flow constant you are adjusting the flow controller is adjusting the light liquid flow. How does this work? How is this any different from what was being done in scheme one. Let us just go over that. My explanation is slightly, well let us see. So, let us say this The let us say this level controller, let us say this level controller opened the valve as it opened the valve, well the flow out increased because the flow out increased this level will start to decrease will go down.

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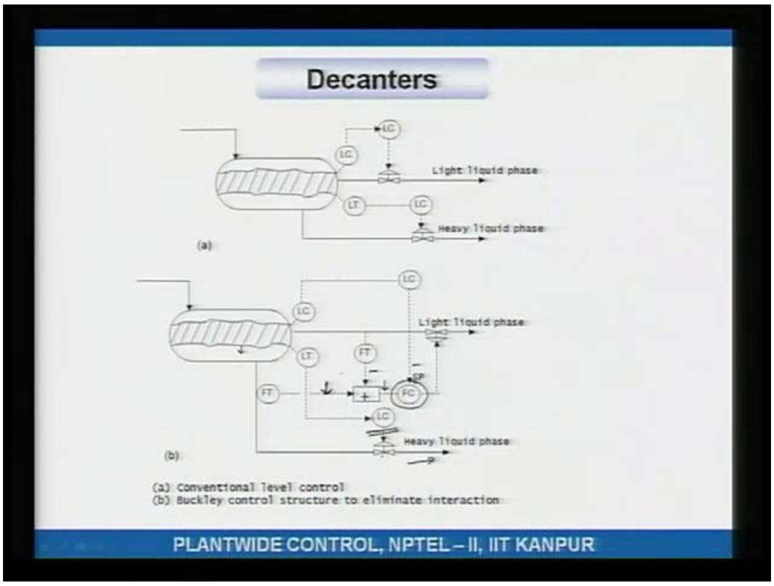

Now, what would what what will this guy do? This flow has gone down because you are taking out more heavy liquid. So, because this flow has gone down, this flow is where it was. So, this is where wherever it was this has not changed therefore, this signal goes down set point is where it is. So, what does this flow controller do? It will start to maintain so, total flow has gone down. Therefore, it will what open. Oh shit I made a mistake here sorry. If you are opening this valve, this flow will go up. Let us just do it all over again. Erase all in conslide. So, the level controller opens this valve.

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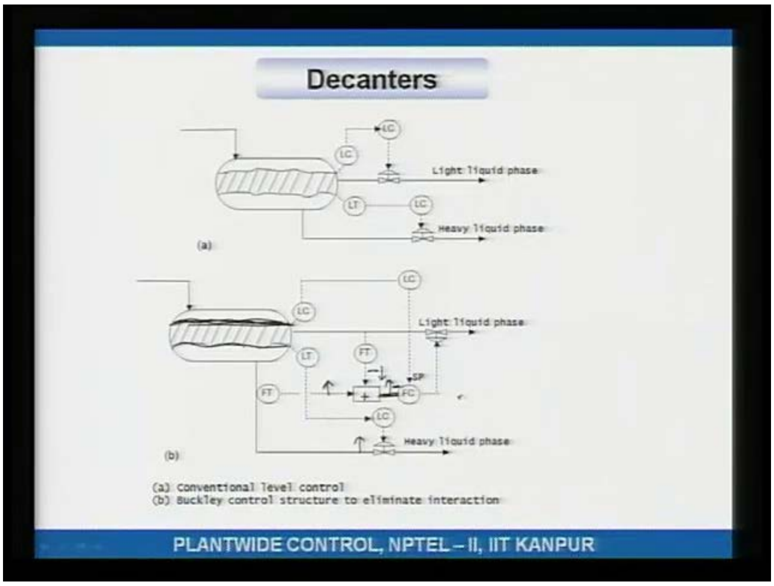

This flow goes up, if this flow goes up this is where it was, this flow goes up, if this flow goes up in order to maintain the total flow which is this guy, if the total flow has gone up and I want to maintain the total flow at set point. What will this flow controller do? This flow controller will close this valve. As it closes this valve, this guy goes down because this guy goes down total flow comes back to 0 or comes back to wherever it is suppose to be. Therefore, now since the total flow is maintained constant nothing will happen to this level and since this level was increasing or decreasing, whatever had to be done to adjust the level of the liquid liquid interface that has been done and because you are maintaining the total flow, instead of the light flow nothing will happen or the nothing will happen to the top level you know you know this guy.

So, I hope this was reasonably clear so by maintaining the total flow. See, how did this control scheme come in place? Key inside is top level depend on the total flow out so, to maintain top level control the total flow out that is what is being done here. I am controlling the total flow out this is the total flow out.

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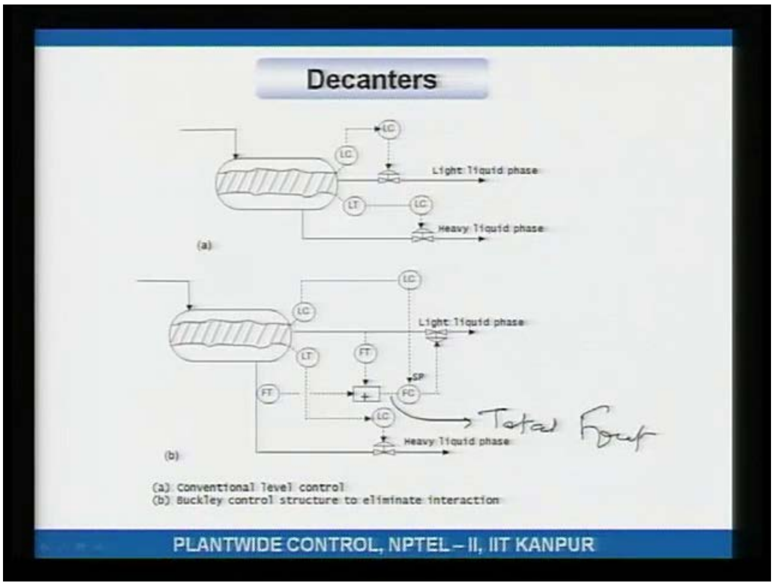

Total F out, see if total F out is maintained constant well level will be maintained constant. So, that is how this guy works. I think we have done enough anyway time has run out from next time onwards what we will do is, will will take deep look at degrees of freedom operating degrees of freedom design degrees of freedom because these degrees of freedom are fundamental to plant wide control system design. So, may be a couple of lectures on degrees of freedom and after we are comfortable with degrees of freedom, we will start looking at what are the things that need to be done or that need to be considered to design an effective plant wide control systems.

Thank you.