Energy Conservation and Waste Heat Recovery
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Lecture - 44
Direct conversion - Magneto Hydro Dynamics (MHD)

Welcome back everyone good morning and welcome to the next lecture on Energy Conservation and Waste Heat Recovery. So, if you recall we are continue we will continue today our discussions on direct conversion of thermal energy to electrical energy. If you recall in the last few lectures we learnt about thermo electric generators as the first kind of device which enables us to convert thermal energy directly to electrical energy. We do not need any mechanical any intermediate mechanical energy conversion in between like in power plants, we do not need moving parts of turbo machinery for example, pumps and turbines neither do we need boiling any working fluid like water or organic Rankine or organic fluids and so on.

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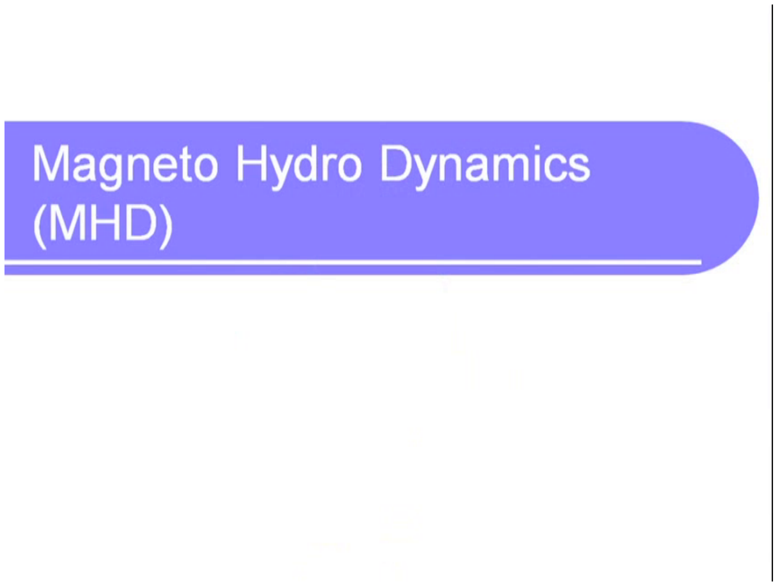

So, what we will do is today we will learn another device or another technique by which we can convert thermal energy directly to electrical energy and that is called Magneto Hydro Dynamics or MHD.

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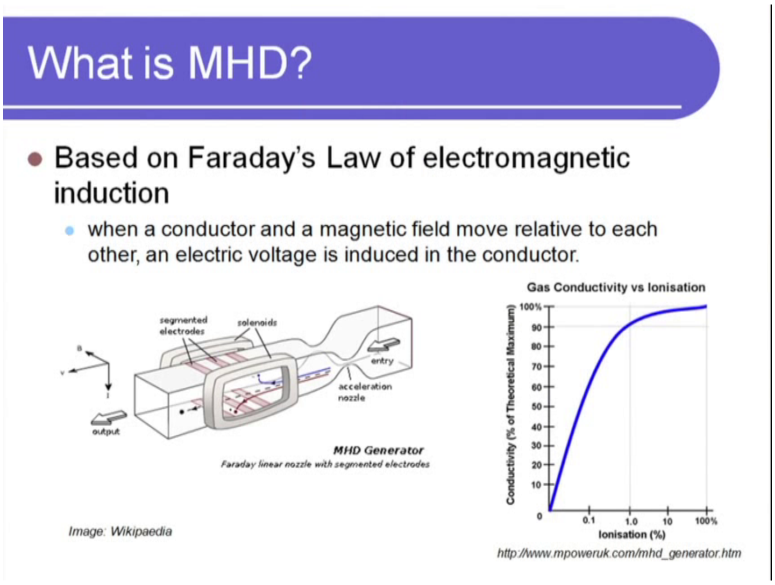

So, what is magneto hydrodynamics? So let us recall from our physics it is a Faraday's Law of electromagnetic induction. What Faraday said is if a conductor and a magnetic field move relative to each other an electric voltage is induced in the conductor fair enough so if you have an electric field, if you have a magnetic field that is sorry and if you have a conductor and the conductor actually moves within the magnetic field or the magnetic field moves relative to the conductor it can be either way. Then what happens is we can give rise to an electric voltage that is induced in that conductor. So this we know and this is actually the principle on which magneto hydrodynamics operates.

What does it do? In magneto hydro dynamics we already have a strong magnetic field that is there that is present and this is shown over here where I am showing these 2 solenoids this is a magnetic field.

So, let us look at this configuration. We are actually having a duct through which a gas is flowing and on one hand perpendicular to the flow of this gas we have a magnetic field that is operating so that is what the magnetic field direction is shown here denoted by b very nice. So, then what happens? Now what did we say we need to have a magnetic field and we need to have a conductor and the two it should be moving relative to each other so where do we get the conductor now so that is the crux of magneto hydro dynamics.

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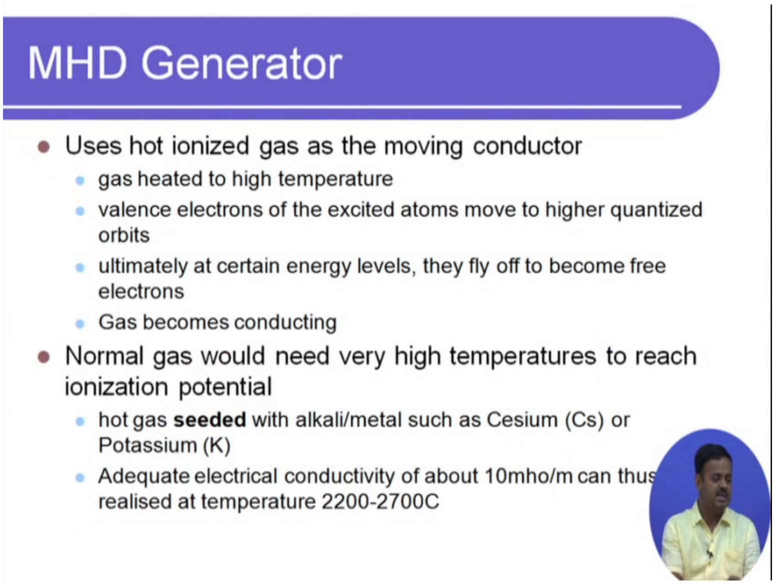

What it says is if we have a hot ionized gas that moves at a high temperature heated to a high temperature then we can have this as a moving conductor. Now how does a gas become conductor is your next question so it can be shown that if an ionized gas is heated to a very high temperature and when I say high temp very high temperature I am talking about temperatures close to 3000 degree centigrade. So if you actually heat up a gas to that higher temperature then the valence electrons can move to because of their high temperature can move to the higher quantized orbits, and then ultimately at certain energy levels they can fly off they can fly off from their outer Orbital's as and become free electrons and thereby the gas becomes ionized and becomes conducting.

So again I repeat that it is possible to ionize a gas by heating it subjected to very high temperature and when you do that what happens is some of the valence electrons of these excited atoms they move to the higher quantized states and ultimately reach a stage where they can break free and become free electrons.

So, when the electrons leave what happens? The gas molecules becomes ionized so you have an ionized gas which is flowing at a high velocity so that is what is happening over here. You have hot ionized gas hot means very hot flowing in this direction perpendicular to the magnetic field that is operated or that is imposed. So, what do we have do we have a conductor that is moving do we have a conductor yes we have the ionized gas which is moving and it has become a conductor by means of you know by means of having some electrons being released from it and do we have a magnetic field yes we do are they perpendicular to each other yes is the conductor moving relative to the magnetic field yes.

So, we have all these conditions that are satisfied and so therefore we will have if we apply some electrodes on the third direction which is at that you know at the ceiling and at the floor of this duct if we may call it so which is denoted by these segmented electrodes as you can see here and if we now measure the voltage across this we are going to measure a finite voltage it will be a DC voltage. Like in thermoelectric generators we are going to give rise to a DC electric source. So, this is the basic principle working principle of magneto hydrodynamics.

We have an external magnetic field applied on a duct through which a hot ionized gas is flowing at very high temperature, because it is ionized it is a conductor it is a moving conductor and therefore due to Faraday's laws of electromagnetic induction we are going to have an electric voltage in the third direction, yeah.

So, now how does this help us with respect to waste heat recovery yeah now a normal gas would require very high temperature to reach this ionization potential very high which is not physically attainable. But however, what you can do is if we can seed we can puts a few small fraction of some materials for example, caesium or potassium which are alkaline or metallic and if we seed the hot gas with these particles with the seeding particles then what happens is this ionization can take place at lower temperatures of the order of 3000 degree centigrade or lower. And we can get adequate electrical conductivity of around 10 mho per meter you remember electrical conductivity unit is mho per meter. So, about 10 mho per meter can be realized it has been shown that if you take typically we talk about combustion gases here and if you seed it with a small fraction a few percentage of by mass a few percent of these alkaline materials particles then we are able to achieve an appreciable amount of electrical conductivity. So the previous slide also had a graph where you can see the gas conductivity versus ionization so if the ionization percentage I am talking about just 1 percent here.

See if the maximum conductivity that you can achieve is denoted in the y axis by 100 percent what we are see is 90 percent is achieved by only 1 percent seeding so it is a very small amount of seed particles that we require, but the seed particles by the way let me I will repeat it again but these seed particles are not very benign they are hazardous. So it is very important to capture these seed particles from the ionized gas once you have once we have extracted the electrical energy out of it clear. So, this is how an MHD generator works. So, let me write down here again.

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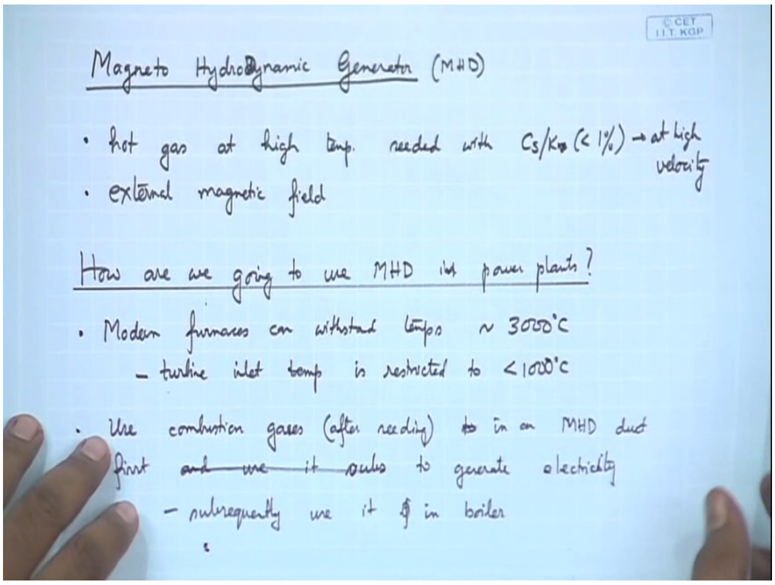

Here is a name Magneto Hydrodynamic generator hydro dynamic let me write it with capitals so that is why it is called MHD. So MHD generator what does it need? It needs hot gas at high temperature seeded with let us say caesium I would say less than 1 percent or potassium. We need an external magnetic field and this gas has to move so at high velocity. So this is typically achieved as we showed in the first diagram through a duct and which has an acceleration nozzle, so it is from your fluid mechanics knowledge you will know that through a converging section if you make it flow then you attain high velocities for the same volume flow rate and this is how we give rise to this moving conductor which give rise to the electric voltage.

Now, how are we going to use this? Let us think of how are we going to use is where are we going to use it in terms of electrical power generation. So one of the ways that we are going to do is the following. So remember how are we going to use it let us write it down. How are we going to use MHD in power plants? Let us write it here, See today the modern with advances in material science the modern furnaces can easily reach and withstand temperatures in the excess of 3000 degree centigrade it is not very difficult.

But on the other hand if you think of our turbines the steam turbines of gas forgets to gas turbines let us think of our steam turbines we are limited by our metallurgical constraints and reliability constraints and so on and other parameters.

We are typically limited to around 850 maybe 900, 1000 degree centigrade. As a result of this restriction we have to restrict the temperature of the combustion gases that we have let us say in a natural gas based in a furnace in a power plant clear so that is the problem. So now so the way that we are going to do is let us say that if we have the combustion gases initially at a very high temperature 2500 degree centigrade, 2700 degree centigrade and so on and my blast furnace is my blast furnace where I am burning this fuel but I am but this combustion is taking place can withstand that kind of temperature so not a problem.

So, if such a case happens then what do I do I have this hot combustion gases coming out at this high temperature. So, first before it is used in the boiler as a heat source I will make it flow through an MHD duct and extract some of the electrical energy out of it and then once it as cooled down I will let it go through the boiler and where it will be used to heat up the water clear so that is what I am going to do.

So, let me write down what I just said, Modern furnaces can withstand temperatures around 3000 degrees centigrade whereas, turbines inlet temperature is restricted to less than 1000 degree centigrade. So the point is use combustion gases after seeding that is in an MHD duct first and use it subsequently MHD duct let me to generate electricity and subsequently use it in boiler clear.

So, the next question that you will ask is what is my maximum temperature? So for magneto hydrodynamics temperature that I am talking about is around 3000 degree centigrade and you can say well my ambient is at 30 degree centigrade so I have a huge temperature gradient 270. So if I can use you know 3000 degrees to 30 degrees if I can cool it down and all this while I use MHD to generate electricity my Carnot efficiency is going to be very high of the order of 90 percent.

If you calculate 2700 over 300 even if you take Kelvin so the Carnot efficiency is going to be very high close to 90 percent so 2700 out of 3300 so I can potentially even if I can operate at a decent efficiency level I can extract a lot of energy electrical energy out of these combustion gases. Unfortunately, not all the good things come together, what happens is the ionization potential of the gas goes down as the temperature comes below 2000 degree so that is what I am showing here.

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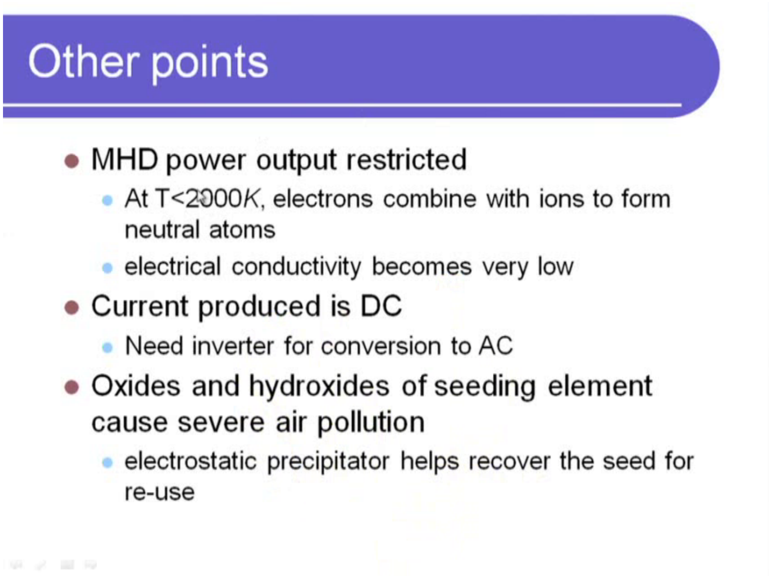

At T less than 2000K, the electrons combined with the ions to form neutral atoms and the electrical conductivity becomes very low. So unfortunately you cannot use it across a temperature range of 3000, 230 or 2 ambient once we reach around 2000 Kelvin we are the MHD output is restricted, but nevertheless so why not use it for the range that we have so if I think about it.

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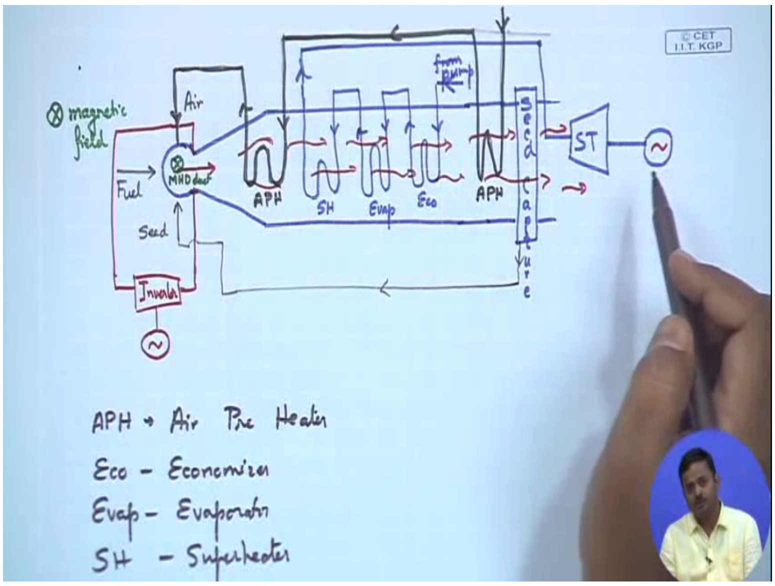

Let us consider I will just draw a schematic here it let us consider a situation where I have an MHD duct and then this goes like this and I have hot gases coming in, so what do I need for combustion? I definitely need air, I need fuel so these two are required and then I would also need because I am talking about MHD, I will also need seed particles or the seeding gas clear.

So now, then I have an MHD duct through which I am letting this flow so this is a 3000 degree centigrade and next when it comes out it has already generated some electricity so I kind of trap that electricity from here I put a magnetic field by the way that I should first also denote over here by this green dot so this is magnetic field and I am able to get electrical energy right.

So, again mark my words this is DC so the electric current produced is DC and therefore what we need is we would need an inverter to convert it to AC fine and this will give me my AC output so by this time the gas has cooled down and then what I can have is I can have my regular boiler faces which is economizer then the boiler and then the super heater.

So, I have economizer then I have the evaporator and then I have the super heater. So this is where now the gas will flow and slowly it is going to lose temperature as it flows through this various parameter various sections of the boiler first it when it is hottest it was the super heater than the evaporator than the economizer and finally what do we get this is my steam that goes to my steam turbine and from there also I get electricity clear. What I can also do is I can this air that I have drawn can also be made to pass through this may be one stage here and sorry one stage here.

So the air can also as it comes, it can be preheated before it enters a combustion chamber so I would say air pre heater. Let me write it down APH is Air Pre Heater, this one I think we know Economizer, Evaporator and Super heater clear and this gas is coming from somewhere this air is coming from somewhere probably from a compressor etcetera, but we can use it to heat it up further preheating maybe prime 2 stages.

Then finally, last but not the least very very important is seed capture so whereby the seed particles will be captured and sent back very very important because as I said the seed particles are hazardous so we cannot let it be there, we must have some kind of a mechanism to capture and recover the seed particles which typically can be done in inside an electrostatic precipitator like e s p and so finally the exhaust gases that come out are devoid of the seed particles.

So, once again I think the quality of this diagram is bit crude, but I hope as I drew you understood what I was trying to do what we are trying to do here trying to show an application where you have an MHD duct, you have this combustible gases you have combustion taking place in the combustion chamber and you have the combustible gases at very high temperature. We have applied a magnetic field perpendicular to the plane of the paper and the hot ionized gases which are seeded is now moving in the from my left to right in the x direction. And so therefore if I measure the voltage across the y direction I am going to get a DC voltage which I have to use an inverter to convert it to AC alright. So by this time the magneto hydrodynamic flow has already been used to generate electricity. The gas temperature has probably fallen down to around 2000 Kelvin or less and now it is no longer useful for magneto hydrodynamic generation.

So, therefore what we will do is now the gas is going to perform it is normal function as the heat source in a boiler as well as for air preheating and that is what it is done. This is air preheating which is shown by the black line circuit and the green line circuit is the boiler economizer evaporator and super heater. And then this one is coming from the feed water pumps as we know from pump.

So, I am not drawing that a whole circuit I think by this time we all know how a Rankine cycle or a steam turbine cycle looks like. So that is how the combustion gases are used right now for it is normal function. But finally before release to the atmosphere it is extremely important that the seed particles are captured because the seed particles are going to be the especially if it goes to the atmosphere it is going to convert to oxides and hydroxides and which can cause severe air pollution.

So, therefore it is not at all possible to let it go in the environment so the seed particles have to be captured and then they can be sent back for to the MHD duct, so that is what I am showing here again the current produced over here is DC keep that in mind so we need an inverter for conversion to AC and the seeding elements must be captured because otherwise it can cause severe air pollution.

So, the electrostatic precipitator can be a device which can help recover the seed for reuse so that kind of brings us to the end of magneto hydrodynamics. It was a small short module by which where we learnt this we started by looking at how what is magneto hydrodynamics it goes for it is based on Faraday’s laws of electromagnetic radiation by which we if you have an electric sorry if we have a moving conductor and a magnetic field next to each other perpendicular to each other.

Then in the third direction an electric voltage can be can be sensed and this voltage is going to be DC, so the way we are going to do that moving conductor the way we accomplish a moving conductor is by ionizing the hot combustion gases or by ionizing gases because when it is subjected to very high temperature some of the electrons have enough energy to fly out.

But that high temperature is very high, but if you seed that gas with a little bit of caesium or potassium or a metal or alkaline way then what happens is that very low concentrations of seeding also this temperature where it can get ionized is brought down to below 3000 degree centigrade which is the temperature that our modern furnaces can withstand so we said that in the modern furnace the combustion gases can go up to 3000 degrees centigrade. But however, the turbine inlet temperature is restricted to less than 1000 degrees because of metallurgical constraints.

So, therefore what we will do is we will let this combustion gases reach that high temperature and use that ionized gas to generate some additional electricity by using magneto hydrodynamics by using magnet or hydrodynamics or using an MHD generator. So thereafter once the gas has cooled down to below 2000 Kelvin which is where it loses it is ionization potential let us use that gas now which is still hot enough to be used as a heat source for the boiler and for air preheating which is what we showed through that schematic that we drew. It is important to note that the voltage that is generated is DC, so we have to convert it to AC through an inverter and also the seeding particles can be hazardous if let out in the environment so must be captured and reused.

We will end with a small note many people ask that is this waste heat recovery because this we are not radially using a source of waste energy the way that I counter this is my thought again and not necessary that everybody has to agree is look we can go to temperatures of 3000 degrees centigrade or higher given in the modern technologies that we have in furnaces, but somehow we are unable to we are not doing that because of some other constraints somewhere else in this case turbines.

So, we can go and have we can go to 3000, but we are not doing that so that way we are not utilizing a potential source of energy. So, in that sense it is wasted and magneto hydrodynamics shows us a way by which that energy which otherwise we would not have utilized can now be utilized for generation of some additional electricity alright. So, with that parting note we will end this module this so we will end this lecture on magneto hydrodynamics. In the next lecture we will look into some another additional form of or another additional technique of direct conversion of thermal energy to electrical energy which is called thermo ionic generation.

Thank you very much and we will see you in the next class.