Energy Conservation and Waste Heat Recovery
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Lecture - 28
Thermodynamic cycles for low temperature application (Contd.), Cogeneration

We are discussing thermodynamic cycles which are suitable for low temperature operation. We have concentrated on vapor power cycle. Vapor power cycles are to a large extent similar to Rankine cycle, but there are certain differences. Already we have discussed Kalina cycle, Kalina cycle has been commercially exploited for waste recovery purposes and to a great extent for ocean thermal power generation. So, from the hots, from the high temperature below the surface of seawater we can get high temperature and that can be utilized for generation of power. Geothermal energy can be used for power generation for these purposes this Kalina cycle has been made very successful.

There are a few disadvantages of Kalina cycle let me tell you she did the disadvantages of Kalina cycle for limitation difficulties in Kalina cycle is that ammonia is more corrosive compared to water. So, water ammonia mixture we have to use typical I mean special kind of or suitable kind of material that is one thing. Another thing in the HRVG; that means, heat recovery vapor generator the vapor fractions is generally high and then the as the heat transfer is to the vapor. So, the heat transfer coefficient is low, so that needs larger heat exchanger.

But there are many other advantages. One of the advantages is that its global warming potential of NH 3 is much less, from the emission point of view, hazard point of view it has got certain bad certain limitations, but from the emission point of view it is not that bad a gas. Naturally occurring gas for centuries, so this has the detrimental effect on environment is less. And as it is lighter than many other gases, if there is any accident, it will I mean the removal of this gas is not a big problem.

Now, after this we come to organic Rankine cycle. So, Kalina cycle once we have discussed let us go to some other cycle of this similar nature that is organic Rankine cycle. Now, organic Rankine cycle will operate at a temperature or it is suitable for temperature in lower than Kalina cycle. So, when there is let us say two hundred degree Celsius temperature of the waste heat source. So, one can think of a an organic Rankine cycle, theoretically organic Rankine cycle can run even for lower maximum cycle temperature.

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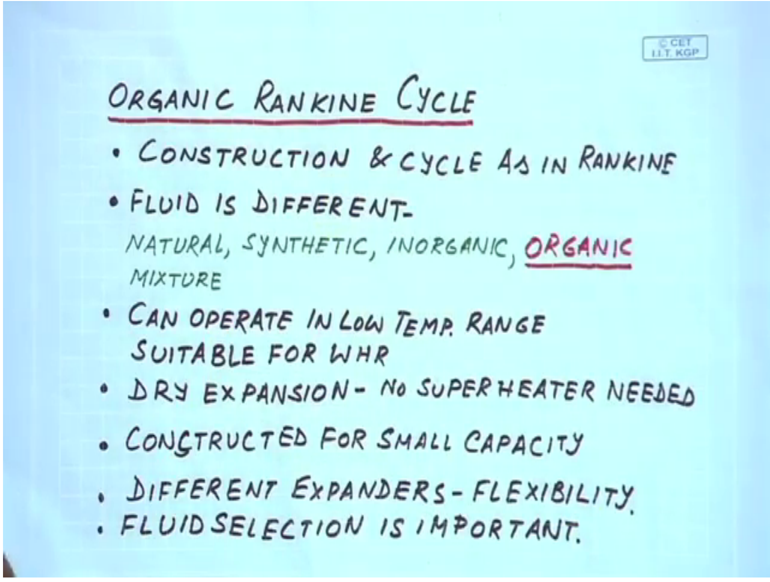

So, if we look into this slide. So, what we get is that construction organic Rankine cycle construction and cycle as in Rankine cycle, construction and cycle means we will have almost a similar type of equipment in the plant and the thermodynamic processes of the cycle they are almost like Rankine cycle. There may be slide variation in some cases, but in most of the cases it is similar.

Then fluid is different, fluid is different through it is other than water, water we are not using as the working fluid. So, what are the fluids? There could be natural fluid, there could be synthetic fluid, in organic fluid, organic fluid and even fluid mixtures are possible. Now the name is derived for organic fluid because many hydrocarbons common refrigerants etcetera are used as the suitable fluid for this cycle. And let me tell you that there are enough opportunities for selecting a suitable fluid I mean it is not that it is limited to one or two different fluids of course, it is true that a few fluids have been tried and people have got more confidence on those fluids those are kind of the same family of the common refrigerant, but or similar to the chemical compounds like your refrigerant, but there could be other fluids also. Then can operate in low temperature range suitable for waste heat recovery and there is a possibility of dry expansion I will elaborate this, but dry expansion is one feature which is very good when we operate we try to operate at low temperature range and it does not cause any damage or difficulty in the expansion process.

See dry expansion is not there that is one of the limitation of water as working fluid it in the low temperature range. That means, when water expands in the low temperature range most of the cases unless otherwise we take some sort of a caution. When it is expanding it will produce condensation and the fluid which will expand that will be a mixture of vapor and vapor and liquid; that means, it will be weight vapor. So, that is avoided when we have got this organic fluid many of the organic fluid.

Then the organic Rankine cycle can be constructed in small capacity that is also another advantage. Waste heat recovery, in waste heat recovery application we get sometimes we get heat from high temperature source, but sometimes we get heat from moderate or low temperature source most of the cases. And in many cases we get limited number of thermal energy limited sorry limited amount of thermal energy. So, for that a full fledged conventional power cycle it is difficult to construct and it is not suitable it will not give the payback for the investment.

So, small cycle sorry small plant can be designed based on your organic Rankine cycle that is one of the advantages. And then one of the very costly equipment of Rankine cycle is the expander or the turbine, so that as this capacity is small so we have got flexibility of selecting the expansion device and then again the expansion is for a low pressure range. So, we have got the opportunity of selecting different expansion devices which are small less costly because it is in the low range. So, that is another advantage of organic Rankine cycle because the cycle sorry if the plant cost will be small plant cost will be low. Then one important point that fluid selection is very important in case of organic Rankine cycle.

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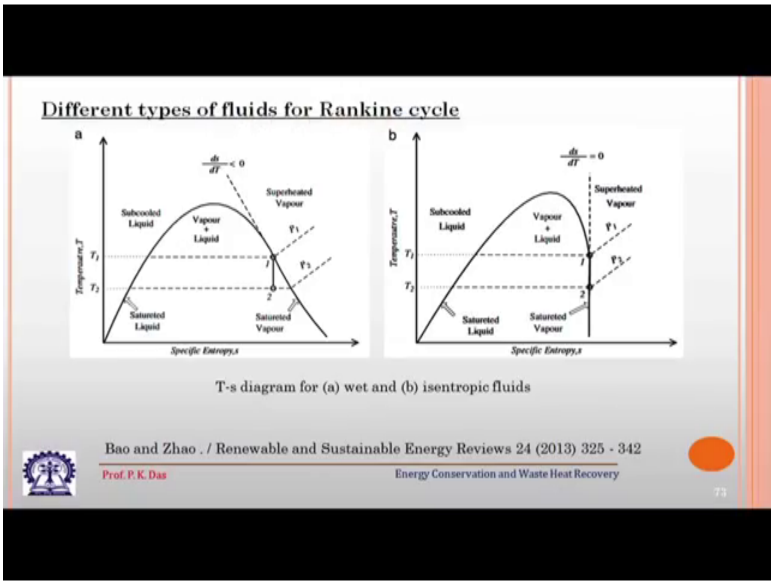

With this I like to elaborate on fluid selection and let us go to the PPT this particular slide the first one what we can see it is called weight expansion. So, let us say from the saturated condition we are expanding the fluid. So, then you will see as it expands its liquid content increases and the vapor becomes weight. So, this is weight condensation and for turbine this is detrimental and for water we will have this kind of expansion. So, the two phase dome represents the two phase dome of a fluid like water and for then we will have this weight expansion which is not good for the expansion device.

This is for different kind of a fluid and here what we see that expansion is almost along the saturated vapor line in both the cases either in this case or in this case we have taken isentropic expansion, but the saturated vapor line follows the isentropic expansion line also. So, in this case we will not have go into the weight region at all we will remain in the dry saturated condition. So, this is a special case of a fluid of a particular fluid there could be some fluid like this.

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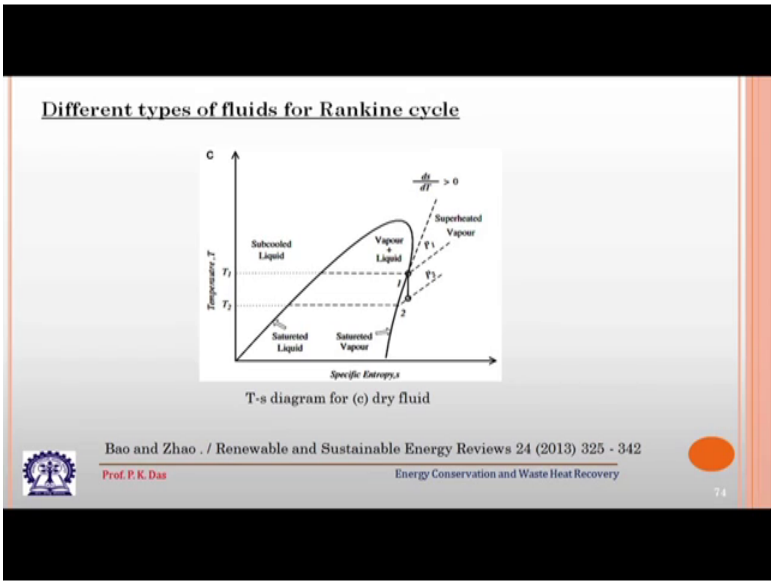

Then if we go to the next slide here we see another kind of a situation and in this what we find that as the fluid is as the fluid is expanding it is going more and more in the superheated region. Instead of going in the weight region, instead of going in the two phase region with higher amount of liquid content which mostly we are familiar with because we have so far we have seen water to be the working fluid of Rankine cycle. So, here it goes in the superheated region and it becomes dry. So, there is no problem of liquid condensation and no problem of damage of the damage of the expansion device.

So, generally organic Rankine cycles are selected, so that we get this kind of a feature. So, if we get this kind of a feature then what happens then super heating is not needed. So, we can operate in low temperature. Either with minimal superheat or with no superheat we can operate we can select this suitable fluid which will expand on in dry condition. So, that is one of the advantage of your organic Rankine cycle.

So, the organic Rankine cycle if I draw the organic Rankine cycle it will be something like this.

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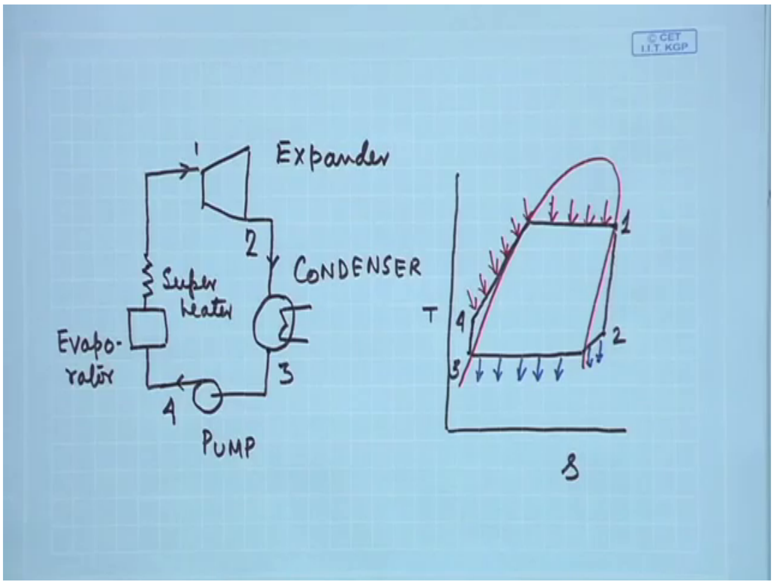

We will have a turbine or expander alright. So, we will have a turbine or expander then we will have usual condenser, this is your condenser and then we will have the pump and then we can have separately we can have some sort of a superheated evaporator and super heater.

So, if we want to see it Indian thermodynamic plane. So, thermodynamic plane it will be something like this. Let us say it will have a typical two phase dome something like this. So, this is your boiler pressure. So, we take with no superheat at all we can have this expansion process and then we can have the condensation process then we can have the pump and then. So, the cycle which I have shown there is no super heater needed because of the typical nature of the fluid. So, this is again T s diagram and let say we have got the heat rejection over here. So, this is the condenser.

If I want to correlate between these two diagram. Let say this is point 1 sorry this is point 1 this is point 2. So, 1 and 2, then 2 to 3 is up to this 3 is up to this condensation then this is 4 and obviously, in this case we do not have the we do not have the super heater. So, organic Rankine cycle has got lot of advantages because it can operate at low temperature and as I have told the cycle is very simple the complexity of normal granting cycles are not there. The expansion device is less costly there is no super heating. Particularly we can convert low temperature heat into useful work. So, that is the advantage of organic Rankine cycle for waste heat recovery and for renewable energy sources it is used very extensively.

Now, the expansion in organic Rankine cycle as the volume flow rate of mass flow rate of vapor is less and as the pressure range is less, so it is not mandatory that we should go for a conventional turbine.

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So, let me show this is the conventional turbine for a big steam power plant this kind of turbine can be used. Even for Kalina cycle a smaller version can be used of this kind of turbine.

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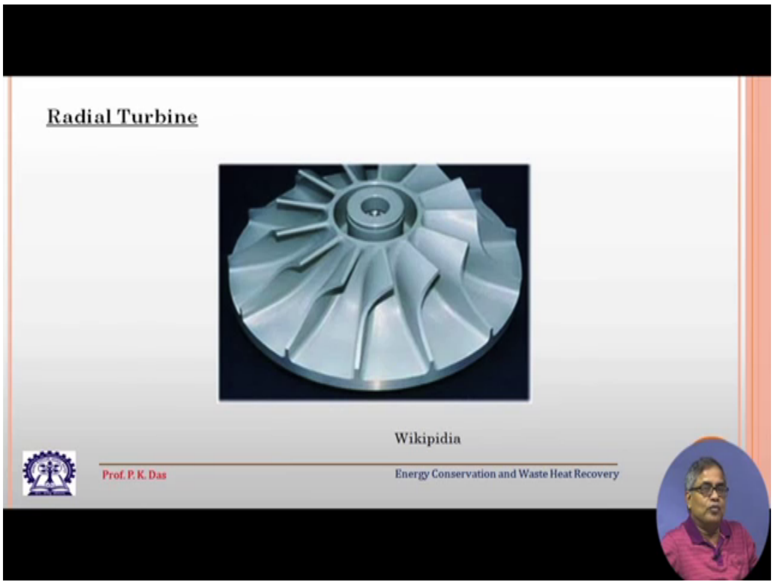

But in case of organic Rankine cycle, generally we use different kind of expander. One possibility is that radial expander or radial turbine where it is having only one stage because I have told the pressure range is very low. So, here within one stage one can do the expansion and one can have this kind of radial turbine there are different designs of radial turbine only I have shown one particular type.

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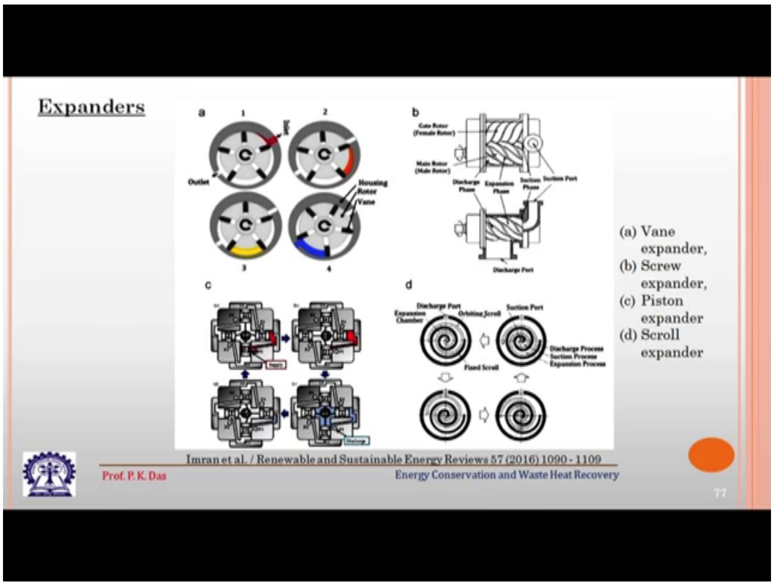

And then these are different possibilities there could be expanders as far as Rankine cycle is concerned when we think of expansion of steam we think of only rotodynamic machines turbo machines, but positive displacement machines are also suitable for your expansion particularly when the pressure range is small and the volume flow rate is small. So, here we show different kind of expanders. See this is a vane type expanded it has shown how a fluid is being trapped and then it is expanding and then it is coming out of another port it is entering through one port expanding and then it is coming out through the other port when it is doing this. So, it will be able to rotate this and which is keyed to a shaft then the shaft will rotate.

So, there could be a screw expander it is showing some sort of a twinning screw expanded and when it with the fluid will pass high pressure through it will pass through the passages of the intertwining screw. Two screws are there so it will try to impart some sort of emotion and one can get work out of it useful work out of it. And there could be piston expander there are number of pistons and with that we can have the expansion hot fluid sorry hot and high pressure fluid will push the piston and then that motion can be converted into rotary motion and there can would be scroll type expander. So, that is also possible.

So, whatever devices I have shown all these are possibilities for your organic Rankine cycle, even for some other cycle which are operating based on more or less Rankine cycle principle, principle of Rankine cycle at low temperature low pressure range. So, this is one of the speciality of this cycle.

See lastly what I like to discuss is a trilateral flash cycle.

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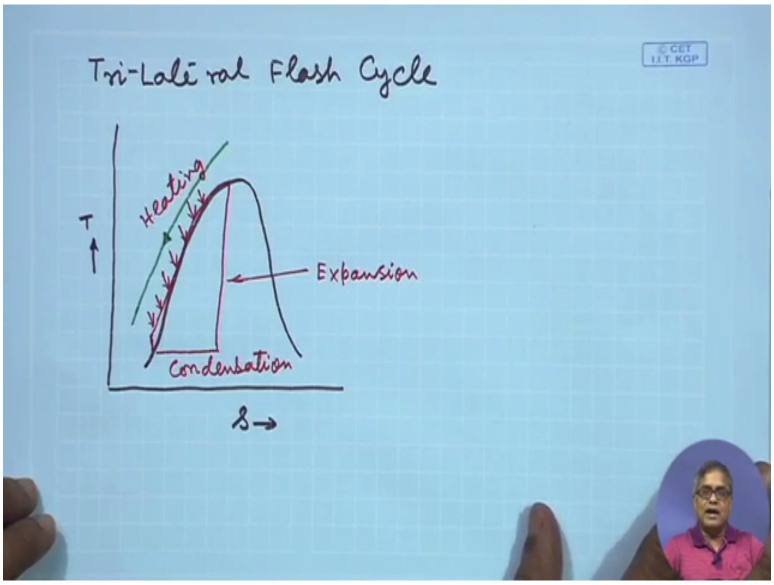

So, if we go back to what I will write this is try lateral flash cycle. So, a trilateral flash cycle I will not spend much time because it is of the same class of other two cycles it is again some modification of Rankine cycle components are same I am not going to draw the block diagram. So, trilateral flash cycle in T s plane if we see it is like this, this is the steam dome and the cycle is something like this it is operating this is the two phase dome it is operating at small pressure. So, the pump work will be less let say we have come up to this point, this point is this line is almost matching with the saturated line after that there is heating and from here what we do we go for expansion and this is condensation. So, this is your heating, expansion and this is your condensation.

So, you see basically it has got three, I mean it is just like a triangle if we neglect the small amount of pump work then it is just like a triangle and it has got three sides of this the cycle has got three sides, so that is why it is called trilateral cycle. And you see total expansion is within the two phase region. And the advantage is that the heating process is following the cooling of the hot gas very is faithful. So, this has got the advantage this is the advantage and that is why the efficiency of this cycle will be high in this low temperature range also its efficiency will be high.

Obviously there are two three things we have to keep it in mind; obviously, water cannot be the fluid there should be some fluid even people have thought of water ammonia mixture and the expansion device would be some sort of a unique device which can handle two phase. So, different expanders I have told particularly screw expanded etcetera they are suitable of handling liquid vapor mixture. So, the design or realization of a trilateral flash cycle is not impossible. So, depending on waste recovery source sorry waste heat sources one can have a trilateral flash cycle. So, now I have described all the different kind of cycles which are variation of Rankine cycle and at low temperature range one can use.

Now, I like to go back, I like to go to a different kind of topic. This is cogeneration of power and process heat. With this we like to end our discussion on cycles and waste heat recovery.

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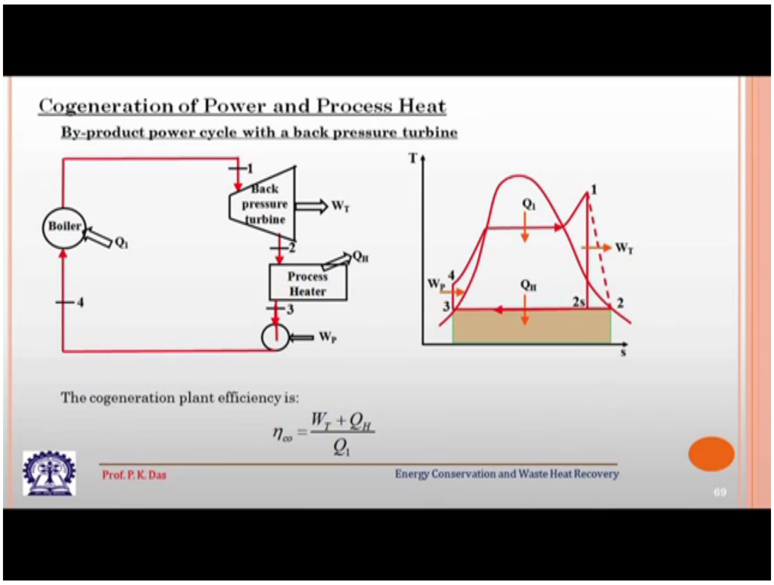

Now, in many factories there will be requirement for process heating and process heating by your steam that is a very good option because the steam the heat content of steam is quite high. So, process heating by steam is a very good option. At the same time the power plant sorry the industries will have their requirement for power for running different kind of machine, for lighting etcetera, for other purposes it will have the requirement of power.

So, initially people use to produce power separately and used to spend energy for producing this heating, but then can we combine them together. So, here we show a scheme a boiler then it goes to a turbine which is called back pressure turbine and then the steam comes out and which is used for process heating without going to a condenser and then it goes to a pump and it again goes back to the boiler.

So, here what we see that we will have all the processes and here the condensation process in a condenser is replaced by process heating. Now, the advantage of process heating by steam is that when steam condenses if the pressure is kept constant then its temperature is also constant. So, constant temperature heating is possible and that is required by many processes. So, efficiency of cogeneration, we call it cogeneration because we are generating power and at the same time we are we are satisfying the heating need. So, that is W T work done by the turbine and Q H divided by Q 1 which is the heat we have taken from the thermal source. So, this is one way of looking into this.

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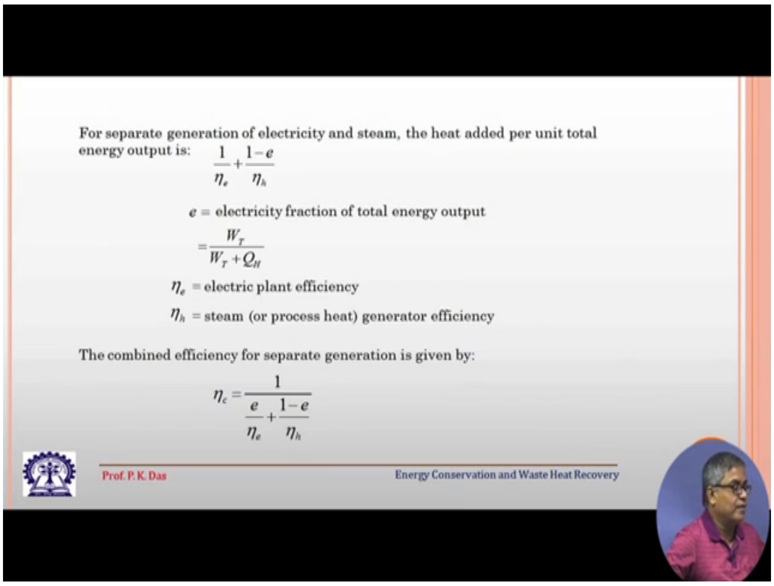

For a separate generation of electricity and steam and then heat added per unit total energy output is this one can get where e is the electricity fraction of total energy output. So, e can be written as W T turbine watt divided by this one. So, this is the total energy taken. So, this is your turbine work and heat and the fraction which is taken for electricity is this. Now, eta e is the electric power plant efficiency and eta h is the steam or processing generation efficiency, the combined efficiency is given by this eta c. And this is one factor by which we should decide whether we should go for cogeneration or not.

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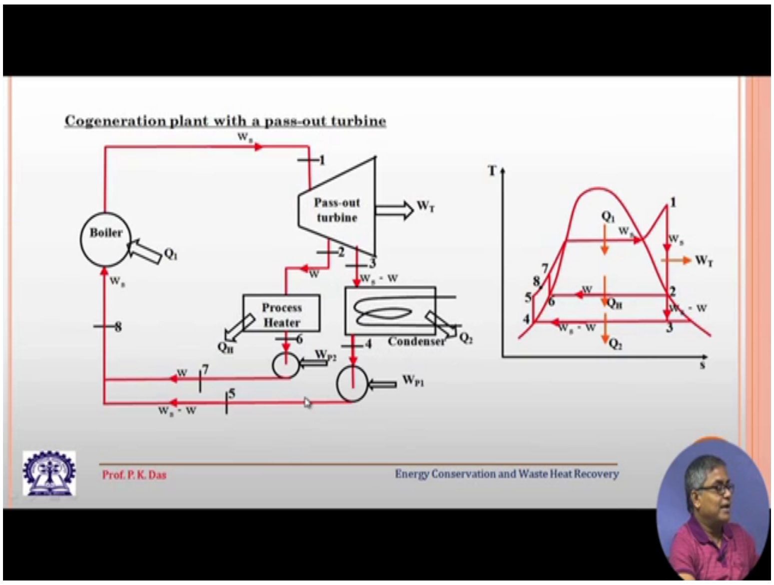

Lastly I like to give the most suitable configuration of cogeneration. So, the earlier arrangement what I have told that is utilized in some places, but it is not very common. Whether sorry, on the other hand what is very common is that in the turbine the steam expands in between towards the low pressure end we take certain amount of steam it goes the processor heater and condenses and rest of the steam is allowed to expand up to the lowest pressure of the turbine then taken to a condenser and condensed then both the condensate goes to the boiler.

The cycle diagram will be something like this at different point we have given the numbers which are important. And we have got this work that is the w turbine the total steam is W s part of heat will go for process heating and part of heat will expand fully. So, this is the from the mass balance Q H will be heat given for the process heating Q 2 will be heat rejected by the condensing steam in the condenser and Q 1 is the heat addition.

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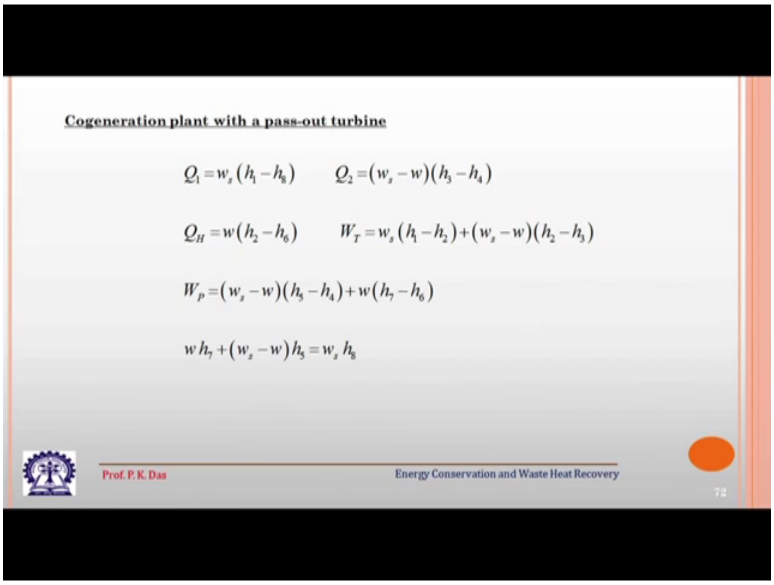

With all these things we can make some sort of energy balance which is very elementary and one can understand taking the help of the previous figure and then from there one can decide the plant layout cycle design how much steam has to be taken out for process heating at what pressure it has to be taken out. So, all this thing one can decide. And obviously, how to determine its efficiency I have described. So, if it is needed to design a plant process for processing and power combined processing and power with this small analysis one can do a preliminary design.

So, with this we come to an end to our discussion regarding different kind of thermodynamic cycles and now we will go means from the next lecture we will go to a very important topic which is heat exchanger. Because we try to recover waste heat and heat has to be converted into different form or transferred to different streams so that is possible and for that we need special devices which are called heat exchanger. So, we are going to spend some time on heat exchanger.

Thank you.