Energy Conservation and Waste Heat Recovery
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Lecture – 07
Thermodynamic principles of waste heat recovery (Contd.)

Hello everyone, so in the last lecture, I have just started explaining second law. And we will proceed with that and we will see how the principles of second law that can be applied for waste heat recovery systems. And we can get different implication of second law or rather we can have a better design of a state recovery system applying second law.

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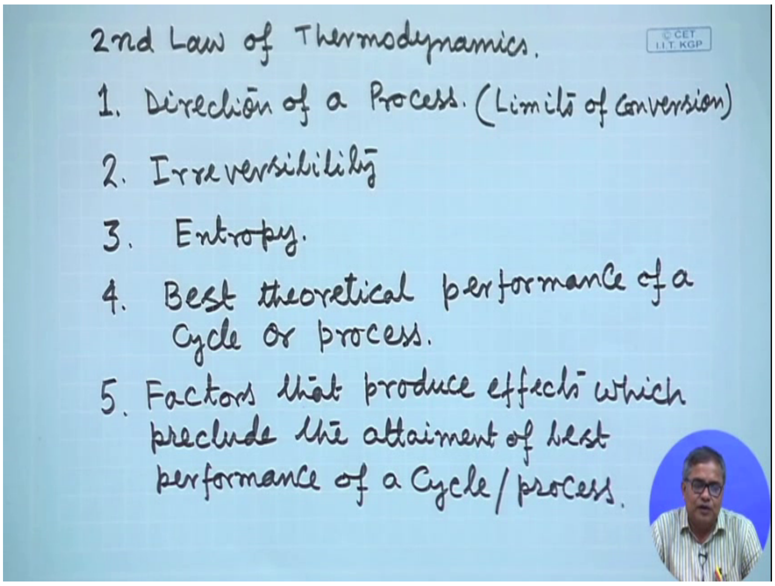

Now, I was discussing the main attributes of second law. What is told by second law, what important information given by second law? First thing I have told it gives us the direction of a process, and it gives us the limits of conversion how one form of energy in transit can be converted into another form. Then it gives us the concept of irreversibility, it also gives us the concept of entropy. Entropy is a very unique property. Again most of you are familiar with the term entropy. And what it is, but for the sake of continuity, we will discuss little bit regarding entropy. And second law makes us aware of regarding our makes us aware regarding this unique property of a system which is so very important for any energy conversion process.

Fourth, it gives or it helps us to analyze the best theoretical performance of a cycle or process. What could be the best theoretical performance limit of a cycle, and process that can be analyzed by second law. Then it also gives factors that produce effects which preclude the attainment of best performance of a cycle or process. So, 4 and 5 - these two these two points is to be taken together. So, second law of thermodynamics not only gives us what could be the best performance of a cycle or a process, it also helps us identifying the factors which will act as impediment, which will act as obstacle resistance for attaining this best performance.

So, once you know what are the factors which is not allowing you to have the best performance out of a cycle or a process then obviously you will try or an engineer will try to remove this. In some cases, it will be possible with the technological infrastructure we are having with the technological knowledge we are having to remove this obstacle. In some in other cases it may not be possible, but at least we know what is the best possible and we try to go close to that best possible performance of the system or the cycle. So, this is very important.

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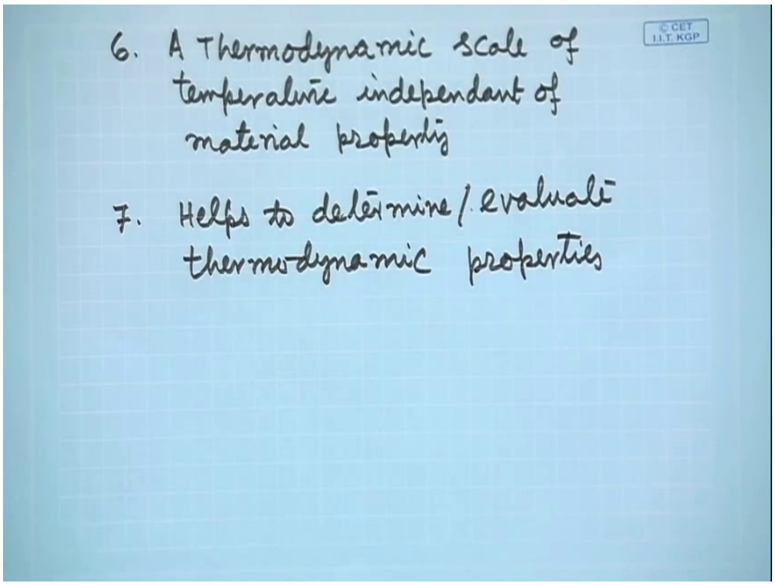

Then other points what we get, this is a corollary, but again it has got great importance. It gives us a thermodynamic scale of temperature independent of material property. This thermodynamic scale of temperature, it is the absolute scale of temperature; it is of utmost importance in engineering practice in determining the efficiency of a cycle etcetera. Then next point this is again a corollary, it also helps us helps to determine or evaluate thermodynamic properties. So, basically we will get certain property law using both first law and second law of thermodynamics. And with those property law, we can determine other thermodynamic properties, so that is also one contribution of second law of thermodynamics.

So, with this we can see that second law gives us or contributes quite a few aspects which are utterly important utmost which are of utmost importance in the case of energy conversion and obviously, waste heat recovery is energy conversion process, and we have to see how this can be applied to waste heat recovery process. But before that let me formally tell, I am not going to write it is available in any book of thermodynamics, but for the sake of continuity let me state the usual statements of second law of thermodynamics particularly for engineering practice.

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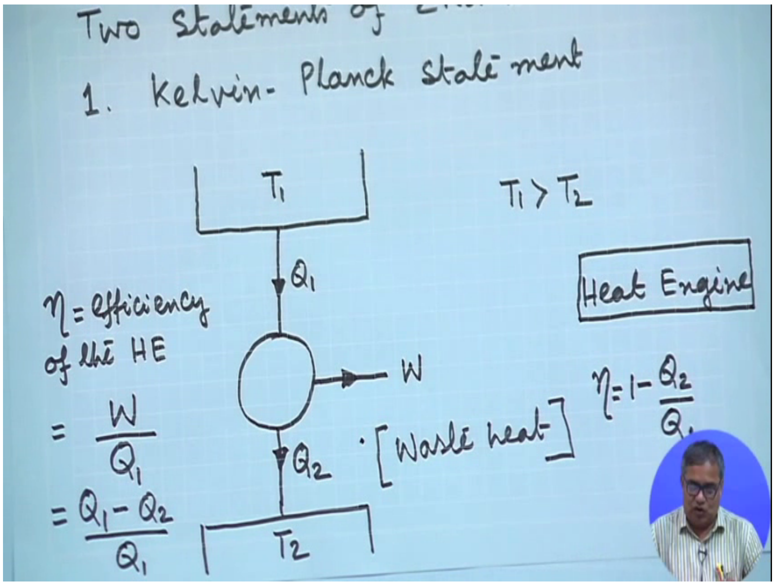

So, there are two statements. Again this is known to most of the participants who are attending the subject, but for the sake of continuity it is needed. And again for those who are coming from other discipline, it is better to have some sort of a recapitulation some sort of a re explanation of these laws and principles so that they can appreciate or rather we can appreciate the later portion of this course. Where time and again these laws will be applied for waste heat recovery system. So, two statements of second law first is Kelvin-Planck statement. So, what does Kelvin-Planck statement convey to us this statement is like this. It is impossible to construct a device, which will operate in a cycle and will produce net amount of work while exchanging energy with a single reservoir or a single body.

So, let us consider one engineering application and from that engineering application let us try to understand the implication of Kelvin-Planck statement. In the conversion of energy, it is very important because this is very common that what we do we burn fuel, burning the fuel we get thermal energy and with that thermal energy we create mechanical energy or work. So, this is one conversion. So, let us say we are thinking of a conversion like this we have got a thermal reservoir, where the reservoir is maintained at a particular temperature T 1. So, this is the identity of the reservoir the temperature T 1 that is the identity of reservoir. And we have got a device which is operating in a cycle the circle which I have drawn that indicates a device which is operating in a cycle.

So, this device which is operating in a cycle it is taking some Q 1 amount of heat from the reservoir. And let us say we try to convert this into mechanical energy or work. So, we are producing W amount of work. Now, from first law, this is possible or rather at first law does not it is not getting violated by what I have drawn by what I have proposed that I will take Q 1 amount of heat from the reservoir and we will convert whole of it into useful work or into mechanical work. So, I am not violating first law of thermodynamics.

But second law of thermodynamics says that it is not possible if I am operating a cycle; that means, if I am continuously producing work. So, it will not be possible that I will take some amount of heat and convert whole up it into work. When I am working or when I am operating a cycle or continuously producing work out of heat or out of thermal energy. Then what is possible, it is possible to produce continuous work if I reject certain amount of heat and if I have to reject certain amount of heat, there would be another body to take that heat the that second body that will also be identified by its temperature. So, this is the second reservoir which is at a temperature T 2 and T 1 should be greater than T 2. So, there can be flow of heat. While the flow of heat is there from T 1 to T 2 only part of the thermal energy, which is flowing that can be converted into work.

So, you see the whole of thermal energy we cannot convert into work, only a part of it can be converted into work, and rest of head should be dumped to a low temperature body or low temperature reservoir. Many a times the high temperature reservoir is called a source and the low temperature reservoir is called a sink. So, this is possible, by Kelvin-Planck statement this is possible. And if we think we will find that our day-to-day experience, our common experience also says that.

Let us think of a thermal power plant. A fossil fuel operated thermal power plant where steam is the working medium or working substance. So, in a steam power plant what do we find. So, coal is burned, thermal energy is produced. So, we can think of we can idealize it that as if it is a reservoir with a constant temperature. So, then with the help of that heat or that that high temperature water will be converted into steam, the steam will be meant to pass through a turbine, the turbine will rotate and produce mechanical energy. Then the steam which is at low pressure and low temperature will come out of the turbine and we will condense heat, when we are condensing heat, what we are doing we are rejecting heat to the atmosphere.

So, heat is taken from a high temperature source which is nothing but the burning of the fuel and heat is being rejected to a low temperature sink which is nothing but our environment. And in between when heat is flowing from high temperature to low temperature, we are producing certain amount of work. And here you see the concept of waste heat is also coming. So, what is waste heat? The heat which we are dumping to the environment that is your waste heat. So, in connection with the present course whatever has been told in Kelvin-Planck statement, we have to have that, but at the same time we can here in this particular case we can identify which is waste heat. So, Q 2 which is called heat rejected. So, this also we can term as waste heat.

Of course, there is a question that how much of it really qualifies at waste heat; that means, whether we can convert certain part of heat into again some useful purpose or not. If that is possible really that part of Q 2 which can be converted into certain amount of useful I mean that which can be converted into some sort of useful energy either in the form of mechanical energy or in the form of thermal energy, so then we will have part of it recovered and that is your waste heat recovery. Here we have to keep it in mind that whole of heat cannot be converted into useful energy, because that then that is becoming or that is amounting to violation of second law. As first law cannot be violated and the principle of energy conservation cannot be violated, second law also cannot be violated. So, definitely certain amount of heat has to be dumped to the low temperature sink, which is nothing but the environment here. But in many of the cases part of it can be recovered and that is your waste heat recovery that is all about the present course.

So, another important thing we another important aspect we get, so here we get a device which is operating in a cycle taking thermal energy from a high temperature source and dumping part of heat into a low temperature sink and converting the rest of heat into useful work. So, this device is called a heat engine. So, here we get the concept of a very useful engineering device which is known as heat engine. And the cycle in which it offers operates that is called a heat engine cycle or a power cycle, because it is generating work or power. Well, here again we can define some other thing you see the energy which we are getting from a high temperature source, generally for which we have to pay that is equal to Q 1 unfortunately whole of Q 1 cannot be converted into W the useful work which we desired to do part of heat only can be converted to W. So, here we can define another thing which is efficiency of the heat engine.

So, let me define it eta that is efficiency of the HE that is heat engine that is equal to whatever we get divided by whatever we have paid for we are getting w why we are paying for Q 1. So, it is W by Q 1 from first law we can write it is Q 1 minus Q 2 by Q 1 or efficiency we can write as 1 minus Q 2 by Q 1. So, again we get one perspective of waste heat recovery. We want to increase the efficiency of this device, if we can reduce Q 2 so obviously, that is a desirable situation. Now, this Q 2, which is rejected to the ambient which is dumped to the earth ambient probably by adopting certain waste heat recovery principle this Q 2 can be reduced, so that has got a direct implication we can increase efficiency. So, well we will see how we can have reduction of Q 2, what are the different options available for reducing Q 2.

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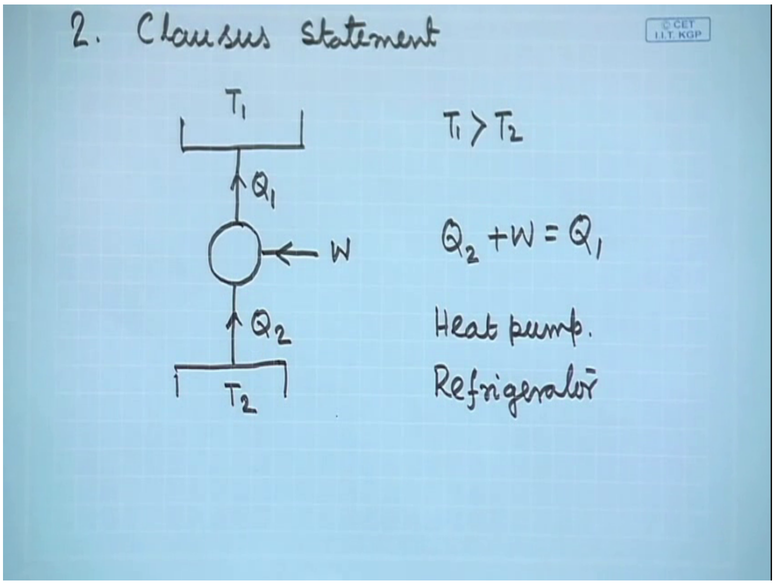

Then let us go to the second statement of second law of thermodynamics. First statement is Kelvin-Planck statement, second statement is known as Clausius statement. So, this statement was given by Clausius. And this statement goes like this it is impossible to create a device which will operate in a cycle and we will produce no effect other than transferring heat from a low temperature body to a high temperature body.

So, again let me state or let me tell Clausius statement, it is impossible to design a system which will operate in a cycle and will produce no effect other than transferring heat from a low temperature body to a high temperature body. So, what is told by Clausius statement let say there are two bodies; one body is at temperature T 1 and another body is at temperature T 2. And we cannot have a device, which we will take thermal energy from the low temperature body where T 1 is greater than T 2 and transfer it to a high temperature body.

Though by first law this is not impossible first law does not put any barrier to this because first law only says regarding the conservation of energy. As long as the heat which we take the thermal energy which we take from the low temperature body the same amount of thermal energy we dump to the high temperature body we give to the high temperature body, this is not violating first law of thermodynamics. But second law of thermodynamics says that it is not possible that means, the flow of heat from a low temperature body to a high temperature body continuous flow of thermal energy from a low temperature body to a high temperature body is not possible.

Again I have told that second law gives the direction of processes. So, it is also giving a direction of process. We know heat can easily transfer from a high temperature body to a low temperature body, so that is the preferred direction of the heat transfer process. But the reverse of it is not possible is difficult to achieve it is achievable, but by some other means that transfer of heat from a low temperature body to a high temperature body it is not naturally achievable, we have to do something to achieve it.

So, what we have to do, we have to give some energy or work from outside. So, if we do that then what we will get that we are taking Q 2 amount of heat from a low temperature body with the help of work that is W, we are pumping in total Q 1 amount of energy to the high temperature body which is at T 1. Now, this configuration it neither violates first law because we know from energy balance Q 2 plus W is equal to Q 1. So, energy conservation principle is satisfied. And is it is also satisfying Clausius statement of second law of thermodynamics that heat cannot automatically flow continuously from a low temperature body to a high temperature body. We have to have some assisting device for this kind of flow and as assisting device we are having the what supply from outside. So, this is again another important device, another important engineering device. In fact, it talks about two important engineering device, so these engineering devices are called heat pump and refrigerator.

So, a refrigerator creates low temperature. So, what we can do what we can see from this example that we are taking heat from a low temperature body which is at T 2. So, it is helping us to maintain that low temperature. So, basically then it is helping I mean the device which I have drawn that is showing a refrigerator where by putting external energy I am continuously extracting heat from a low temperature body. So, this acts as a refrigerator. And when I am calling it a refrigerator, my focus is at the low temperature body and at the heat or thermal energy which I am extracting from the low temperature body.

But at the same time I can have a different outlook also. So, this can also be called a heat pump, because as by a pump we pump water from a low level to a high level. Here also by this device and providing certain amount of energy input in the form of work from outside, I am pumping heat from a low temperature body to a high temperature body; from T 2 to T 1 I am pumping heat. So, this is also called a heat pump and in that case our focus is the high temperature end of this example; that means, our focus is at T 1 and the heat supplied to it that is Q 1. So, this is Clausius statement as Kelvin-Planck statement gave us a very important engineering device called heat engine, here also we are getting an important engineering device. Depending on my choice my preference of working of this device, I can it either a refrigerator or a heat pump. So, I will start from this point in the next lecture.