Energy Conservation and Waste Heat Recovery
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Lecture - 26
Heat recovery steam generator

Hi everybody. So, if we recall we were discussing regarding HRSG or Heat recovery steam generator. Heat recovery steam generator as I have told that there could be many variation of heat recovery steam generator depending on the steam pressure they it can be it can be classified as single pressure duel pressure triple pressure like this.

Obviously single pressure is the simplest arrangement in a HRSG or it is the simple most design of HRSG and we will start with the description of a single pressure HRSG to know; what is the layout?

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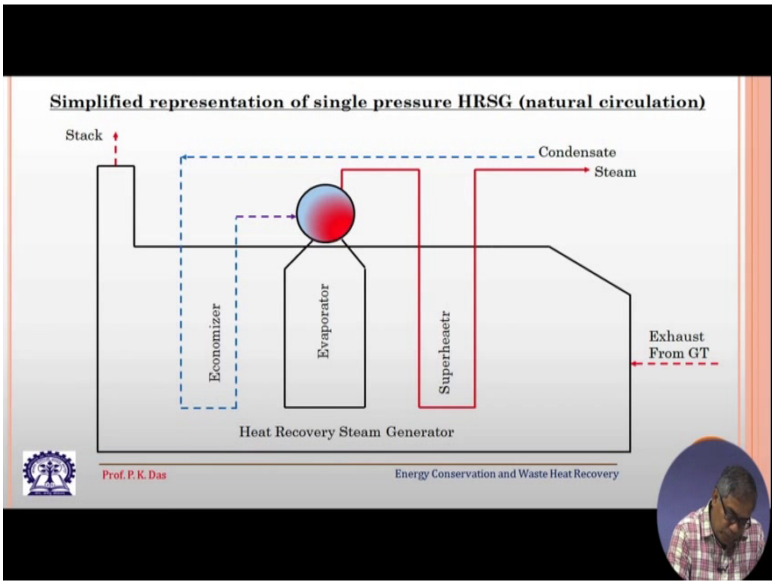

So, you see this shows schematically one single pressure HRSG the arrangement here is horizontal which is very common and Exhaust from the gas turbine which is high temperature gas.

That is coming to the HRSG and as it passes through this due to heat exchange the temperature of the gas reduces, ultimately when we have extracted in am enough amount of energy we covered enough amount of heat from it then it goes to the stack or chimney.

So, we are generating I mean we are we are supporting one steam power plant with the help of this thermal energy and in steam generation for a power plant there could be 3 parts if recall you see this is the Ts diagram st power plant and if you recall then this is the 2 phase dome this is where the steam comes from the feed pump.

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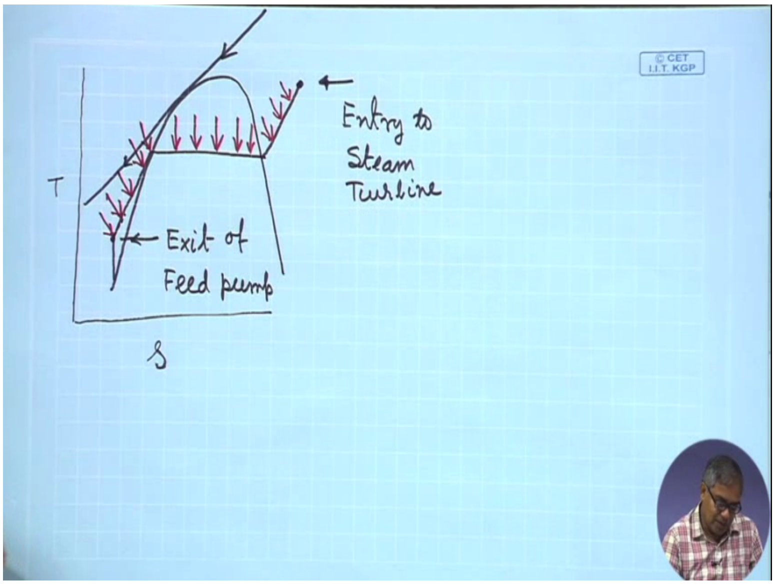

So, it follows a process up to this and then it goes to the turbine. So, this point Exit of Feed pump and this point Entry to Steam Turbine. So, the entire process is there is heat addition, but this heat addition process if we see it has got 3 parts. First part is your first part is your increasing the temperature of liquid water. So, this is actually this actually takes plus sorry takes place in a in a part of the boiler which is known as economizer and then there is evaporation. So, that is of course, the main part of the boiler and then after that once we have got saturated steam it goes to the super heater where it is temperature is further increasing. So, here you see the; if we see how; they this also I have shown earlier, that how the gas temperature reduces it is like this.

So, highest gas temperature should encounter the super heater then when it is little bit cool. So, it should supply heat for evaporator and then when it is much cooler than it should supply thermal energy for the economizer and that is what we are getting. So, if we see that this is your super heater it encounters the high temperature gas here and then there is evaporator there is a steam drum. Basically then there is a steam drum it is it is coming from the steam drum and then of course, for evaporation there will be a circuit.

So; that means, the condensate at the lowest temperature when it comes gets into the saturated condition that should be at the furthest end of the heat recovery steam generator, because here the exhaust gas is at the lowest temperature. So, from the steam side if we see that condensate comes from the feed pump goes through the economizer, goes here which is for the evaporation there is a steam drum, and there is a circulation I have shown that natural circulation, but there could be a pump also after that saturated steam comes out of the steam drum and it is superheated in the super heater and goes out. So, this is your single pressure HRSG.

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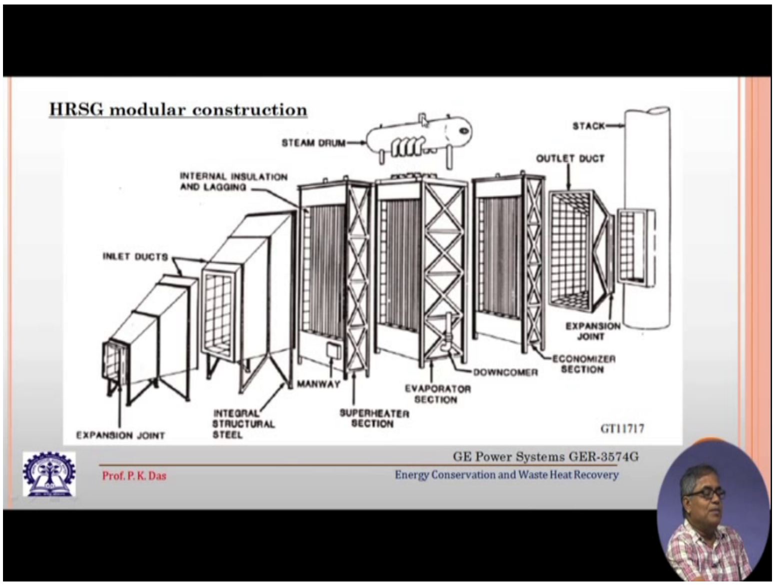

Now this kind of figure is quite common. So, a horizontal a horizontal HRSG will have some sort of a modular design if we just pay some attention. So, here the hot gas from the; from the gas turbine exit will come. So, basically we can think of the HRSG as a duct this is a duct of course, the duct is of not constant cross section and in that duct there are number of heat exchangers. So, through the duct gas is flowing hot gas is flowing it is temperature reduces as it encounters different kind of heat exchange surfaces.

So, first one is the superheated we can correlate with our earlier diagram. So, this is the superheated section then we have got the evaporated section in the evaporator section at the top there will be boiler drum. So, this is the boiler drum and these are the these many tubes and back side also there are tubes. So, these are basically risers there will be large number of risers through which steam water mixture will come to this theme drum and will get separated then there are down comers. So, these are down comers the down comers will be tubes of larger cross section, but then they are their number will be less and through down comer generally on the liquid comes out of the steam drum.

So, these are the down comer down comer you can see and at the top there will be pipeline by which steam will be taken out from the steam drum and then it will go to the superheated sorry then it will go to the superheated which is on this side and from where the water is coming to the steam drum this is coming from the economizer. So, this is the economizer. So, direction of steam flow is in this direction and direction of hot gas flow is in the opposite direction.

Then after all these things this hot gas it is temperature is now quite low and it will pass through the pass through some sort of that connection to the chimney or stack. So, this is what we will get in actual condition what is the HRSG.

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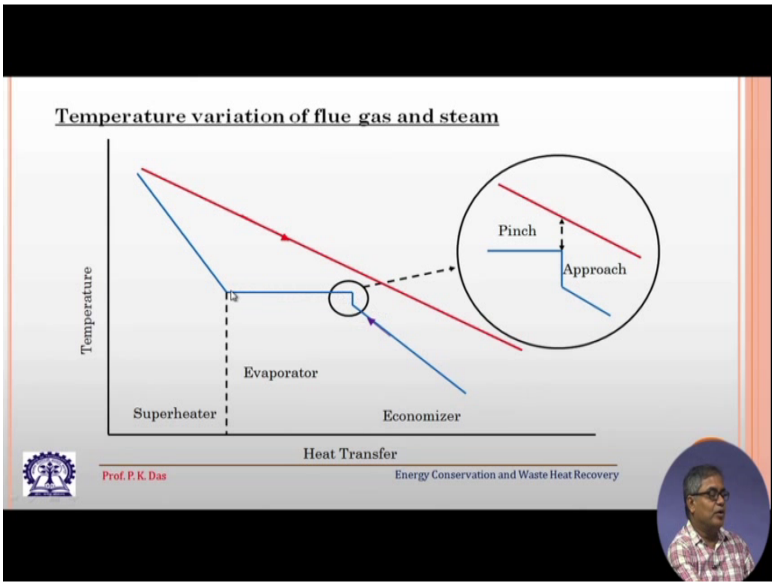

Now if we see how the temperature is changing this kind of figure I have shown earlier also. So, this is how in for a single pressure, this is how the temperature of the gas stream ready is getting reduced and this is how the temperature of the working fluid of the steam cycle that is increasing. So, this part is economizer up to this it is economizer and then there is evaporator starting from here to here it is evaporator and then there is super heater.

So, there are 2 points which are to be noticed very carefully one there is a Pinch that is here this is the point at which it enters the Evaporator and then this is the red line is the Temperature of the v gas stream. So, the difference of temperature or this point is called pinch point and this temperature difference what a; what we will get that is called pinch temperature. So, this is basically this is not a temperature, but a temperature difference and along with this there is something there is another vertical line which is called approach. So, what we find that in the economizer it will not be achieving the saturation temperature. So, there will be small amount of sub cooling with that small amount of sub cooling it will go to the evaporator and this difference; that means, the small amount of sub cooling that is called the approach.

So, this approach and pinch they are very important for pro for the practical design of a one HRSG and we are going to explain them in some slide later on.

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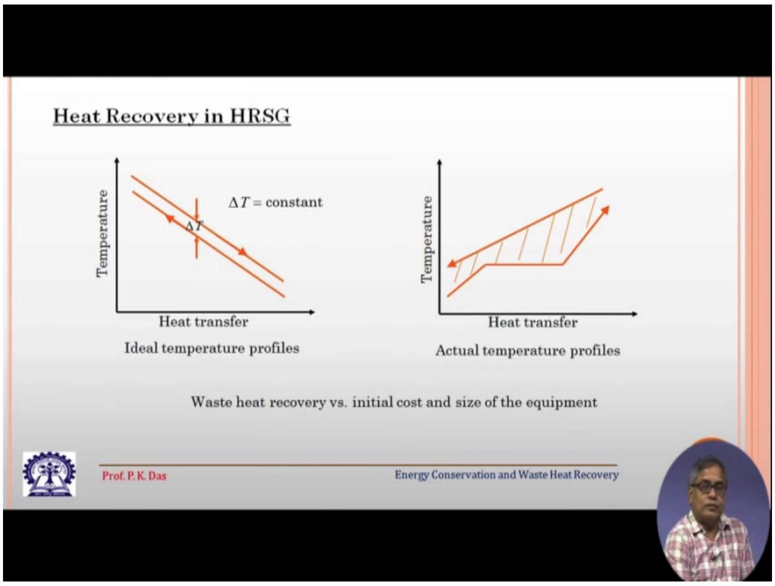

So, HRSG is basically a device for recovery of thermal energy and let us see how it is taking place whether we are doing good work or not;

So, basically HRSG one can look into in a gross sense as a counter current heat exchanger; in a counter current heat exchanger in any heat exchanger there will be 2 fluids involved for the heat exchange process and in counter current heat exchanger these 2 fluids are flowing in opposite direction. So, the HRSG forgetting about the individual heat exchangers inside the inside the HRSG grossly we can take it as a counter current heat exchanger.

So, gas stream it is temperature will decrease like this the liquid stream that temperature are liquid and vapour stream the temperature will increase like this for a counter current heat exchanger if we can make them flow in such a manner. So, that the delta T between these 2 streams are small enough practically 0 then we get very high efficiency of energy exchange between these 2 streams. In proper sense we can extract the waste heat to the maximum amount possible, but unfortunately in an HRSG the temperature profiles are not like this gas stream is cooling. So, this has got more or less a temperature profile like this, but the liquid and vapour stream.

That is going through single phase heat transfer then vaporization and then your again single phase heating of the vapour stream. So, the temperature profile will be like this. So, what we can do; we can bring them very close, but there is 1 point if we bring them very close then waste heat recovery is quite efficient, but the initial cost and size of the equipment increases. And again what happens due to this kind of a situation where there is no change in temperature, but heat transfer is taking place there will be certain amount of temperature difference between these 2 streams and we know this temperature difference delta T it amounts to irreversibility. So, there will be certain amount of irreversibility which is inherent to the process. So, this we have to keep it in mind.

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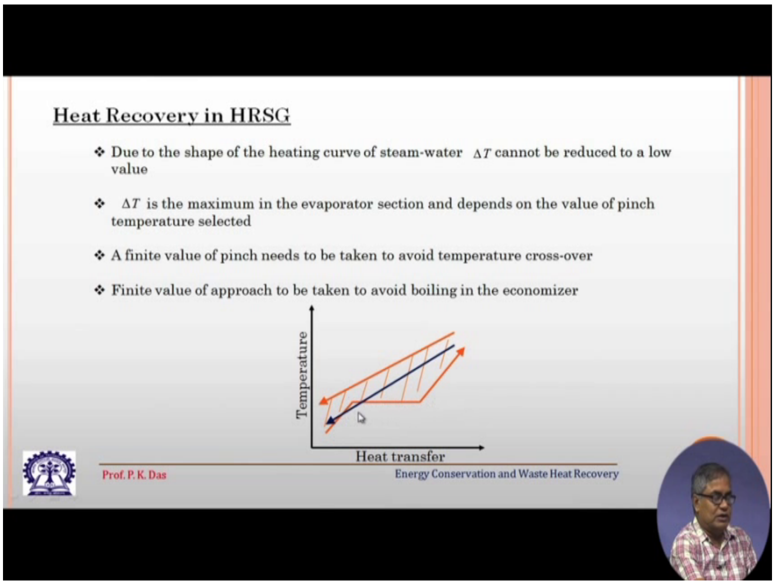

So, due to the shape of the heating curve of the steam water delta T cannot be reduced to a low value. So, this is one point which we have to keep it in mind, delta T is maximum in the evaporator section and depends on the value of pinch temperature selected a finite value of pinch. So, pinches here. So, a finite value of pinch has to be taken to avoid temperature crossover, suppose we go on reducing this is the smallest temperature. So, we try to bring them close and close. So, that we have got maximum amount of waste heat recovery. So, what happens that during operation sometimes it may be like this?

That the gas stream temperature is reducing like this and the vapour stream temperature is increasing like this and there is a situation which is denoted by this crossing of these 2 temperature curve which is known as temperature cross over. So, this is not allowed in a heat exchanger this violates second law of thermodynamics and then the system will not operate. So, to avoid this we intentionally keep some sort of a finite pinch between the gas stream and the vapour stream and that is why there will be irreversibility some good amount of irreversibility and certain amount of waste heat recovery will not be possible.

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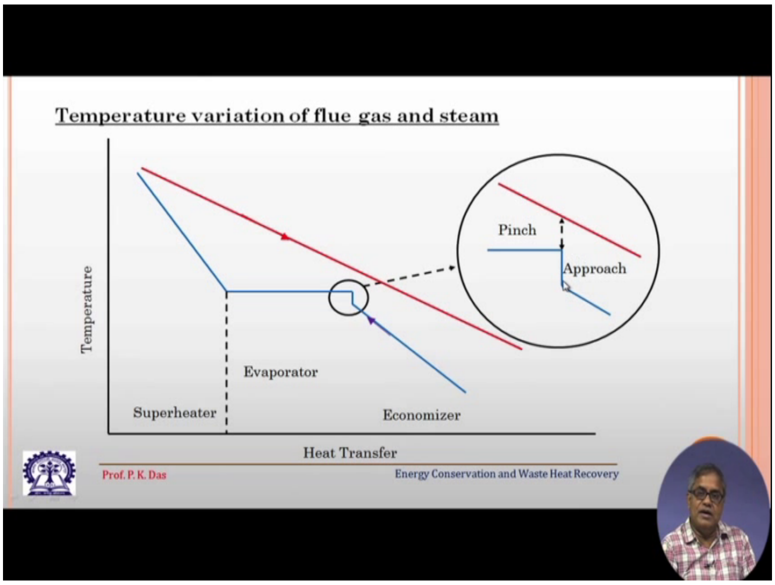

Then we have to also keep some finite amount of approach let me remind you; what is the approach?

What I have told that from economizer the fluid will not come in the saturated condition there will be certain temperature difference. So, this is called the approach and this is also essential why because the economizers are not designed to handle steam. So, if during operating condition if there is a small change of operating parameters and if steam generates within the economizer so there will be that is detrimental for the equipment and that is not permitted. So, intentionally we have to keep some sort of approach generally the approach could be of the order of 8 degree, 10 degree and pinch could be order of starting from 10 degree, it could be 15-20 degree Celsius. So, that is the value of approach and pinch there could be some variation, but I have given some sort of emotional values. So, these are the values nominal values I have given.

So, these are the values which we follow or which are followed for pinch and approach in case of HRSG design, but when we do this keeping in mind the operation of the equipment; obviously, we are losing something that total amount of or heat waste heat is not recovered to it is full potential . So, let us go back.

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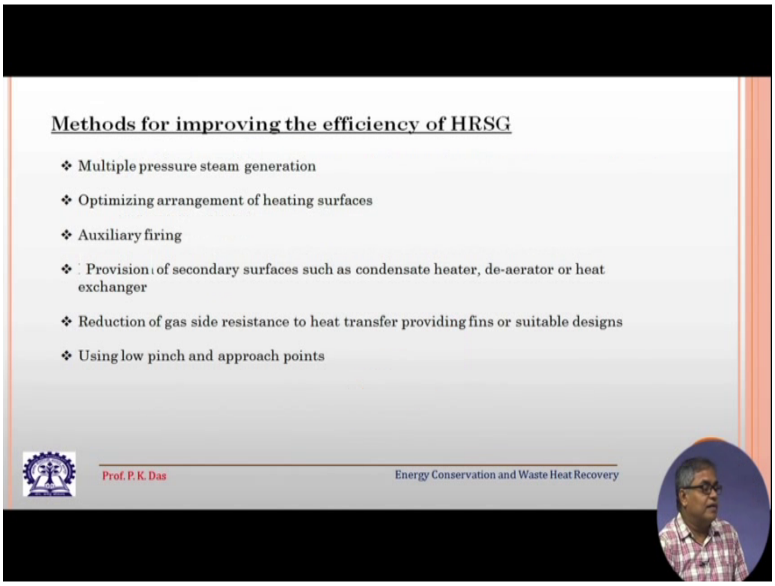

Then let us discuss the let us see. So, this I already I have discussed that finite value of approach is to be taken to avoid boiling in the economizer to protect the equipment and then when we know all these things then what are the methods for improving the efficiency of HRSG.

We have described a single pressure HRSG which is most common which is simple, but not gives does not give the best utilization of your waste heat particularly when the system is large suppose we have got large amount of exhaust gas to be handled and exhaust gas is available at a good amount of temperature high amount temperature then these single pressure arrangement is not good enough.

So, we go for multi pressures in generation; multi pressure steam generation there could be dual pressure which is again very common and there could be triple pressure more than 3 different pressure level people have not tried the design of HRSG and are going to see how the dual pressure thing work optimizing the arrangement of heating surfaces see when we will go for a large system there are let us say duel pressure system. So, for each pressure there will be economizer, there will be evaporating section there will be super heater and again we can go for reheating of this steam. So, these so many heat exchanger surfaces are there and; obviously, one can think of that how these surfaces can be arranged with respect to the flue gas path. So, that maximum exchange of thermal energy is possible see I have shown this idealized diagram if you recall that this is the way hot gas is losing it is temperature.

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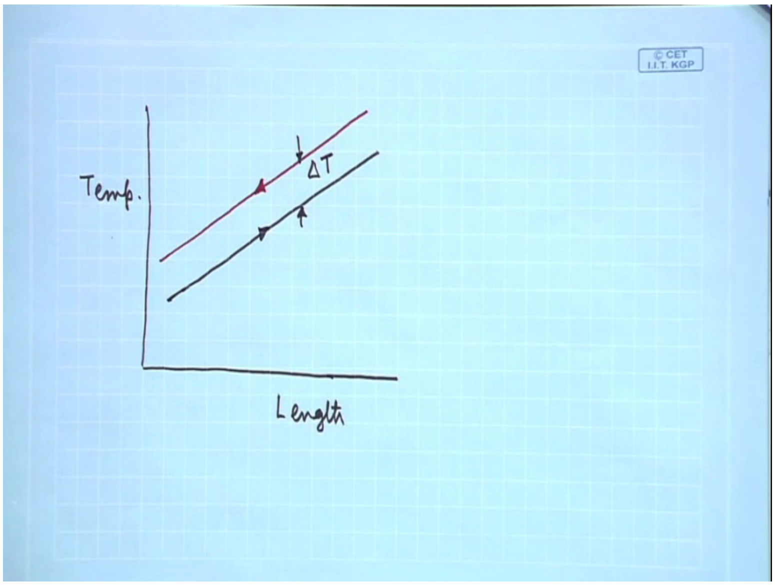

So, this side is your temperature and let us say this side is your length length of the HRSG and if it is ideally a counter current type of heat exchanger HRSG is counter current type of heat exchanger. So, the cold fluid steam could have gained it is temperature like this could have been ideal and for a good heat exchange, one could have kept this delta T uniform along the length as far as practicable.

Now as I have told you to steam generation process it is not possible, but when we are having number of heat exchangers, some of them are for super heating, some of them are for heating the liquid to achieve certain saturation temperature some of them are for vapour generation so; obviously, we can try to arrange those heat exchanger in such a way.

So, that we come close to this kind of a figure. So, that is what has been told in the PPT optimizing arrangement of heating surfaces. Then we can have auxiliary firing I have already told that by auxiliary firing we can increase the temperature of the gas and increase it is volume. So, more power can be generated on the steam site then prohibition provision of secondary surfaces such as condensate heater de aerator or heat exchanger. So, by this again some sort of a change in the cycle layout. So, we can have some extra amount of thermal energy generated then reduction of gas side resistance to heat transfer by providing fins of suitable designs.

So, by gas side heat transfer coefficient will be small compared to the liquid side heat transfer coefficient. So, that can be improved by providing some sort of fins on like that then using low pinch and approach points. So, as I have told that pinch and approach point we have to provide for the equipment operation of the equipment. So, we can reduce them by a good design by a good estimate we can reduce them. So, these are the methods by which we can have a better design of HRSG.

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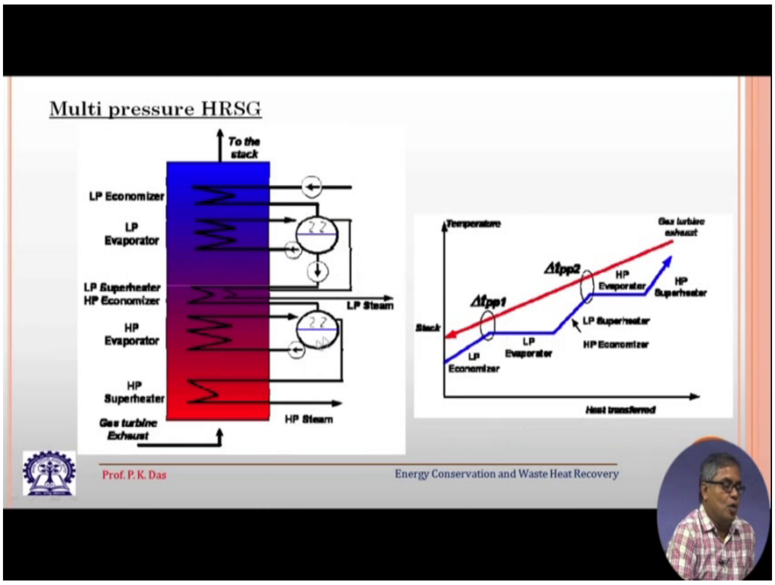

So, let us look into this provision. So, here what we have shown a HRSG with duel pressure operation. So, let us see that for dual pressure we have got 2 steam drum each of these steam drum is one particular pressure. So, when it is duel pressure we call it low pressure and high pressure and as the gas turbine exhaust is going it is temperature is reducing. So, low pressure side will be on the low temperature side also and high pressure side will be at the high temperature side. Here what we can see this is the lowest temperature before it goes to this stack.

So, here water should enter for the low pressure side. So, low pressure economizer it should go to the steam drum and in this steam drum there will be some sort of a circulation. So, this shows symbolically the pump. So, this is a force circulation system and in this steam drum there will be some sort of a circulation. So, from the steam drum the steam which will come out this is the steam which is coming out from the steam drum LP steam drum.

It will be reheated with the Re heater. So, here sorry it will be superheated in the super heater. So, we are getting LP super heater over here and the LP steam will come out so; obviously, we can have a turbine for expansion of this LP steam. Then from the bottom of this LP steam drum we can extract certain amount of water certain amount of liquid which is at elevated temperature it is temperature can be elevated further. So, that it is suitable now for and what we are doing we have we are doing we are we are pressurizing the water. So, now, it is temperature can be elevated further. So, that it is suitable for the hp drum. So, this can be considered at HP economiser. So, in HP drum it comes again in hp drum there is a circulation.

Steam is being produced. So, steam will be taken from this and there will be some sort of a HP super heater and it will go out. If we see the temperature profile of the 2 fluid stream in the HRSG, now what we can see that gas stream is changing it is temperature like this whereas, the vapour stream or liquid stream is increasing it is temperature like this. So, more or less you see we are following some sort of a parallel line of course; this kind of nature cannot be avoided as there is steam generation I have already explained, but compared to the single pressure operation by providing 2 pressures.

We are these 2 curves are becoming are coming close to some parallel curves. So, this is the achievement we get by producing 2 pressures while we will operate in triple pressure we will have much closer curves for the gas stream for the cooling of the gas stream and heating of the vapour stream.

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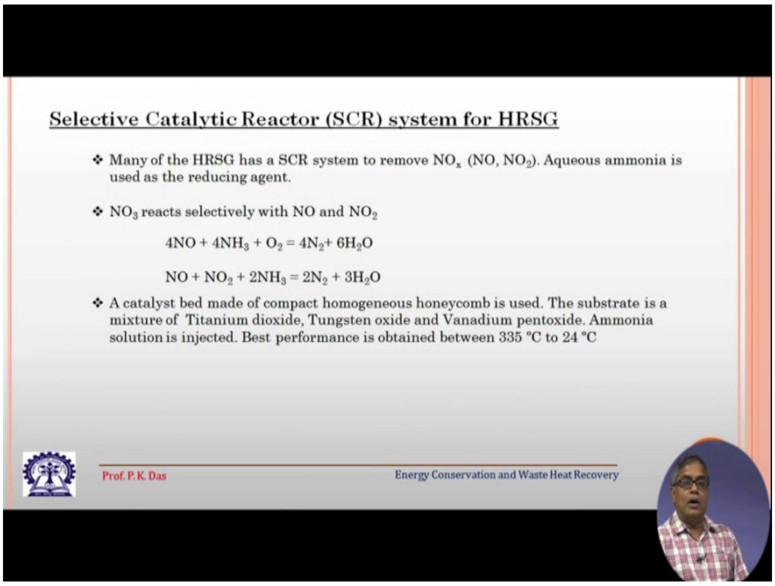

Now in many of the many of the HRSG will use a selective catalytic reactor or SCR. So, that will operate on NOx particularly it will operate on NO and N 2 aqueous ammonia is used to reduce as the reducing agent.

Ammonia reacts selectively with NO and NO2 and then these are the 2 reactions which are given 1 with NO and 1 with NO2 a catalyst bed of compact homogeneous honeycomb is based the substrate is a mixture of titanium dioxide tungsten oxide and an vanadium pentoxide. Ammonia solution is injected best performance is operate obtained within some sort of a temperature window and generally it operates within that to reduce the reduce the emission. So, that is; what is also a part of the HRSG? So, with this we come to an end of our discussion on HRSG.

Thank you.