Waste to energy conversion

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Lecture – 20
Efficiency Improvement of Power Plant – 1

Good morning everyone, now we will start a new module Efficiency Improvement of Power Plant. In a conventional power plant carbonaceous feedstock is used in the plant for combustion and the combusted gas that is flue gas is used for the production of steam. So, high heat of the flue gas is used to convert water to steam and that steam is further used for the production of electricity in steam turbine, but if we use gasification; so gasification based plant produces syngas.

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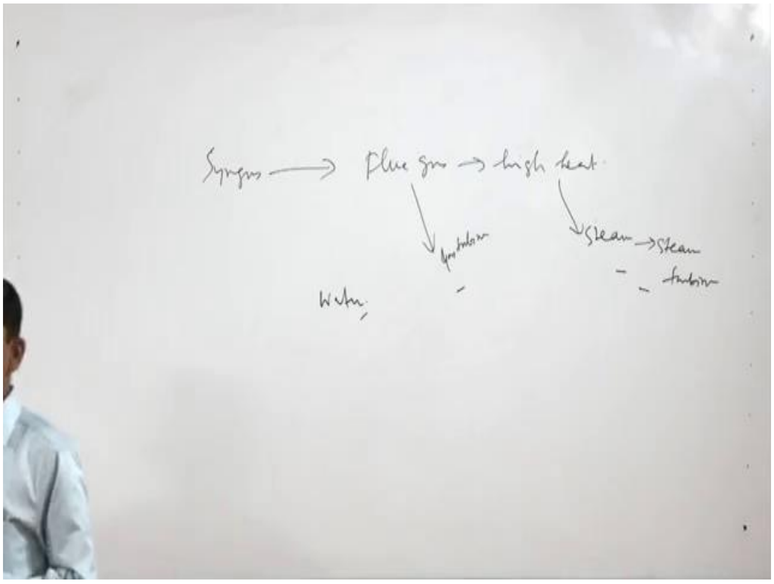

It can be further combusted; syngas is combusted to flue gas so high amount of heat is released. So, this can be used either to steam production and followed by steam turbine or directly this flue gas can be used in gas turbine for the production of electricity. So, there are two options in this case either we can use gas turbine followed by steam turbine or only steam time turbine or only gas turbine. So, efficiency of the process will depend upon which type we are adapting, not only that there are many other factors which influence the efficiency like say the heating, preheating of the of the water which is used for the steam production here whether water is preheated or not, whether air cooling or water cooling is used to reduce the temperature of the flue gas. So, there are different factors on which the performance will depend and one important factor is that there are number of losses and due to the losses the efficiency is reduced.

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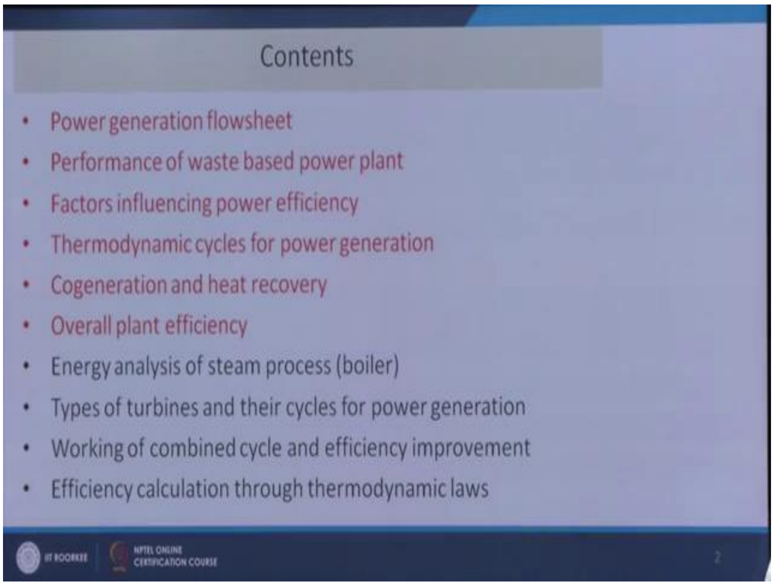

So, in this module we will discuss the power generation, its flow sheet, performance of waste based power plant, factors influencing power efficiency, thermodynamic like cycles for power generation, cogeneration and heat recovery, overall plant efficiency and then we will discuss energy analysis of stream process and types of turbines and their cycles for power generation, working of combined cycle and efficiency improvement and last we will see efficiency calculation through thermodynamics laws.

Now, we will see the flow sheet for power generation, so if it is a conventional power plant that is combustion based. So, we will be using some fuel in this case waste and biomass.

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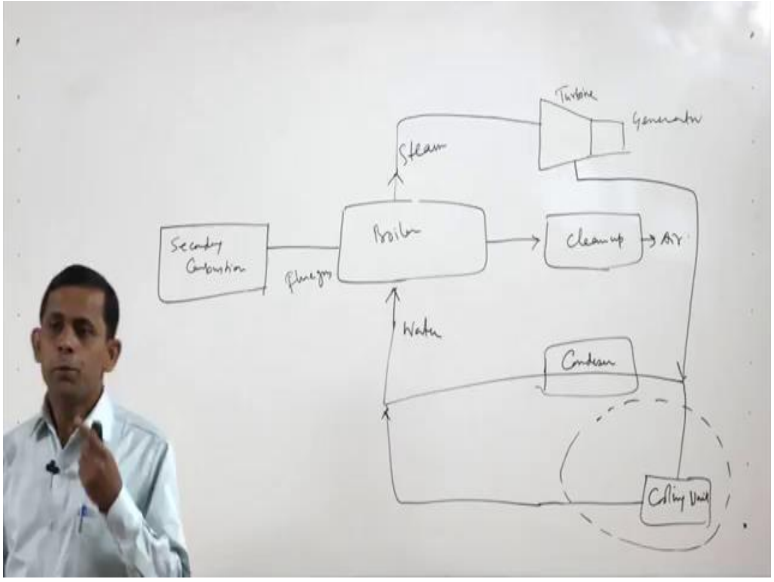

So, that will be used in your furnace or incinerator or gasifier whatever it may be. So, in this case it is incinerator and in incinerator the primary and secondary oxygen is supplied. So, secondary combustion chamber is used to produce flue gas. So, this flue gas will come and we will use this flue gas to produce steam. So, this is water flue gas will us steam and this steam will go to turbine that is steam turbine along with the generator and this flue gas after heat recovery in boiler further production of steam, it will be going for clean up and to air.

So this is the flow sheet and when we are getting the steam turbine, so its output will be condensed and will be recycled back. So, condenser it will be there and it will give the water for the boiler input. Now this steam, which is coming out from the turbine that can also be sent to some cooling purpose; so some cooling unit; so this cooling unit will; obviously, the temperature of this will increase and again it will come to this. So, addition of this part is optional and if we add this part, the performance of the power plant will increase.

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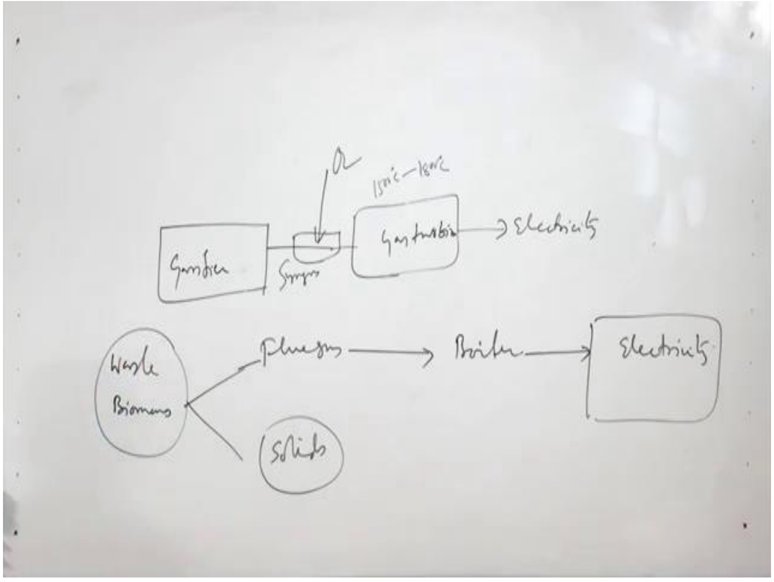

So, this is the flow sheet of conventional power plant; now if we use the gasification based power plant, obviously this secondary combustion will not be there. So, we will having the gasification gasifier here and this will be directly used for gas turbine for the electricity production. So, it will directly go to gas turbine before that it will give a syngas, so that syngas will be reacted somewhere with the oxygen. So, high temperature will be generated and pressure will generated, so here the temperature is around say 1500 degree centigrade 1800 centigrade, so that gas turbine will give us electricity.

So, this is the flow sheets for the production of electricity in the power plant. Now if we think on energy perspective, then we will see that waste or biomass or any feed that will give us flue gas and solids that is ash and slug. So this is not desirable; this ash and slug is not desirable it will reduce the efficiency. So, flue gas which is produced that will be used in boiler heat transfer and will give up steam and actually we will give the electricity, so electricity we will get. So, in this process if we see then the performance, the overall energy production in this plant will be guided by many factors.

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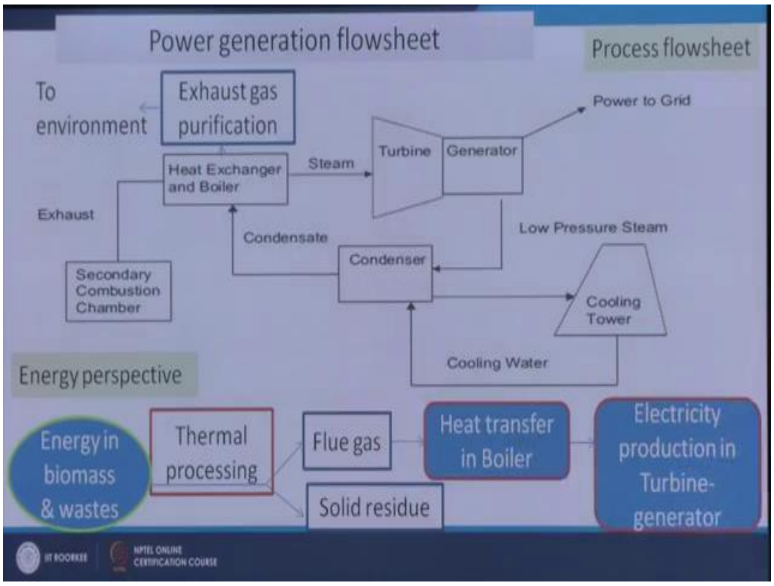

The first one; the secondary combustion chamber what type of fuel we are using, now the what is the heating value of this waste or biomass or any carbonaceous feedstock. Then what is the efficiency of this reactor? Like whether we are using incinerator or gasifier or type of incinerator, type of gasifier like fixed bed, fluidized bed, entrained bed all those things will influence the efficiency.

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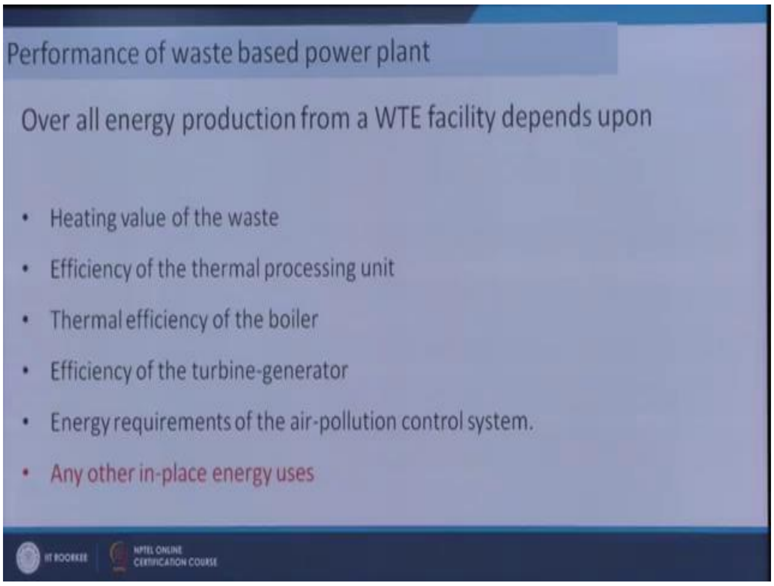

Then heat exchanger in boiler, so boiler efficiency will also be responsible and then you will see it is coming to turbine and generator. So, efficiency of turbine and efficiency of generator will also influence the overall performance, then it is coming to condenser then in condenser what type of fluid we are using either we are using air or whether we are using water that will also influence the overall performance of the process.

Here either this heat available in the outlet of the turbine is used for the heat recovery or not so that will also influence the overall performance of the process. So, these are the heating value of the waste, efficiency of the thermal processing unit, thermal efficiency of the boiler efficiency of the turbine generator energy requirements of the air pollution control system. So, here the air pollution systems are there the exhaust pollutions is going to the environment after proper treatment. So, what amount of energy is required that also influence the overall performance of the process and any other in place energy uses.

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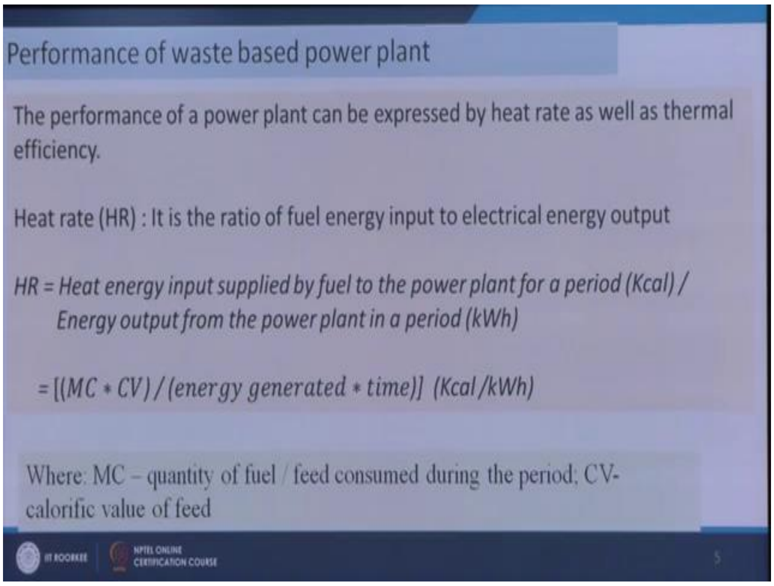

Now, I will see how can we quantify the performance, so to quantify the performance of the process; we have two parameter one is heat rate and another is thermal efficiency. So, heat rate is related to, it is the ratio fuel energy input to electrical energy output, so how much fuel energy is given as input to the plant within certain time and how much electricity generated within this time period; the ratio is heat rate.

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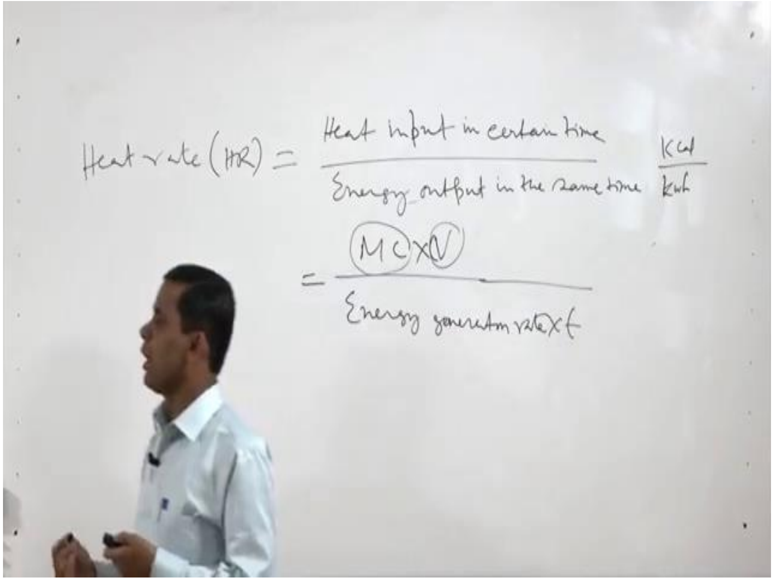

So, heat rate H R is equal to it is the ratio, so heat we are giving the input to the plant that is heat input in certain time, divided by how much energy we are getting, so energy output in the same time. So, this is kilo calorie and this is equal to kilo watt hour, so this is the unit of heat rate. So, what is this heat input; that means, what is the amount of biomass and waste we are using that is M C into calorific value C V of the material, how much materials we are using and calorific value that is the total heat input and within this time period, what is the energy generation rate? Energy generation rate into time, so this our H R or heat rate. Next we will see thermal efficiency, so thermal efficiency can be defined as the ratio of energy generation into time divided by heat input from the feed stocks.

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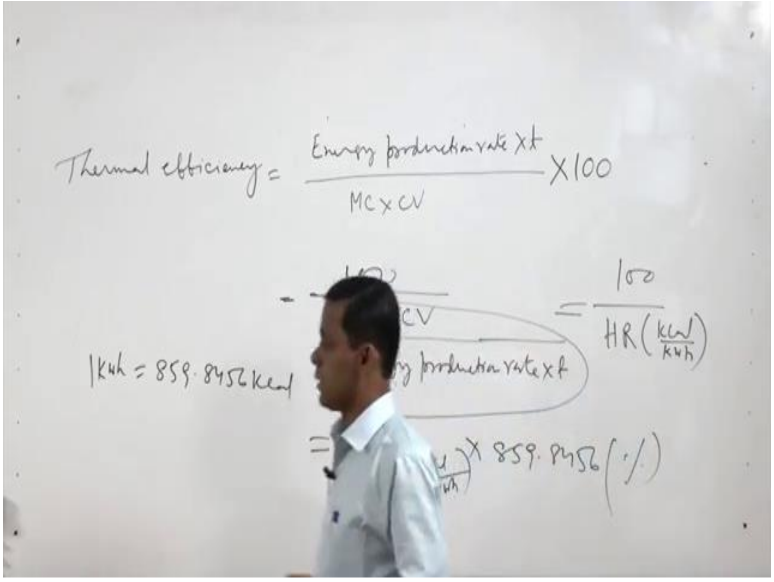

So, this thermal efficiency is energy production rate into time that is energy produced divided by how much energy is given M C into C V; that is actually gives us some idea what is the design value and how much energy we are getting, so, that is the ratio of this.

So, this can be written as and as if as we are interested to get it in terms of percentage, so we will multiply this into 100. So, this is equal to we are getting 100 divided by M C into C V divided by energy production rate into time. So, this is nothing, but H R in kilo calorie per kilo watt hour. Now we know that 1 kilo watt hour is equal to 859.8456 kilo calorie 8456 kilo calorie, thus if we want to get the thermal efficiency in terms of percentage from the heat rate so then we can write it this is equal to 100 divided by H R in kilo calorie by kilo watt hour unit into this conversion factor, so that will be 859.8456 in percentage.

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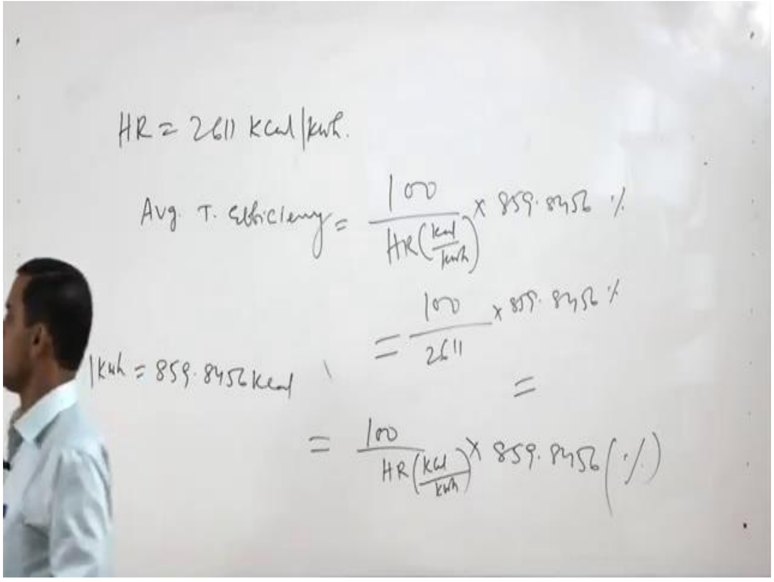

Now, let us calculate on thermal efficiency of a plant, so it is given; let us see the statement if the average heat rate of a power plant in 2015 is 2611; H R is equal to 2611 kilo calorie per kilo watt hour then we have to calculate the average efficiency of the plant. So, average efficiency thermal efficiency is equal to we have got 100 divided by H R in kilo calorie per kilo watt hour into 859.8456 in percentage, so in this case 100 divided by 2611 into 859.8456 percentage so that is equal to we are getting around 33 percent, that is equal to 33 percent.

So, now we have seen how to calculate the thermal efficiency on the basis of heat rate and the energy supplied and how much energy we are getting from the thermal power plant. Now we will see the factors which influence the power efficiency, so turbine types and boiler design significantly influence the power efficiency and conventionally.

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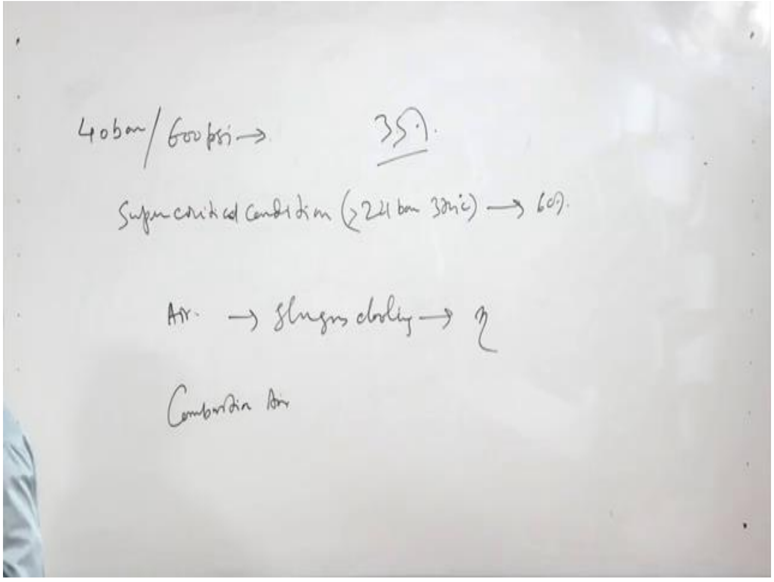

The 40 bar of like 600 P s i pressure is used for the production of electricity in thermal power plant and typical efficiency is 35 percent; only 35 percent. So, the pressure of the steam if increased say above super critical conditions, condition that is 221 bar and say 374 degree centigrade above this. So, here is this case efficiency increases, so 35 percent it can be increased to 60 percent that is 3 percent. So the type of condensing device is also responsible to give higher efficiency if we use water for the cooling or air for the cooling of the flue gas, we will get different efficiency for the air and water.

Now the heat source to preheat combustion air, so if we use some combustion air that may be preheated. So, in that case efficiency some where we can preheat it and somewhere we may not preheat it, so the efficiency will vary. The steam or energy recovered on flue gas, so the flue gas which is used to produce steam after that also it is having an higher temperature and that temperature further can be used to recover energy from the flue gas and if we use that often then it will improve the efficiency and the last is number of boilers are used than turbines we are using in the process.

So, number of boilers and turbines is more the efficiency will be more. Now we have come to know about the performance of the thermal power plant in terms of efficiency. Now how can we quantify and how can we understand in a better way, whether the process can further be improved, the efficiency can be improved or not. So, this understanding will be developed if we know and if we learn about different thermodynamic cycles. So, first the steam turbine; for steam turbine the rankine cycle is basically used to understand this steam turbine cycles.

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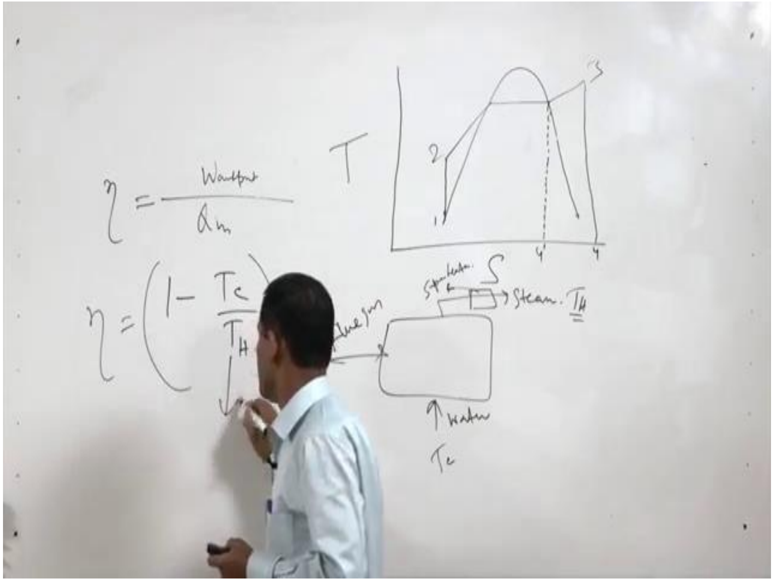

So, in rankine cycle if we develop the temperature entropy diagram then we will see it consists four steps; the first step is your adiabatic compression and second step is your, we do some expansion. So isobaric expansion it will go like this, so 1, 2, 3 and we will get 4 and this is 4 dashed, so this is the diagram of our rankine cycle.

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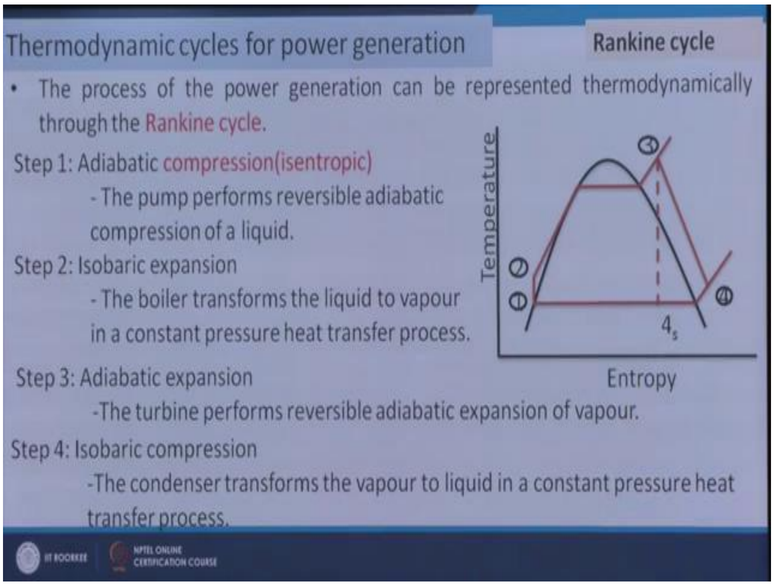

So, in this diagram rankine cycle we are getting first step, this is up second step. So, first step is because of the pumping of the water, the second is the boiler; in the boiler temperature increases then boiling takes place then steam pressure increases and temperature increases and the third is adiabatic expansion. So, adiabatic expansion means the turbine performs reversible adiabatic expansion of vapour, the steam which is generated that is sent into the turbine so the expansion takes place in adiabatic condition and that is your 3, 2, 4.

Now, in ideal condition these should be vertical line so that the loses will be less, but in reality this does not happen and the fourth step is the condenser transforms the vapour to liquid in a constant pressure heat transfer process; that means, after the electricity productions in the turbine, the exhaust from the turbine is a steam. So, that is condensed and the condensed air is recycled back, so isobaric compression this is the forth step of this rankine cycle and this rankine cycle this is ideal, this 1 and 2 vertical line or isentropic operations are ideal conditions, but in practice the ideal condition does not exit; so efficiency decreases, so maximum efficiency will get when this cycle will follow.

Now, we see why the ideal condition is not achievable we not get the efficiency for the ideal rankine cycle because there are some heat losses in the processes as well as there are some frictions losses. So due to the frictions when steam is flowing through say piping or in boiler that will produce some losses, What losses? Friction losses and friction loss will generate lower pressure. So, that will give lower pressure and we will see that higher pressure is required for getting more efficiency. So, that is why the friction loss gives us lower efficiency and deviates from ideal to real conditions of the rankine cycle.

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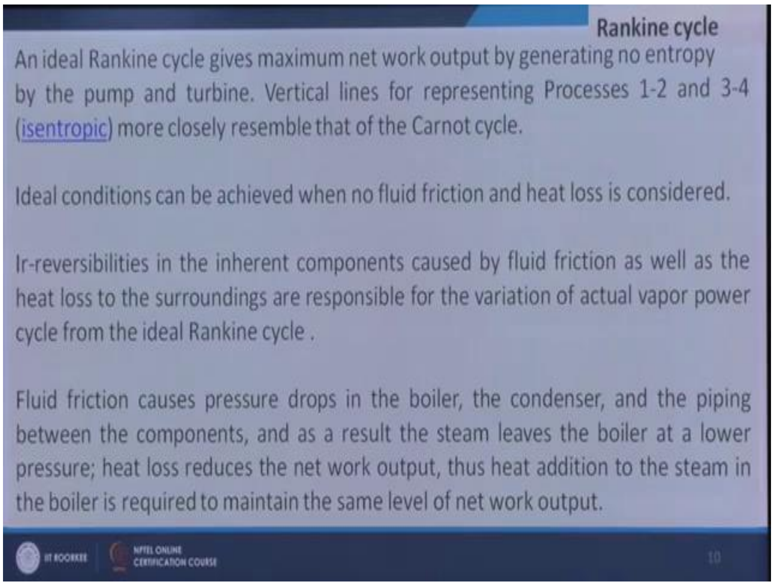

So, here the fluid friction causes pressure drops in the boiler; the condenser and the piping between the components and as a result the steam leaves the boiler at a lower pressure just now we have discussed.

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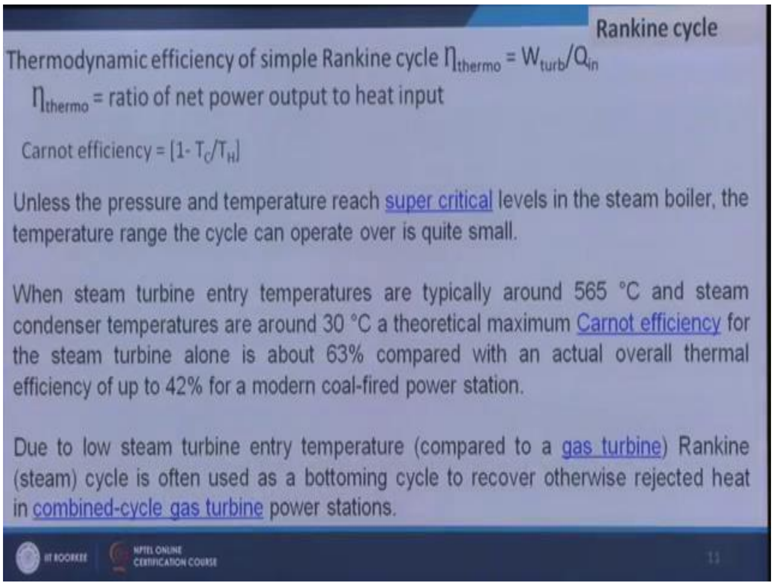

Now, what is the efficiency of these rankine cycle? What is the efficiency? Efficiency; obviously, the work output at turbine divided by Q input, how much heat we have given and how much work we are getting, so this is giving us the efficiency; the maximum efficiency we can get by current efficiency 1 minus T C by T H. So, in this case what is T C and what is T H; obviously if we have one boiler we are using the flue gas here, we are using water and we are getting steam. So, high temperature of the steam T H we may use some heater also that is super heater, so we are getting T H and this is our T C these value is giving us efficiency.

So, more the value of T H more will be the efficiency or less of the value of the T C will also give us more efficiency; that is why the super critical condition if the boiler is used the steam is produced in super critical condition, the T H is very high then we get maximum efficiency. One example is given here, so hence turbine entry temperature is typically around 565 degree centigrade and steam condenser temperature is around 30 degree centigrade, then the maximum thermal efficiency of the steam turbine alone is around 63 percent which only 43 percent for a conventional pool fired power station.

So, due to the low steam turbine temperature with respect to gas turbine; the gas turbine the temperature is around 1500 degree centigrade, but here it is around say in super critical condition 565 degree centigrade, so due to this low temperature requirement for steam turbine, so this is used in bottoming cycle of a combined cycle plant. Now we will see the thermodynamic cycle which is used to understand the working of a gas turbine.

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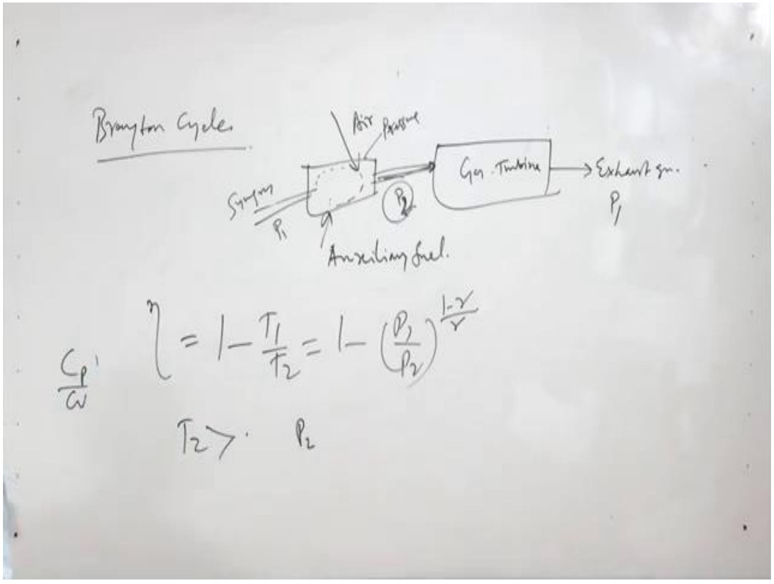

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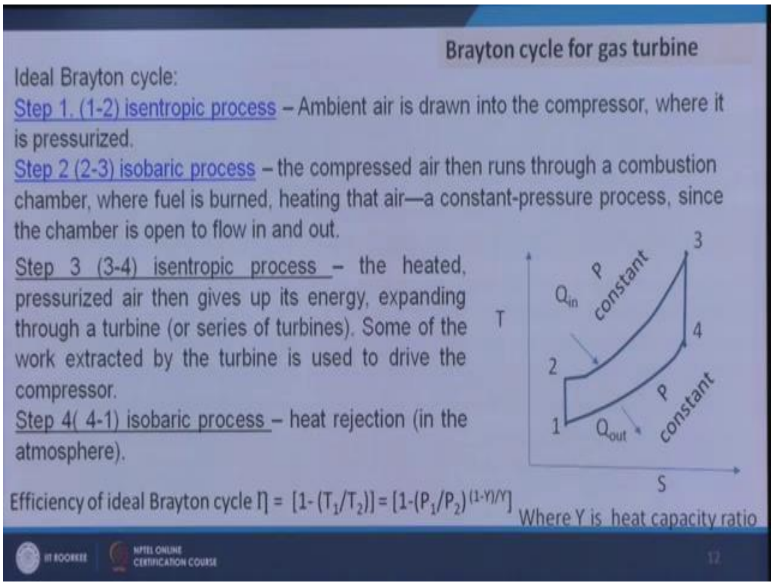

So, the gas turbine is represented by brayton cycle, so in this cycle we have again four steps; the first step this one 1 to 2; this 1 to 2 is the first step. So, this first step is isentropic process ideal one, then the isobaric process then 3 to 4 we are getting again isentropic process and 4 to 1 we are getting again isobaric process. So, this process 4 processes; this 1, 2; 2, 3; 3, 4 and 4 to 1 are considered in case of brayton cycles. For ideal brayton cycles 1, 2 and 3, 4 are isentropic processes, but just like rankine cycle, in reality these are different from the ideal conditions to some extent for every operations because of different types of losses friction etc.

So, in these case we see if we have Q input here and Q output here and this P is constant here, P is constant here also. So, this is a P 1 and this is a P 2, so P 1 and P 2; that means, we have one gas turbine it is giving us some exit gas; exhaust gas with P and it is having the P 1 before that we are using some air and some combustion chamber say it is a syngas, so here heat rate, so P 1 is increasing; so now this P 1 and this is your P 2.

So, the efficiency of this process is equal to 1 minus T 1 by T 2 or is equal to 1 minus P 1, P 2 to the power 1 minus gamma to the power gamma. So, this gamma is equal to heat capacity ratio that is specific heat at constant C P and C V constant pressure and this C V this ratio is gamma. So, from this expression we see that if T 2 value is higher; if T 2 is very high then efficiency will be higher. Similarly P 2 value is high then also efficiency will be higher thus the P 2, this is P 2; this is P 1. So, this P 2 value which we are getting after combustion of the syngas or some we can have any other auxiliary fuel. So, this fuel will us some combustion here in this chamber and a constant pressure will be maintained that will release the flue gas to the gas turbine.

So, that pressure is higher pressure than the pressure which is having here, so this ratio more the ratio will be more the value of P 2 will be giving us more efficiency. Similarly more the temperature here will be giving us more efficiency, but how much temperature we can apply that is limited by the material of constructions of the reactor of the system, it is around say 1500 to 1800 degree centigrade and this pressure P 2 by P 1; thus P 2 that is 16 time of P 1; 11 to 16 time of P 1, this is normally used. Now in the brayton cycle ideal cases, we have seen two isentropic process and two isobaric process that is 1 to 2 and 3 to 4 isentropic, 2 to 3 and 4 to 1 isobaric, but in reality we will not get any isentropic process, those will be adiabatic process, isobaric process and isobaric process

3 and isobaric process 4 and 3 is adiabatic process, so these are the real case brayton cycle.

Now, we will see how the efficiency can be monitored by using bottoming cycle or topping cycle. So, bottoming cycle, topping cycle and combined cycle this three concept has come; three classifications of the cycles have thermodynamic cycles we have developed; so one is your topping.

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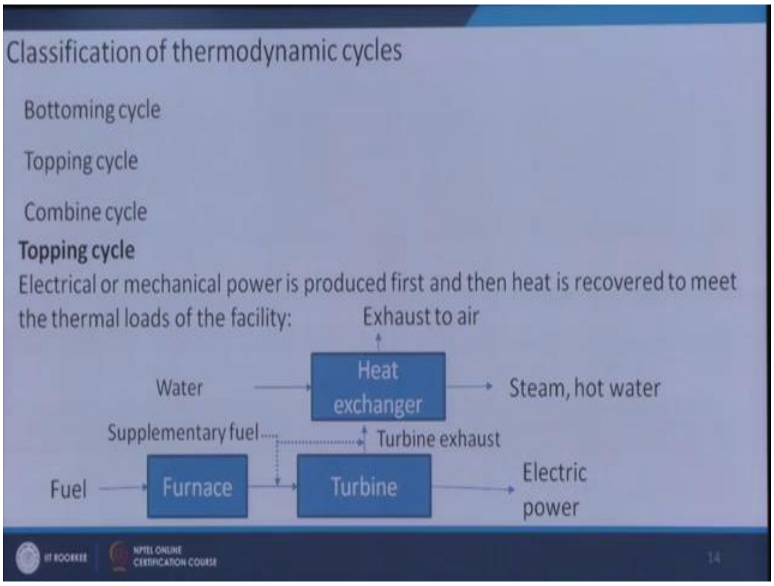

So, topping cycle means we will be extracting mechanical and electrical energy first, then heat recovery. So, in this case we will use fuel then it is combusted, then it will come and it will go to directly to turbine. So, we actually this is gas turbine if required we will put here some supplementary fuel to increase the temperature of this flue gas generated here; if it is a gasifier then it will be syngas, so oxygen will be sent and high temperature will be generated.

So, this is turbine electricity produced first; then turbine exhaust this will go this will be having also very high temperature and that will be used this exhaust will be used for the waste heat recovery. So, water is sent through this heat exchanger or boiler and then we will get steam or hot water and then we will the exhaust from this, it will be exhaust to air some cleaning is required here gas cleaning; so this is the topping cycle.

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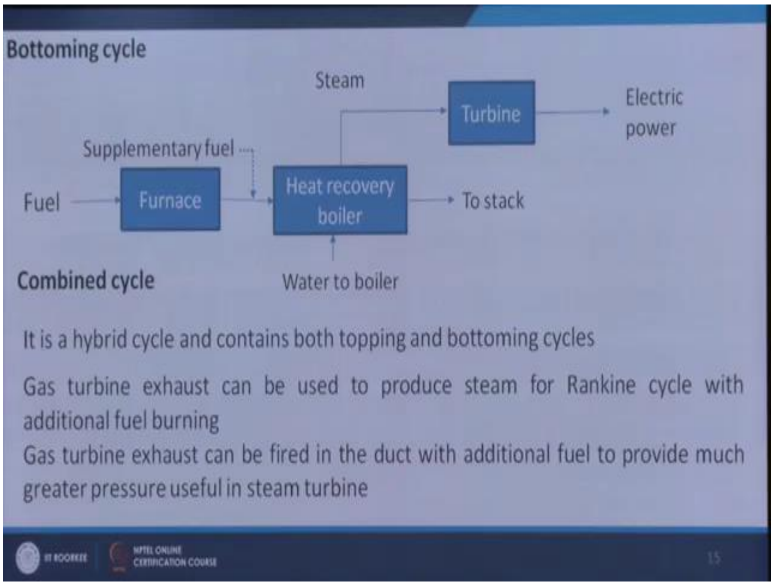

And this is the bottoming cycle, so bottoming cycle what will be happening; we will be producing heat first. So, here it is the furnace, so fuel is coming combustion is taking place. So, we may supply some supplementary fuel to increase the temperature here and it will come to the heat recovery unit that is boiler. So, boiler will send water, so that water will be converted to steam and steam will be used to produce electricity to the steam turbine and the flue gas from the boiler will go to stack for your treatment, so this is called bottoming cycle.

So, the combined cycle means both topping and bottoming cycles will be used simultaneously and this case we will get. So, gas turbine exhaust can be used to produce stream for Rankine it; additional fuel burnings.

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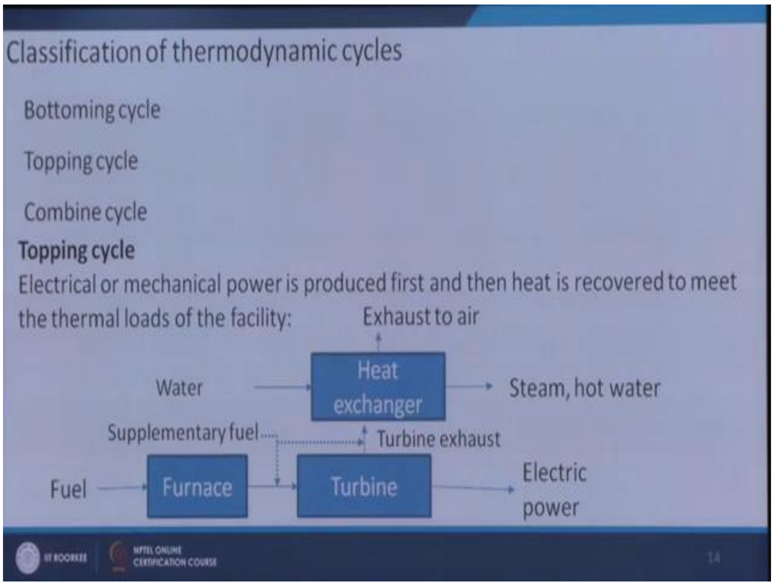

In the first case we have here the turbine exhaust, it is going here and we are producing steam or hot water. In place of this, if we use the steam for electricity production using steam turbine again. So, then this will be called as combined cycle now by using different cycles and number of turbines we can improve the efficiency. Another approach is also there to improve the overall efficiency of the process that is your co-generation and additional heat recovery.

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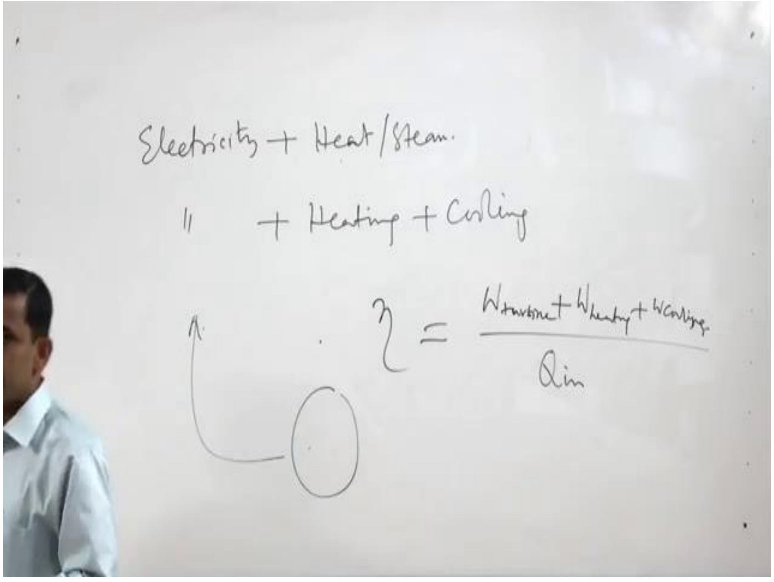

So, cogeneration we can use the flue gas for the production of steam, we can or production of heat or we can use it for the production of electricity. So, cogeneration means we will produce electricity as well as we will produce heat or we will steam. In this case the efficiency increases, so you have two options either you can use electricity plus heat or electricity plus heating plus cooling, so two situations may be available there.

So, the third case the try generation are combined cooling heat and power applications these refer to simultaneous generation of electricity and used for heating and cooling. So, just we have discussed in the beginning of this module that some part optional form turbine to cooling and then it is heated and it is to the boiler recycled back to the boiler. So, this is one example of try generation and try generation improves the efficiency and here the value of efficiency is equal to not only the work at turbine, it is also the work for heating and cooling divided by Q input; total input we are giving.

So, that is why in this case we get more overall efficiency of the plant this is some example how the combination of this steam generation heat generation and electricity generation improves the efficiency. If it is say only heat production maximum 80 percent steam 80 percent, but power if 30 percent only power 35 efficiency, but steam and heat separately gives more efficiency, but you can combine these two; either say steam and power or heat and power then also we get intermediate overall efficiency and this is your maximum efficiency we are getting here; that is heat and power.

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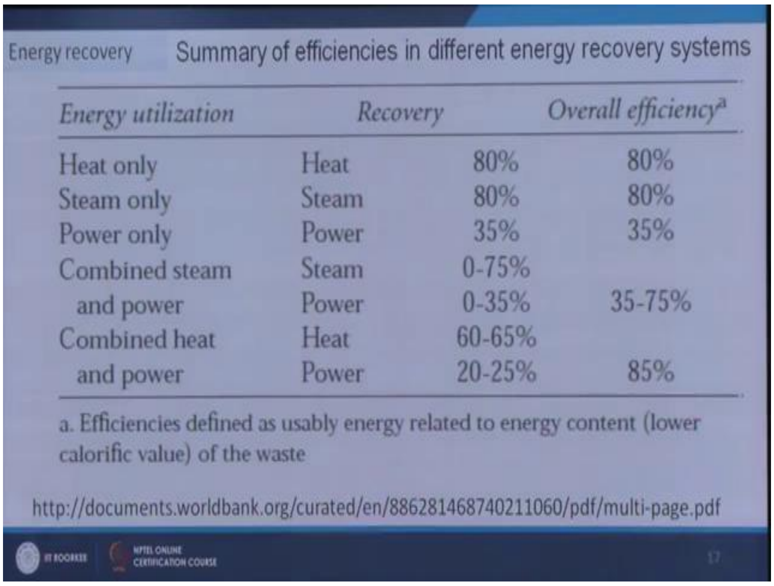
Energy recovery

Summary of efficiencies in different energy recovery systems

Energy utilization	*Recovery*		*Overall efficiency*[a]
Heat only	Heat	80%	80%
Steam only	Steam	80%	80%
Power only	Power	35%	35%
Combined steam	Steam	0-75%	
and power	Power	0-35%	35-75%
Combined heat	Heat	60-65%	
and power	Power	20-25%	85%

a. Efficiencies defined as usably energy related to energy content (lower calorific value) of the waste

http://documents.worldbank.org/curated/en/886281468740211060/pdf/multi-page.pdf

So, heat and power this combined heat and power applications gives maximum efficiency. So, efforts are going on to get maximum efficiency and to improve the efficiency of the power plant. So, after this in this module and in this part and the second part we will discuss on overall efficiency of power plant and about different losses.

Thank you very much.