Energy Conservation and Waste Heat Recovery
Prof. Anandaroop Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 40
Direct Conservation – Introduction to TEG

Hi good morning and welcome back to the next lecture of Energy Conservation and Waste Heat Recovery. Today what we will do is we will move on to the topic of Direct Conversion Devices. So, let me write that down and then we will see what we mean by that the topic today or actually a cluster of topics that we are going to discuss over the next few lectures deal with Direct Conversion Devices.

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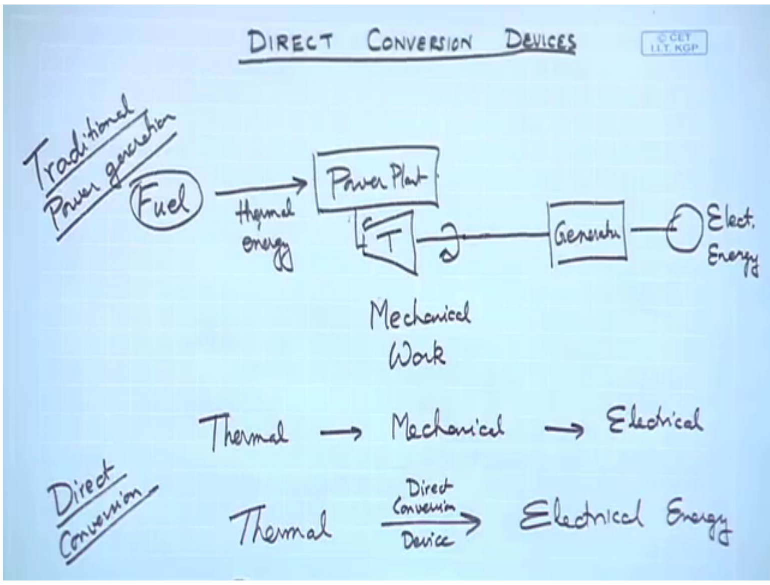

So, what do we mean by this direct conversion devices what is it that we mean by this now imagine in a power plant when we get electricity out of that how do we get electricity in a power plant we have fuel that is burnt. So, let us say this is Fuel then the Fuel when it is burnt gives out thermal energy which then goes to your power plant whereby out of where what we have is a turbine right.

So, we have a turbine here from where we generate mechanical work. So, the power plant we have thermal energy from there we get mechanical work, because of the motion of the rotating motion of the turbine and then this turbine again is connected to a generator whereby we get electrical output or electrical energy right.

So, what are we having we are having Thermal to Mechanical then to Electrical and in the process we are having a lot of equipments you know like boilers turbines etcetera in the in the power plant in this in this conversion from thermal to mechanical and then again we have a generator from mechanical to electrical direct conversion. So, this is what we call traditional power generation right.

So, this is from fuel in direct conversion; however, what we have is we have a source of thermal energy and which is directly converted to electrical energy. So, this is some device. So, this device can be of several types and what we are going to discuss today is one of those. So, what I would say is this is the conversion or let me say direct conversion device right.

So, once again what we mean by direct conversion device is let us say we have a source of heat a source of thermal energy with us for example, some waste heat which is the focus of this course and we want to utilize that waste heat and the energy trapped in that waste heat to generate additional electricity. So, these direct conversion devices offer one means or one type of means by which we can convert the thermal energy directly to electrical energy.

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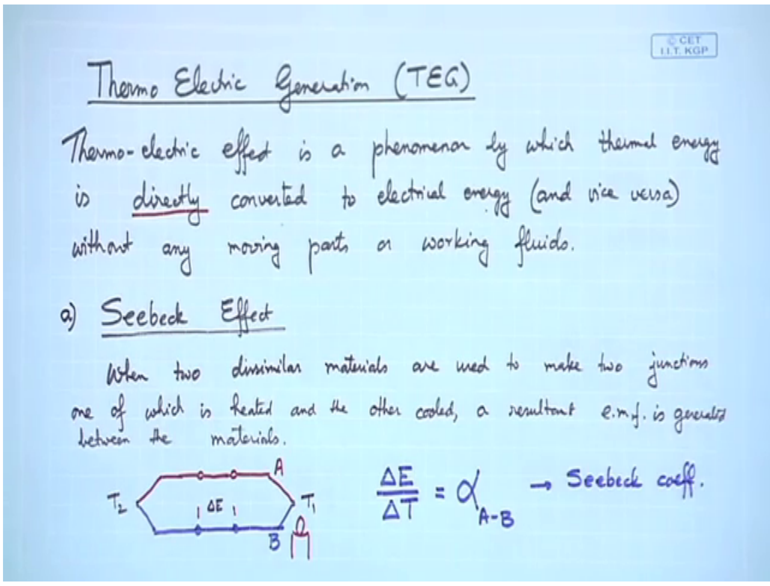

So, what we will do today we will discuss one type of such direct conversion device which is called Thermo Electric Generator. So, today what we will talk about is thermo electric generation also often called TEG. So, this is going to be the focus of our lecture today thermo electric generation, again this is a means by which it is a phenomenon by which thermal energy can be directly converted to electrical energy without any moving parts or working fluids like what we need in a traditional power plant.

So, again let us write it down that thermo electric effect is a phenomenon by which thermal energy is directly converted. So, this directly word is very very crucial here. So, let me underline that directly converted to electrical energy and it can be the opposite way also. So, and vice versa let me write that down even though in this course we are concerned more with converting thermal energy to electrical energy, but thermoelectric can also do the reverse and without any moving parts or working fluids well for that matter when we look at the other types of direct conversion devices the same definition will hold good to a large extent.

So, this is a very generic definition of what a thermoelectric generator can do without going into the details of it is construction.

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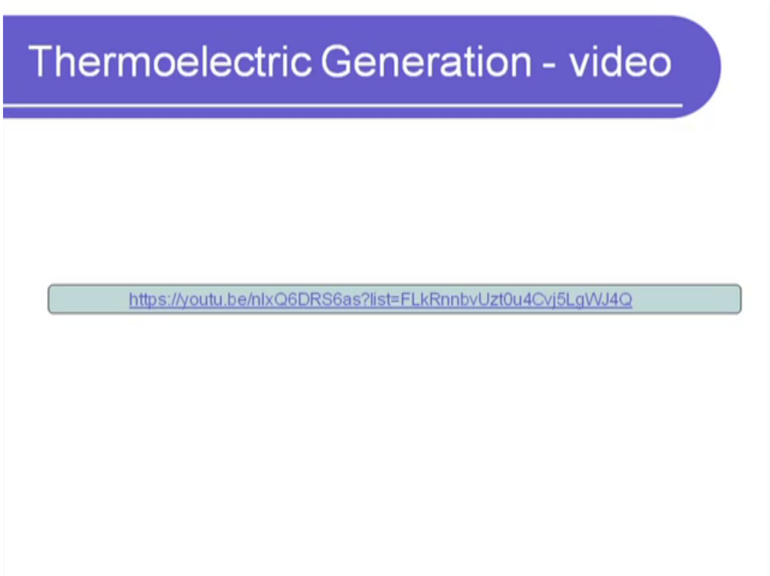

So, to start with what I will do is a teaser, I will play a small video here just to tell you what this is let us at this point not be concerned with what is there inside a thermoelectric generator we will just consider it to be a black box as we will see here and this video shows a small experiment.,

Small experiment.

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So, we have thermoelectric model the solid state device consist in of semi conductors connected by metal parts and send which in between ceramic substrate. It is attached to the electric fan, we put it on the copper base which would be the cold side and it even it is just at the room temperature and now we puts kettle with a hot water on top of the generator, temperature gradients adduce electricity in the model and thus make the fan rotating this sounds like an excellent way to generate electric power there are no move in parts no work in fluids and it is very.

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So, what did we see in this video that we just played, what we saw was there was this device which we are calling the thermoelectric device at this point again let me repeat at this point let us not be concerned as about what is inside the thermoelectric device. The thermoelectric device as we saw came as a thin whatever as a thin square or square piece with what is called ceramic plates on both sides. And in this experiment what was done was there was a temperature gradient that was created across the thermoelectric device, how did we create that on one side there was a pretty big mass of copper and we can assume it to be close to room temperature and an isothermal block and on the other side what the experimental is did was he put some a hot kettle with hot water inside.

So, there was definitely a temperature gradient that was created across this thermoelectric module and then as we saw the module had 2 leads coming out of that which was connected to a fan. So, as soon as the temperature gradient was created we saw that the fan started running. So, what does it mean it means that in a thermoelectric module if we are able to create a temperature difference across the thermoelectric module that is we can generate electricity? So, it almost sounds like it almost sounds like magic right I just had a small innocuous small piece I maintained one end I maintained one end at a higher temperature other end at a lower temperature and I was able to get electric and electrical energy out of it which was used to run a fan in this case.

So, let us see why is this happening what is there inside a thermoelectric device which is leading to this phenomenon. So, to understand that what we will do is we will go back in history a little bit and talk about something which is called Seebeck Effect.

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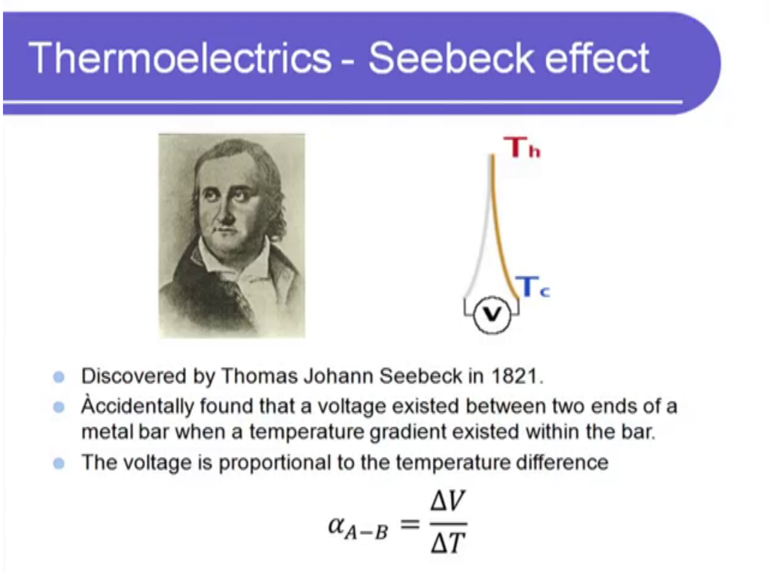

So, Seebeck what he did was many years back Thomas Johann Seebeck almost I would say close to 200 years back what he did was again this many of us do not know he accidentally found this by the way. He accidentally found that if we took a metal bar and if there is a temperature gradient across that metal bar, then he was able to show that there is actually a voltage that existed between the 2 ends of the bar.

So, this is what Seebeck found at the beginning as an accident and he worked on this on this finding a lot and then finally, what we know as a Seebeck effect today is that if 2 dissimilar materials; if you have 2 dissimilar materials that are used to make 2 junctions and one of them is kept at an elevated temperature and the other one is kept at a lower temperature, then you will get or we will get a e.m.f or a voltage across the materials right.

So, again I repeat let me write it down also when 2 dissimilar materials are used to make 2 junctions; if 2 dissimilar materials are used to make 2 junctions one of which is heated and the other cooled a resultant electro motive force or e.m.f is generated between the materials. And the most common application that we as thermal engineers utilize Seebeck effect is while measuring temperature through a thermocouple right it uses Seebeck effect, but let me write this down.

So, let us say I have 2 dissimilar materials and one at temperature T 1, the other at temperature T 2 and let me denote those materials in this fashion one by red color and the other by blue color all right. So, let us say this is material A and this is material B and what we are doing is on one end let us say we are heating it up the other end is maintained at a lower temperature, then what we will see is if you measure a voltage across any 2 points. Let us say these 2 I am going to measure an e.m.f or a voltage which means that there is a current that is flowing through this.

Seebeck also showed that we can write this e.m.f that is created is directly proportional to the temperature difference delta T and the proportionality constant was named as Seebeck coefficient. So, this is the Seebeck coefficient all right. So, the same thing is shown in the slide over here alpha AB which is often denoted often the alpha is used to denote Seebeck coefficient from A to B is the proportionality constant that relates the amount of voltage that we are going to get or the e.m.f that we are going to create due to a temperature difference delta t clear. So, this is Seebeck effect.

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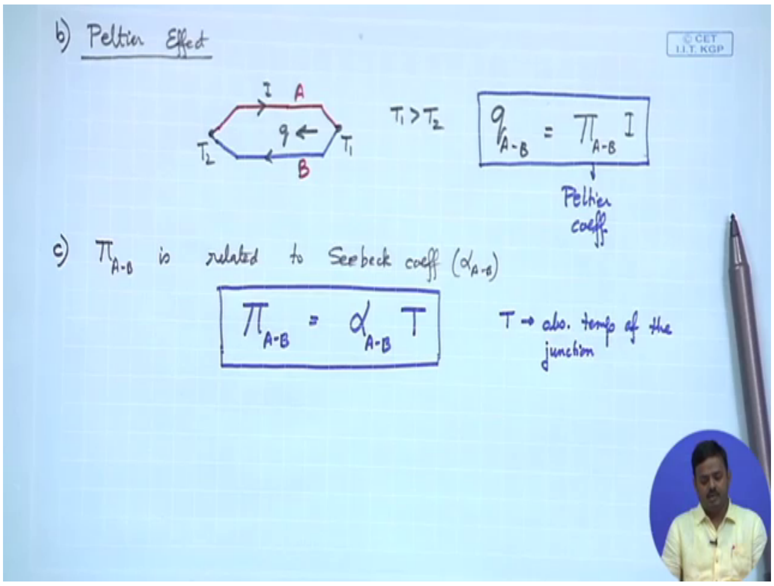

Now, hand in hand what happen was Peltier. So, let us talk about the next thing which is Peltier effect. Peltier effect many a times is said to be just the opposite which means that if a direct current flows through a pair of junctions of dissimilar materials, then a temperature difference is created across the 2 junctions resulting in heat flow, again I repeat that what it means is if you have again 2 2 materials A and B. So, I am going to write it as A going to write it as B and let us say if we now have a current a direct current flowing through this circuit from A to B let me close a circuit join these, then what happens is if a current is flowing through this the same current over here, then what happens is we see that there is a temperature difference that is created across the ends say T 1 and T 2 and let us say T 1 greater than T 2 and as a result of which there is a net flow of heat from the hotter junction to the colder junction.

So, this is the reverse of Seebeck effect again I am not writing it down let me repeat it again that if a direct current flows through a pair of 2 disappear of dissimilar materials, then a temperature difference is created across the 2 ends, across the 2 junctions thereby resulting in heat flow from the hotter junction to the colder junction. So, here we are actually making the current flow and giving rise to a temperature difference whereas, in Seebeck effect the temperature difference was the cause and the e.m.f and therefore, the current flow was the effect.

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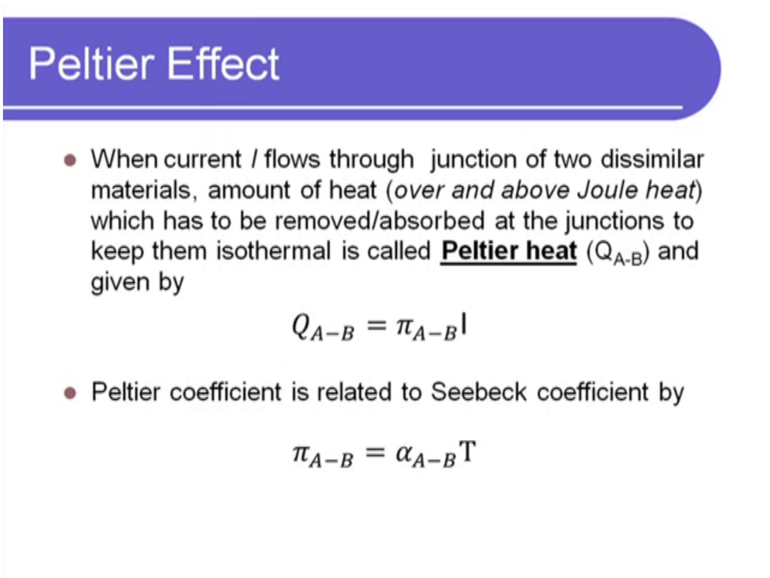

So, this is how Peltier effect is often defined as, but actually what happened was it is a little more involved. The Peltier effect which says that when a current flows through a junction of 2 dissimilar materials, the amount of heat and this is over and above joule heating because whenever you have a current flow you will have joule heating, but there is an amount of heat over and above joule heat, which has to be removed or absorbed at the junctions to keep them at the same temperature at constant temperature and this additional heat which has to be removed which is over and above joule heat is known as

Peltier heat and is given by this expression. So, I will denote it as q of A to B is equal to pi AB times current and here again this pi AB is known as the Peltier coefficient.

So, therefore, on one hand we have a definition of Seebeck effect and the definition of Seebeck coefficient and here we have the definition of a Peltier coefficient, which relates the amount of Peltier heat that is generated due to a current flow across to this across the junctions of dissimilar materials and that relates it to the heat that is generated is related to the current that is flowing through the circuit that is formed because by these 2 dissimilar materials and the 2 are related by the Peltier coefficient clear.

So, now that we know what is Seebeck effect what is Peltier effect the last thing that we just state here without any proof is that Peltier coefficient pi AB let us say is related to Seebeck coefficient; Seebeck coefficient alpha A to B and how is it related it can be shown that it is related in this form pi A to B is equal to alpha A to B times T, times absolute temperature clear and so what is T, T is the absolute temperature of the junction that we are talking about clear.

So, this is how it is related. So, with this background let us move on a little bit and talk about what Seebeck found let us move back again and talk about what Seebeck first found accidentally, he found that when he took a metal bar and maintained a temperature gradient across the 2 ends he was able to measure an e.m.f or a voltage across the 2 ends. So, why does this happen.

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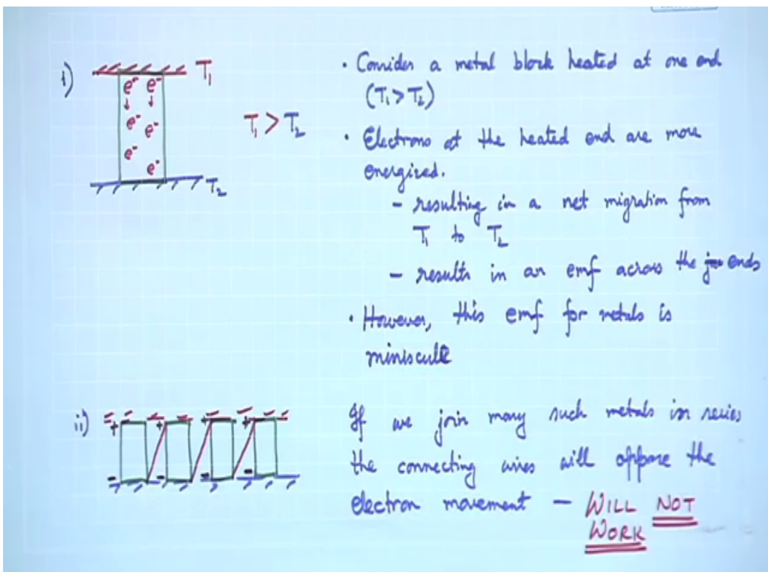

So, now in hindsight at that point it was an accident, but later it was also explained. So, let us consider a metal in this form a metal bar, I am maintaining one end at a temperature T 1 and a maintaining the other end at a temperature T 2 where I know that T 1 is greater than T 2. If this is the case what happens if this is the case what happens is we have electrons right the what are the what are the current carrier so the charge carriers in a metal these are electrons.

So, let us say I have a lot of electrons everywhere. So, the electrons that are close to the hot end get more energized and then they will start vibrating at a more vigorous rate compared to the electrons that are a way right . So, therefore, how does it work is therefore, what happens is the electrons at the higher temperature end are more energized they will they will start vibrating more vigorously and net result is there will be an effective migration of electrons from the hotter end to the colder end.

So, let me write it down. So, when it works is how it works is consider metal block heated at one end. So, which is what T 1 greater than T 2? So, then what happens the electrons at the heated end are more energized clear, why there more energized because they have now higher energy because of the higher temperature. So, result resulting in a net migration from T 1 to T 2 and therefore, results in an e.m.f electro motive flows force across the junctions or ends across the ends let us say , but; however, keep in mind that this delta v or the e.m.f is minuscule.

So, let us write that down also; however, this e.m.f for metals is minuscule. So, the Seebeck coefficient for metals is very very low. So, if that is the case what do we do if we want to have an appreciable e.m.f. So, one may argue that why not take a bunch of these metal blocks and arrange them in series. So, that the voltage is add up fair enough let us see what happens. So, I will take a bunch of these materials. So, let us say. So, this is scenario 1, scenario 2 what is scenario 2 I will have a bunch of these metal blocks let us say 1 2 3 4 let us say 4 4 now and what I will do is I will maintain this end of all of them at a lower temperature and this end of all of them at a higher temperature clear fair enough.

So, therefore, definitely what I will get is I am going to end up with a positive voltage here and a negative voltage here, positive negative positive negative positive negative no questions about that absolutely fine. So, the hotter end will be positive for all these metal blocks and the colder end will be negative for all these blocks. Now the question is how do we connect in series, if you have to connect it in series what we will have what we will have to do is we will have to connect them by conducting wires the negative end to the positive end and so on.

So, let us do this clear. So, if we do this now what happens, we have generated an e.m.f across these metal blocks, but; however, these connecting wires are also metals and because of the temperature difference across them because of the temperature difference across them, they are also going to give rise to a potential difference and that e.m.f that delta e or e.m.f or potential difference that is created will be opposite to the direction of the e.m.f that we are generated in these metal blocks. So, they are going to oppose. So, therefore, this arrangement will not work.

So, let us write it down. So, if we join many such metals in series if we join many such metal blocks in series, the one that we saw over here then what will happen is the problem is the connecting wires will oppose the electron movement. So, the electrons instead of going from here to here will actually tend to come in the in the metal wire or the connecting wire will tend to migrate from the hotter end to the colder end there by opposing the emf that is generated in the metal blocks . So, therefore, this is not going to work. So, let us say let us write down so will not work.

So, we need to think of some other means not just electrons in metal blocks, but something else that we have to use as carriers if we have to use the thermoelectric effect for generating electricity. So, that is what we are going to cover in the next lecture. So, let us end here by. So, today what we covered is we started with a small video of what thermoelectric effect is well before that we talked about what is the direct conversion device, then in the thermoelectric effect we saw a small video where a thermoelectric generator was able to conduct which was able to generate electricity simply by maintaining a temperature difference across it is ends.

So, we saw that it was almost magic and then we said why is it happening let us look into that and that is what we are doing now we talked about Seebeck effect, we talked about Peltier effect and in the next class we will continue our discussions on this so.

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