Waste to energy conversion
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Lecture – 21
Efficiency Improvement of Power Plant – 2

Hi friends. Now we will start discussion on the second part of the module Efficiency Improvement of Power Plant. In the first part we have discussed on the power generation flow sheet and its performance, different types of losses, and thermo dynamic cycles which are used to understand the operations of the power plant and its performance, and cogeneration and heat recovery absence for the improvement of deficiency of the process.

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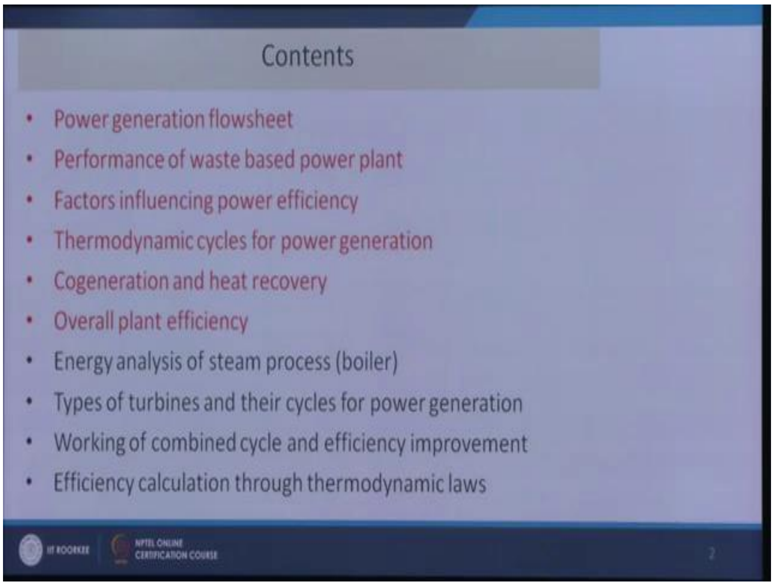

In this part we will discuss on overall plant efficiency, energy analysis of steam process, then types of turbines and their cycles for power generation, working of combine cycle and efficiency improvement, and finally efficiency calculation through thermodynamic laws.

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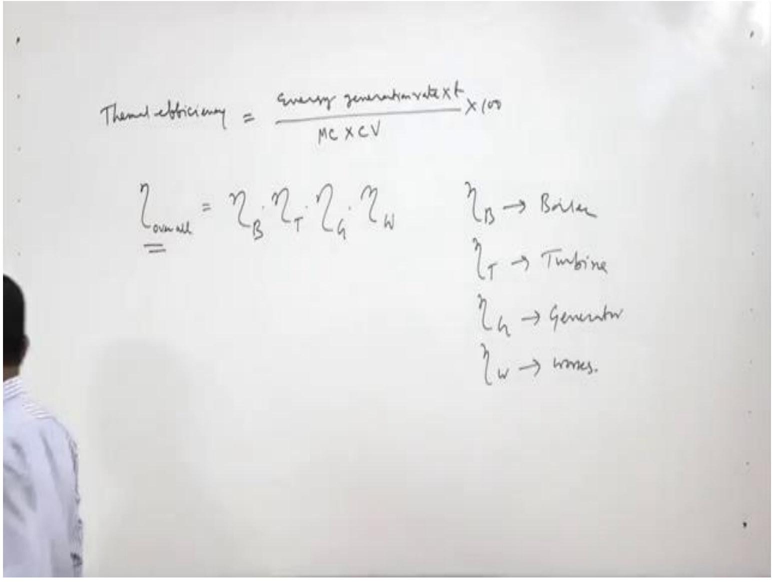

Here we know that thermal efficiency is equal to energy generation rate into time divided by amount of material used into calibri value of the material into 100. In the first part we have discussed on this. Now we will see how this thermal efficiency is dependent on different parts and how the overall efficiency can be calculated.

So, overall plant efficiency that is dependent on the efficiency of boiler, efficiency of turbine, efficiency of generator, and efficiency of works. So, turbine, generator, boiler and works these four efficiencies will influence the overall efficiency of the unit. For boiler, efficiency T for turbine, efficiency G for generator and efficiency works for works.

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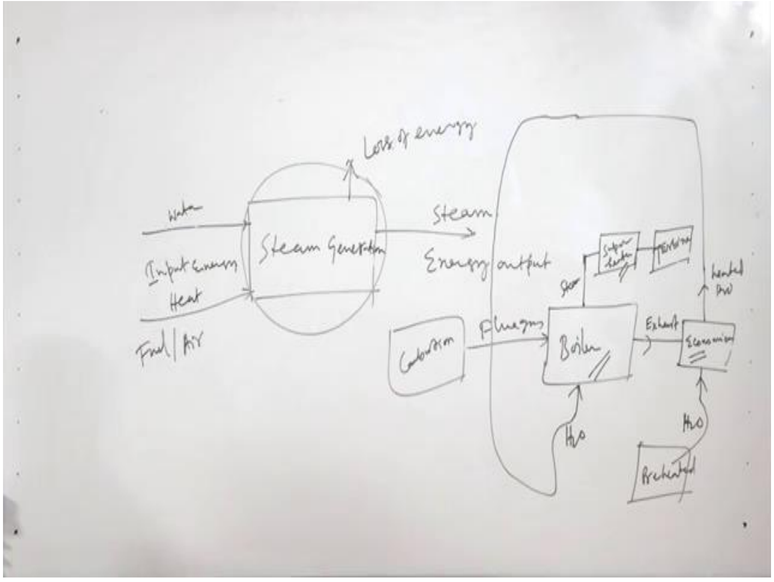

So, now we will see how the steam process works or a boiler works. In a boiler our objective is to generate the steam. So, we have some heat input; input heat and we have some output. So, input energy in terms of heat in water as well as we are also having some heat in the fuel and air. So, this heat is input to the system and then it is giving us steam. So, some energy stored here, so that is our output; energy output. And in between these processes we are getting some loss of energy. So, this is the concept of energy input output and some losses.

Now how this generation is going on? If we think the steam generation unit then we can divided in to some parts, like the first part the main part is a boiler who will send here water, and through this we will get flue gas after combustion here say then flue gas will come out from this boiler unit and it will be having some heating value also, so here the exhaust of the boiler that will go for heat recovery that is called Economizer. So, economizer here we will put some water that will be heated and that can be recycled back to this boiler. So, that some sort of heat is recovered. And then from boiler we are getting the steam that steam has to be super heated. So, we need super heater. Then super heater will increase the pressure and temperature of the steam that will be used in turbine

So, the whole steam generation system we can divide into boiler economizer and super heater the three main unit we can consider. In some cases this water is also pre heated.

As we have discussed in the first part of this module that this is optional in some cases it is used.

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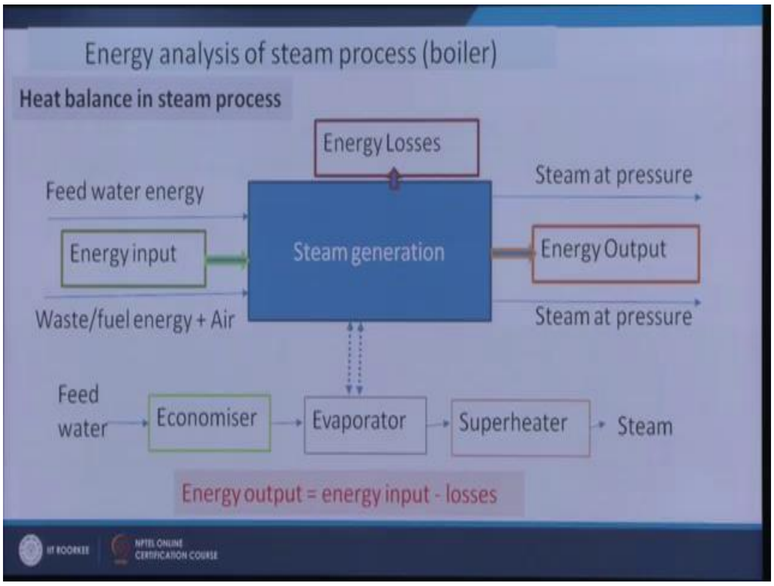

So, our boiler super heater and economizer are three main important parts. So, we have shown here then feed water is coming economizer then evaporator then super. So, this boiler is evaporated, so these are the parts.

Now we will see how the energy conversion is taking place here. So, what is our input and what is our output, what is our losses then what is the energy balance in the system now we are going to discuss on that. Now let us consider some amount of fuel is used in the combustion unit. So, it is releasing its heating values, so high heating value. So, that will give HHV and that will be associated with the flue gas and flue gas will be use to produce steam.

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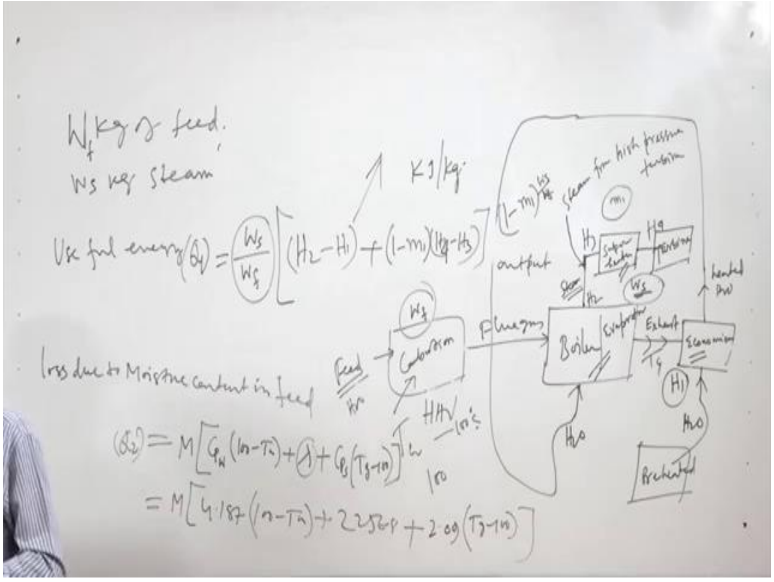

So, if we use 1 kg of or say if we use W f kg of feed here, if we use W f kg of feed here feed in this case any fuel in our case may be waste and if it produce W s kg of steam; that means this is W s kg of steam, then what is the useful energy? Useful energy means the energy which is available with the feed stock part of it is converted to steam that is useful. In some cases the heat is also used; for the production of this steam we are using some amount of energy here in the economizer, we are using some amount of heat here, some amount of heat in economizer, some amount of heat in boiler or evaporator, and some amount of heat is here also. So, total heat we are using that is available in our steam so that is useful energy.

So, useful energy in this case if we define it as Q 1 that is equal to W s by W f: W s is the kg of steam generated and W f is the kg of fuel we are using. So, W s by W f is the steam generated per kg of heat stock. So, this into; so if we use 1 gram of or 1 kg of heat, so W s by W f of steam will be generated. That means, same amount of water was used, so that was the heat of that water the temperature of that water was raised in the economizer and then there were some evaporation and then again temperature change.

So, if we see here the H 1 is the enthalpy of the water of this W s by W f amount of water is and H 1 is enthalpy here. And H 2 is the enthalpy here, after evaporation. And then H 3 is super heater and H 4 is here going to turbine. So, if these are the enthalpy of the water and steams at different stages then useful energy will be W s by W f into how much H 2 minus H 1 plus; here one interesting point is that we are producing this is saturated steam. So, if in our plant we have number of turbines the one turbine will be at higher pressure, so higher pressure steam will be exit from the turbine after use and it will be having lower pressure, it may be possible that if the downstream turbine is using lesser pressure that exit from the first turbine can be used here. The steam exit from the first high pressure turbine can be used here. So, steam from high pressure turbine.

So, we are assuming that m 1 mass fraction of steam is added in this place. So, we do not need to raise the heating value of the steam from H 3 to H 4 of that all steam is generated here. So, we will be in that case 1 minus m 1 into W s by W f that amount of heat content will be used, will be increased. That is why this will be 1 minus m 1 into H 3 H 4 minus H 3; H 4 minus H 3. So, this is the heat content in or energy we are getting in useful form that is in kg per kilo joule per kg of feed stocks. So, that is in kilo joule per kg of feed stock. This is our useful energy.

Now we will consider what are the losses; then if we get useful energy and if we get loss then heating value which is generated which is available with feed stocks that is equal to available energy plus losses. So, available energy and we have defined it as useful energy; available energy or useful energy plus losses.

Now, what are the losses let us see. The first loss we can get here, if moisture is present in the feed stock; if the feed stocks which you are using that is having some moisture or water. So, heat which will be liberated here in the combustion chamber some amount of heat will be consumed by the water available in the feed stock. And to raise its temperature from the ambient pressure say T a to 100 degree centigrades in the boiler; sorry 100 degree centigrade for its vaporization and then 100 degree centigrade to this output the temperature of gas is exit gas temperature.

That is why some amount of feed will be consumed here and some amount of heat will be consumed by the steam to raise its temperature. And some amount of energy will be used to fade change some water to steam. That is why the loss due to moisture content in feed that is equal to m moisture content into C p d t for the water. So, C p is equal to water into d t; what is d t, 100 minus T a. So, 100 minus T a plus m lambda that is equal to latent heat and C p g steam; C p of steam into T g minus 100; so this will be the heat consumed by the moisture available in the feed stock and that will not be used for the steam production here. So, this is our loss.

Now if we put the value of C p w and C p steam then this loss is equal to m into we can get 4.187 into 100 minus T a plus this lambda, this lambda is equal to 2256.8 kilo joule per kg. And specific heat of steam that is equal to 2.09 kilo joule per kg or degree centigrade; so 2.09. So, that will be T g minus 100. So, this is our heat loss due to moisture present in the feed stock.

So, some other losses; if hydrogen is present in the feed stock hen hydrogen will also be converted to water and that water will further use some heat, that will not be used in the process.

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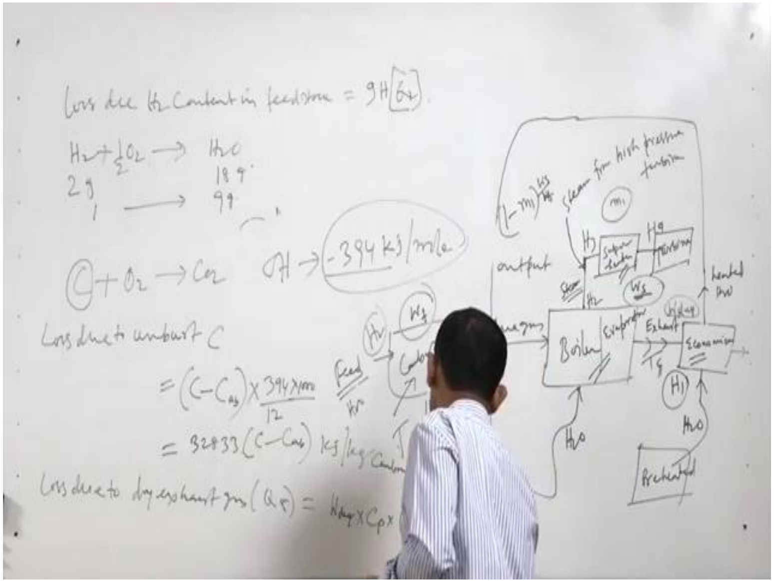

So, in this case loss due to hydrogen content in feed stocks that is equal to 9 into H into this one Q 2. Why so, because this hydrogen which is available in the feed stock that will work with the oxygen then it will give H 2 o. So, H 2 plus half o 2 it will give us H 2 o, so 2 gram of hydrogen is giving us 18 gram of water. So, 1 gram hydrogen is equivalent to 9 gram of water. And that 1 gram hydrogen will produce 9 gram of water that is why 9 into H into this Q 2; that will be the heat loss due to the presence of the hydrogen in the feed stock.

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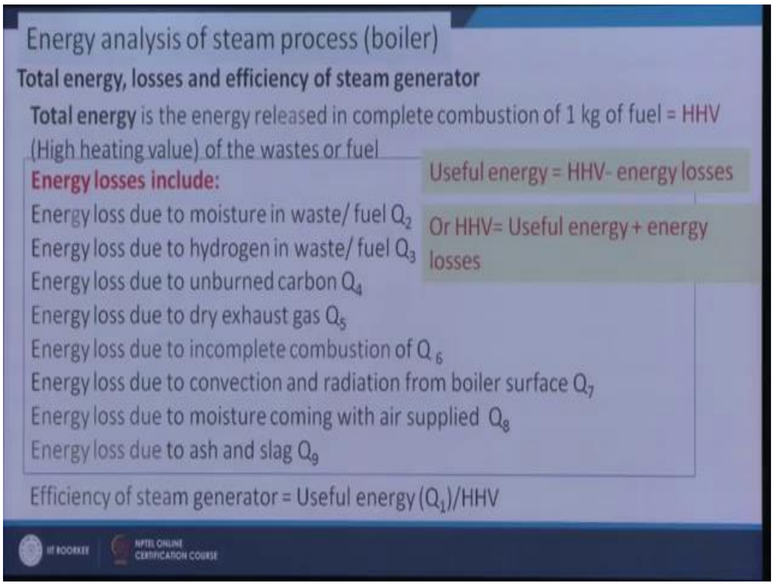

We will be having some other losses also, like energy loss due to unburned carbon. So, all carbons present in the feed stocks may not be completely converted. So, some unburned carbon will be available. So, the heat content of the unburned carbon we are not being able to utilize in this case and that is why it is loss. So, unburned carbons in ideal cases which is in unburned that can react with oxygen and it can give us Q 2. In this case del H is equal to 394 kilo joule per mole. So, this is the heating value of this. So, depending upon the carbon which is not burned we will lose some amount of energy that is our loss.

That is why heat loss due to unburned carbon we can write that how much carbon is present unburned that is C minus C ab absorbed; how much carbon is absorbed total carbon minus C absorb so that is the unburned carbon; that into heating value of this one. So, heating value we have seen here that is 394 kilo joule per mole. So, 394 divided by 12 kilo joule per gram so into 1000 that will be kilo joule per kg. So, that is equal to we will get 32833 into C minus C ab into kilo joule per kg. So, that is the loss. What is that kg? Kg carbon, this is not the feed stock this is carbon.

Next, other loss we may have energy loss due to dry exhaust gas. So, dry exhaust gas means after this steam generation the exhaust from the boiler or evaporator this will be having also some heating value that is T g is having that T g, so it will be having some heating value. So, that if we do not use any other heat recovery unit, so that is going to be lost. So, loss due to dry exhaust gas, this is our Q 5. So, what is this? We have to see how much exhaust gas is generated W deg dry exhaust gas. So, W deg is the mass of dry exhaust gas which is generated per kg of fuel. Then W deg into C p d t, so C p of that gas into d t, what is d t here that is T g minus T a, so this is a T g and what in value we have T a; so T g minus T a.

So, this is the amount of heat loss we are getting due to this reason. Now we will see loss due to incomplete combustion.

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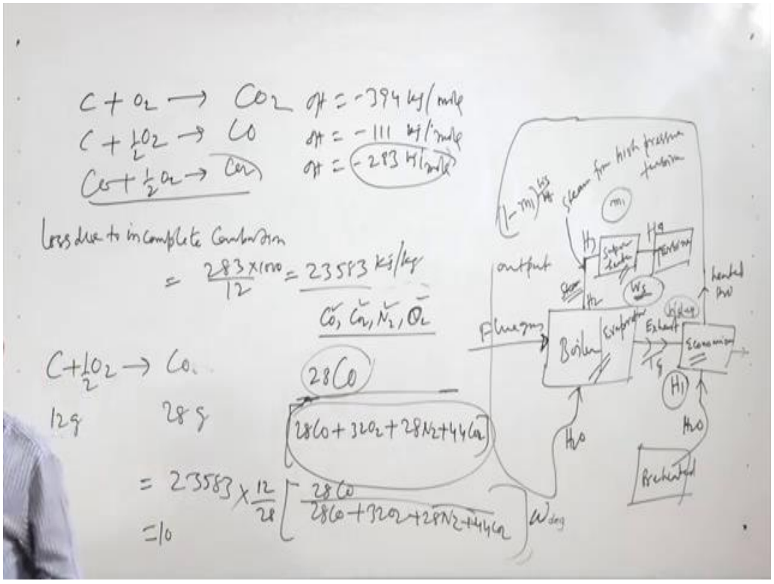

So, incomplete combustion means carbon which is present in the feed stocks that can react with oxygen, that can give us CO 2 or this can react with oxygen and give us CO or CO can further we reacted to give CO 2. So, here del H is equal to minus 394 kilo joule per kg here del H is equal to minus 111 kilo joule per kg. So, here del H is equal to minus 283 kilo joule per kg. Now if the carbon is not completely combusted this reaction will not proceed and we will lose this amount of energy.

So, per kg of carbon will be losing minus 283 kilo joule of energy. So, loss due to incomplete combustion will be equal to 283 divided by 12; this is per kilo mole; so this is per mole, this is per mole, this is per mole and this is also per mole, so to this into 1000 that is equal to 23583 kilo joule per kg. So, that is due to loss of carbon. Now we have to convert it in terms of kg fuel. So, this conversion can be done if we know the combustion of the flue gas it will be having CO, it will be having CO 2, it will be having nitrogen, and it will be having O 2.

O 2 will be available because in the previous modules we have discussed that for complete combustions O 2 is to fuel ratio should be higher. If it is lesser than complete combustions may not take place even though stoichiometric oxygen is provided. So, some amount of oxygen may be available. So, in this case if we know the mole fraction of this all those; so mole fraction of CO divided by mole fraction of CO plus mole fraction of CO 2 plus mole fraction of N 2 plus mole fraction of O 2. So, this will be the amount of CO present in amount of total gas flue gas.

So, now, if we multiplied with the molecular rate of this in terms of mass this will be 28 into CO plus O 2 that is 32 into O 2 plus 28 into N 2 plus 44 into CO 2. So, that will be the mass ratio in this. So, out of this much of total flue gas this much will be the CO. Now C plus O 2 that is giving us CO half O 2 that is giving us CO, so 12 gram will give us 28 gram of CO; 12 gram of C will give us 28 gram of CO; That is why the loss due to incomplete combustion in terms of kilo joule per fuel will be 23583 into 12 by 28 into this one; 28 CO divided by 28 CO plus 32 O 2 plus 28 into plus 44 CO 2 into this will be. Now this term is becoming is equal to 107 into then W deg into 28 CO by 28 CO plus 32 O 2 plus 28 into plus 44 CO 2.

So, this will be the loss due to the incomplete combustion of this. Next loss is due to convection and radiation.

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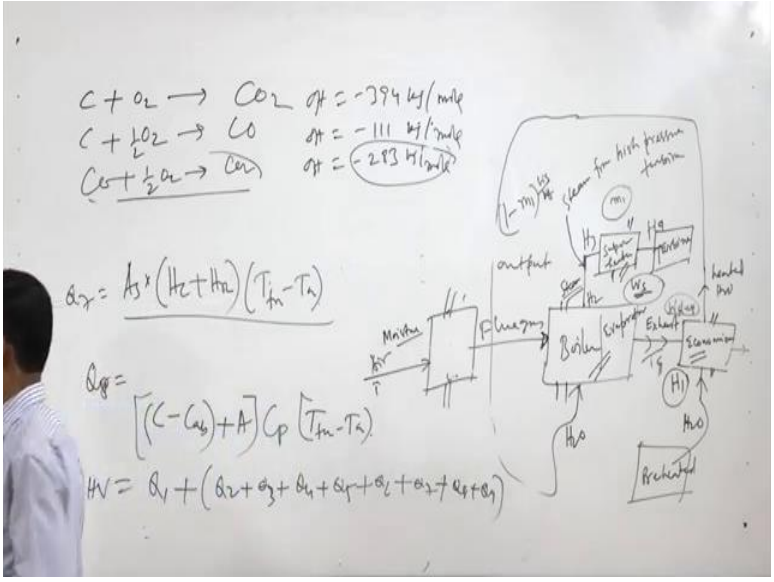

So, we have here some furnace we have some boiler sector. So, furnace from the wall there will be heat radiation and convection. So, if we know the total area expose to ambient air, so from this, from this, from this everywhere there will be some radiation and there will be some convection loss. So, if we know the total area and if we know the heat transfer coefficient for convection and radiation then the temperature difference T furnace minus T a for this case further cases if we consider this will be the higher loss because the temperature is not that much here. So, some maximum loss will be there. So, this will be the total loss due to radiation and convection; that is equal to Q 7.

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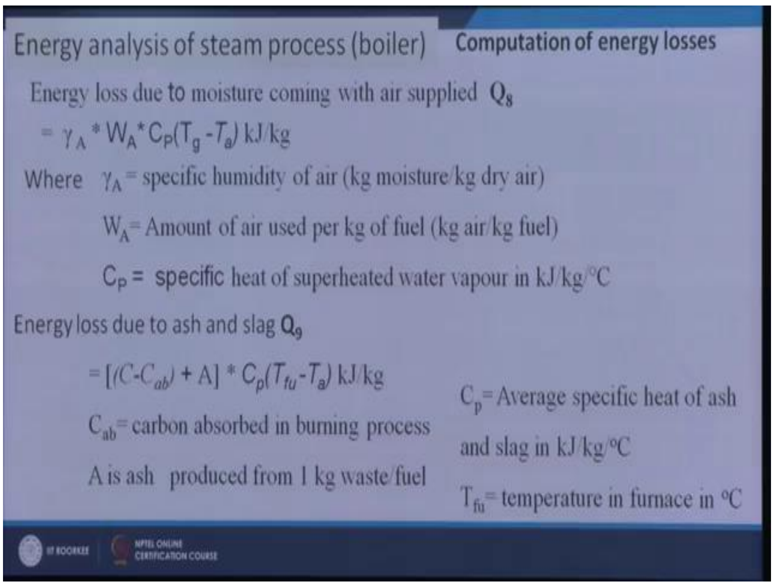

Next we will see energy loss due to moisture coming with air supplied. So, moisture which is coming, here we are providing air for the combustion, it may contain some amount of water so that moisture which is available here that can be determined on the basis of humidity of the air. So, humidity of the air; so Q 8 that is equal to say humidity of the air into amount of air used w a into C p into T g minus T a; that is the temperature change from m into T g. Now, in this case the air containing the moisture the latent heat is not considered.

Next is energy loss due to ash and slag. So, ash and slag will be generated in the furnace so that will be having also some amount of energy that will not be used for further applications. And in this case the slag means total carbon minus C ab the unburned carbon plus ash into C p into d t; d t means t f furnace minus T a into T a. So, this is the amount of heat loss due to ash and slag. So now we have got almost all the losses.

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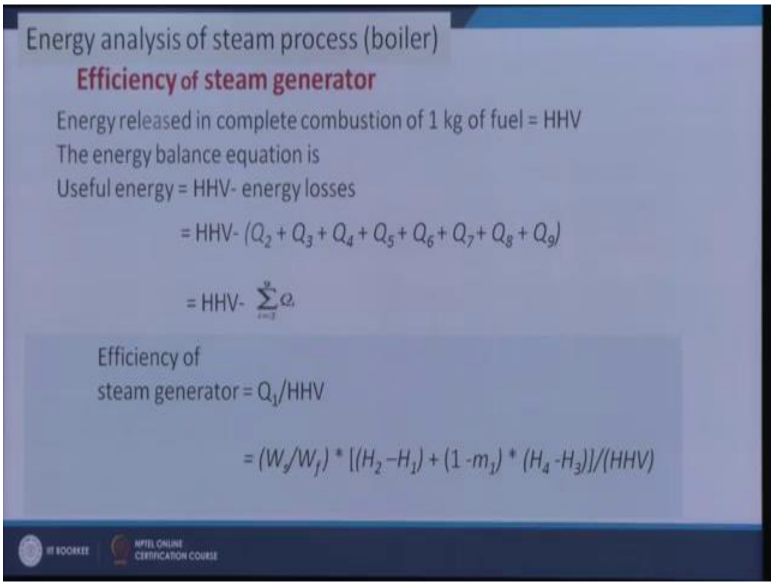

So, we can get HHV that is equal to Q 1 which we have got that is useful energy plus the losses; losses mean some of Q 2, Q 3, Q 4, Q 5, Q 6, Q 7, and Q 8 and Q 9. So, this is the HHV equations.

So, what will be the efficiency in this case? Efficiency will be useful energy that is Q 1 divided by HHV.

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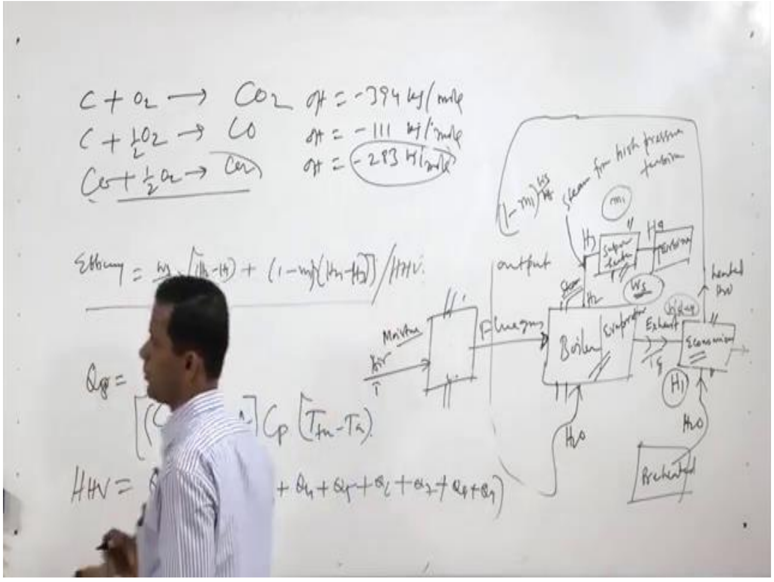

So, that efficiency that is equal to W s by W f into we have got that is H 2 minus H 1 plus 1 minus m 1 into H 4 minus H 3 divided by HHV. So, this is the efficiency of this.

Now we are coming to discuss on different types of turbines. Already in the first module we have discussed first of this module the different steam turbine, gas turbine and both combine cycle can be used.

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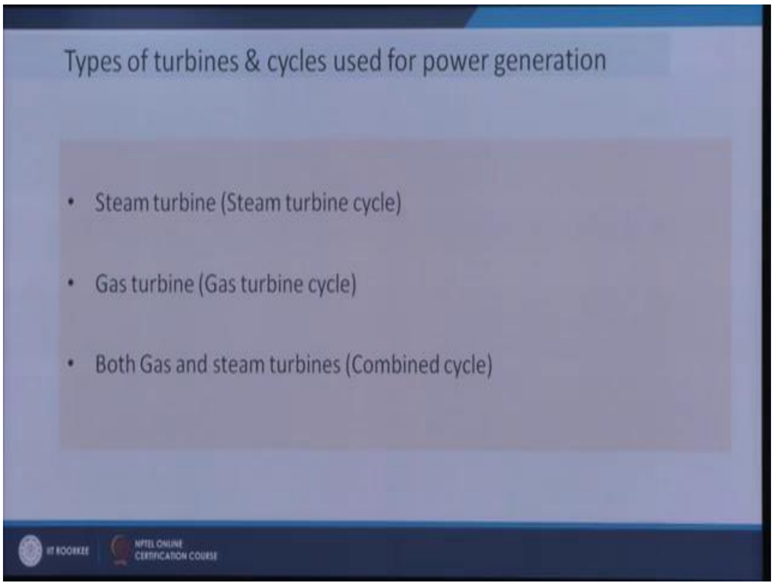

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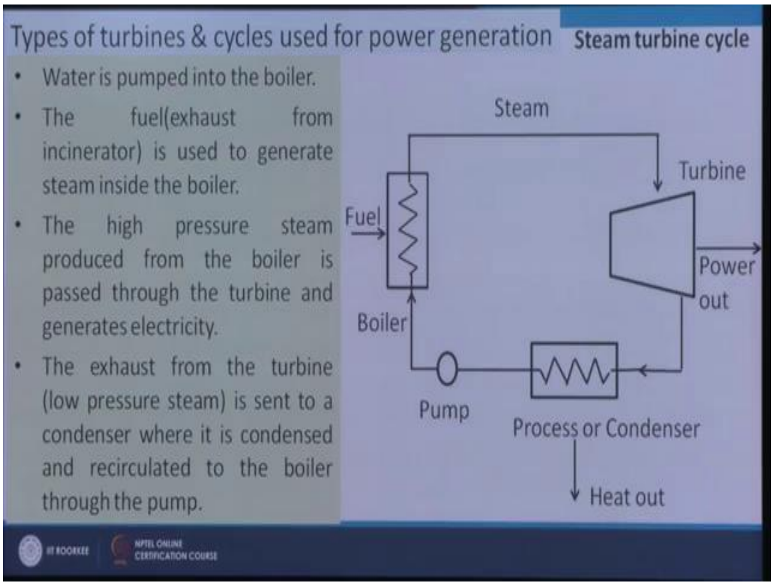

So, here this is the working of this. In case of steam turbine the steam is produced here and it is coming to turbine and then electricity generated. And after condensing this recycle back. Already we have discussed these things.

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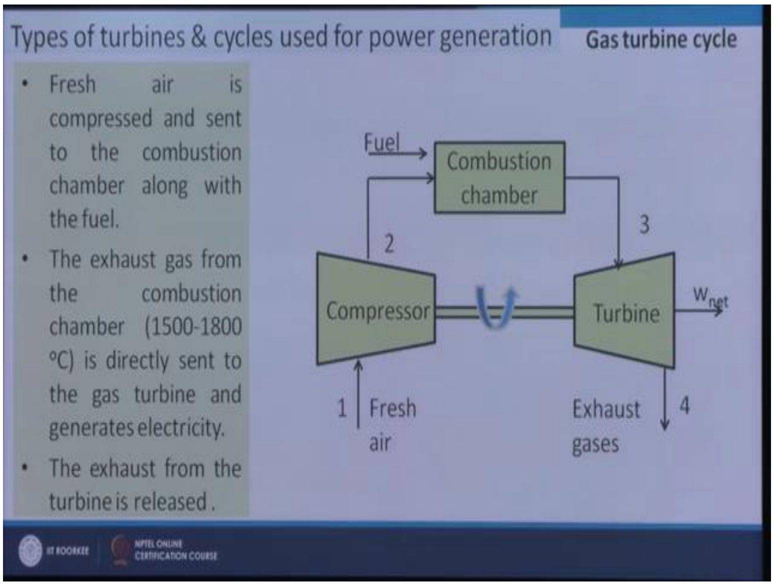

Similarly, the turbine cycles we have also discussed in the first part of this. So, where its sent compressed and then combustion takes place and then the combusted gas is pass through the turbine gas turbine and then we get some work here. And this temperature is around 1500 to 1800 centigrades, we have discussed in the first part of this module.

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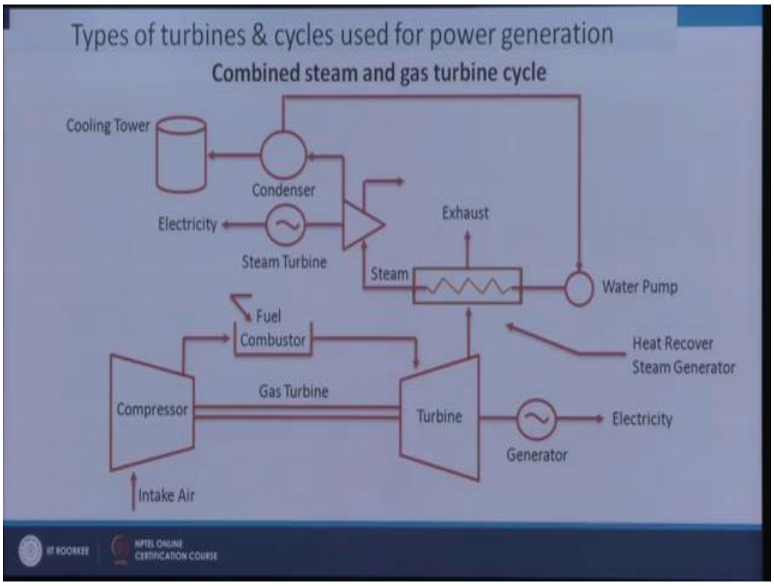

And this is a combine cycles; means steam and gas both turbines is available. So, first the turbine this turbine will work fast gas turbine it will work fast the exhaust of the gas turbine will be used first steam generation and then the condensation will be going on.

So, these is the combine cycle operation and in combine cycle as both types of turbines are used, so loss of energy or loss of heat is reduced. So, efficiency is more.

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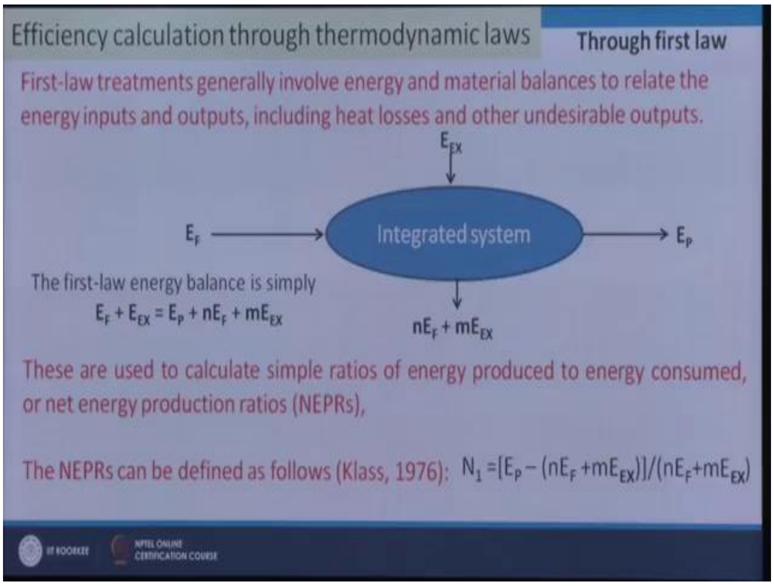

This is the thermo dynamic loss which can be use to understand the efficiency. For example here: in this process if we use E f the energy of the feed E x external energy and we get product energy E p. So, then the one parameter has been considered that is NEPR- Net Energy Production Rates. For the first law net energy production rates is considered that is equal to E p minus n a plus m E x divided by n E f plus m E x.

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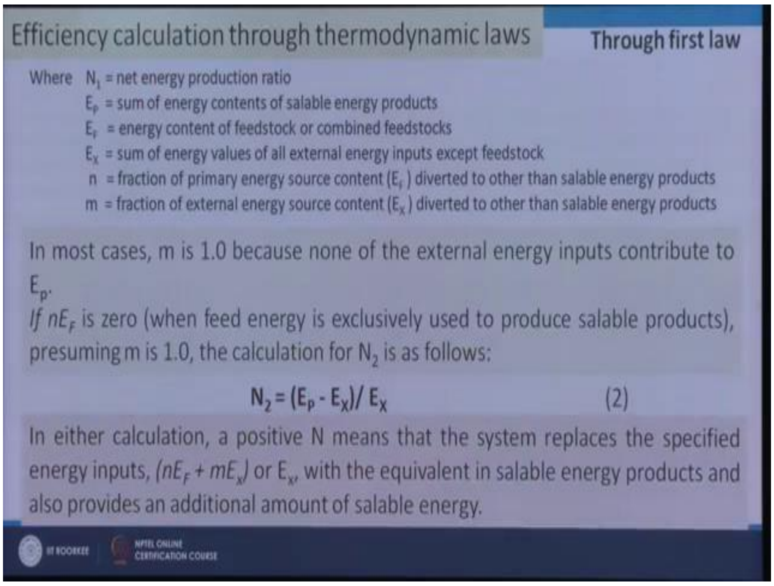

So, this is proposed by this scientist. And normally m is equal to 1 and n is equal to 0, because m is m is what fraction of external energy content diverted to other than salable product. So, this is equal to normally 1 and n is equal to 0. So, N 2 expression is E p minus E x by E x. This indicates that the n p is always positive; that means the energy which is produced that is much more than which is consumed.

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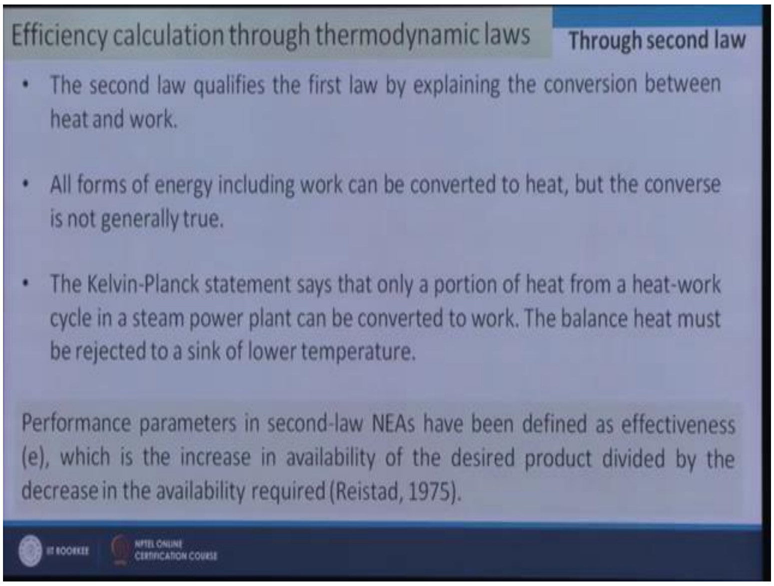

The second term gives us some another parameter that is net energy availability.

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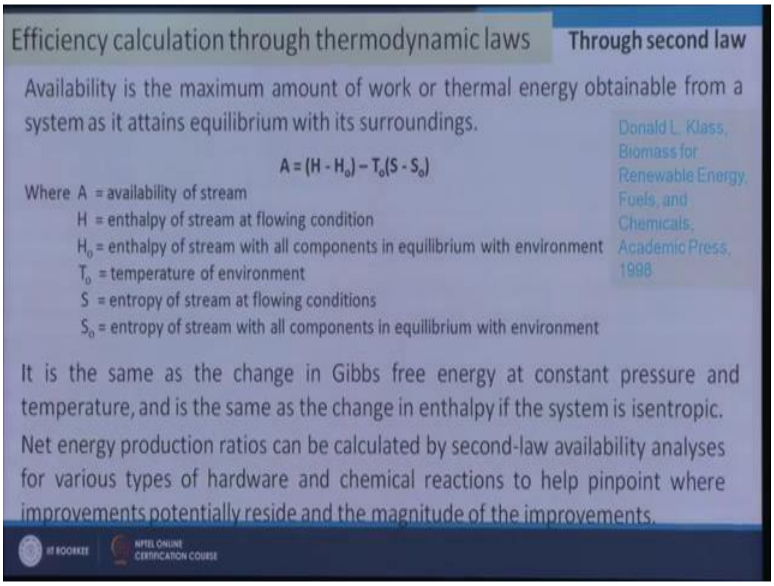

And net energy availability is defined as a is equal to H minus H o minus T into S minus S o. So, H is the enthalpy of stream at flowing condition and H o is a enthalpy of stream with all components in equilibrium with environment. And similarly the S and S o are and T o is a temperature of environment. Now this is similar to del g equal to del H minus t del s. So, it gives pre energy relationship.

So, second law gives us some availability, analysis and it is net energy production ratios can be calculated by second law availability analysis for various types of hardware and chemical reactions to help pin point where improvements potentially reside and the magnitude of the improvements; means where we can put more efforts for the improvement of the efficiency; so up to this on this module.

Thank you very much for your patience.