Engineering Thermodynamics
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Week-05
Lecture-24
Second Law of Thermodynamics

Namaskar! Welcome to our channel. In this lecture, we will start a new topic on 2nd law of thermodynamics. In this lecture, we will introduce the second law of thermodynamics. thermal energy reservoir and heat engine. We will try to understand that, and we will discuss the statement given by the Kelvin Plank on the Second Law of Thermodynamics. Let's start You must have noticed that the process of many processes. You must have noticed that there are many processes which are usually done in one direction only. Especially when water goes down slowly from the top. But it is difficult to go up from the bottom. It is not a natural process. You have to apply external force. Similarly, you will also feel that if you are a mug of hot coffee, we keep it in the room and the room temperature usually decreases with coffee with the temperature So the heat will go out of the coffee. The energy of the coffee will slowly go through the boundary and go into the surrounding. So, the transfer, the direction of this process, the heat transfer as we call it, is from hot temperature to cold temperature. So, a cup of hot coffee in a cold room is not too hot. you know that. So, the direction of the process is fixed in this. If you take another example, if you take an electrical circuit and the current flows through it, then it will generate heat. But if you put heat on this electrical wire through any medium, then it is not that it will give you electrical current. So here also a process has happened. Here also a direction of that process has happened. Like we were talking about direction here. So here also a direction. By transferring heat in any wire, electricity will not be produced. You know this. Naturally you see this. You feel it. But you connect this with the direction of the process. That this process also has a direction. Take another example. Here is a shaft that rotates. If we put weight here, if it rotates, If it rotates more, The heat will develop here. But it is not that if I put heat here, it will start rotating automatically. It means that there is a direction in this also. that it will not move by transferring heat to the wheel of the footwear. So, there is a direction in this. So, there is a process of the process. Now we will talk about how to connect this to the first law and the second law. In these three examples, your first law is valid. If I put heat, then it is not that the first law will violate, the heat is transferred. Now, it is different that this electrical energy is not converted. But it is not that it will violate the first law. So, you can apply the first law in this. But you can't guarantee that this process will happen. So, all these processes satisfy the first law. Although this process does not ensure that it will happen. So, there is no guarantee that your process will be successful. This is what it means. So, how to say that there is a guarantee? For that, we have the second law. So, we will discuss about it So, now we understand that any process moves forward in a certain direction, not in the opposite direction. So, this is an important message. And the first law does not impose any restrictions on the direction of the process. And by satisfying the first law, it is not ensured that the process can actually take place.

So, we have given three examples. This should be clear. So, whether any process can be reduced or not, its direction is given through a second law in thermodynamics. We convince it with a second law that this direction is possible, this process is possible. If you reverse that direction, it violates the second law. So, second law is important because it is on the one side of the process. If your wallet it, it will not be in the process. For example, your heat transfer from high temperature to low temperature will be on the same side. This is the direction of its process. If the electric current flows in the current, then the heat will be generated. But it will not be the opposite, that if we put heat, then the electric current will come. So, this is not possible. So, this is valid for the first law, but it will be the opposite for the second law, in which you are putting heat and electric current will come. So, this kind of process will only happen when the first and second law is satisfied. This is a very important message. You should understand this. Like any process, this should also be right, this should also be satisfied, and this should also be right.

Now the question arises, what is this second law? To understand this, we have to understand the heat engine. Which is the engine of the Ushma, as it is called. In Hindi, it is called heat engine. The devices that we use in our home like refrigerator, fridge, car, steam plant, etc. All have the same engine representation. Engine does not always mean that it is according to the engine of your car. Engine means that there are many types of devices in it that are connected in a way and how they are working. After that we will discuss. So, let's understand this now. But before that discussion, we will see two definitions, or we will define two things One is called source and the other is called sink That is the thermal energy source and Thermal energy sink So these two are thermal reservoirs. It is a symbol of the energy. It means that this body is very large. Like your atmosphere, sea, river, lake etc. The thermal energy capacity of these, as we had studied earlier, is heat capacity. If you multiply it in mass, then you get the thermal energy capacity. So, this is so much that if you take out energy from it, then also it does not matter the temperature. It does not matter the condition. So, this kind of thermal reservoir can be of two types. From where the heat can be taken out. and second is where you can easily transfer heat, so one is your source from where you are taking out the energy and second is the sink from where the energy is going back so what is the Thermal Reservoir? This is the body, a carbonic body with high thermal energy capacity which can perform a heat-resistant operation without any changes in the temperature. So, this is the statement that the hypothetical body has a large thermal energy capacity from which it can supply heat or absorb heat without any change in its temperature. So, this is your thermal reservoir. And you can understand it in two ways. One is the source, and the other is the sink.

In the next lectures, we will use the same way thermal energy source or thermal energy sink or source or sink and we will use thermal reservoir. We will not sayenergy. Try to understand this. Now, one more thing that comes to mind is that another question arises in this that as we said, large thermal energy capacity means a body with a large thermal energy capacity this does not mean that your body will grow large like you have taken the ocean, it is not necessary that you will always take the sea for this such a body, such a subject, such a body Suppose you have a metal body with a large energy capacity. It is not important to have a large body. It is important to understand that we are talking about a large energy capacity. not too much in volume Let's move forward. Now, one more thing you should understand is that there is a very good and interesting relation between work and heat transfer. If you take a paddle, it has become a shaft, suppose it is rotating, then naturally if you rotate it, if it is in water, then the heat of the water will increase slowly. The temperature will increase, heat will transfer in the water. Because you are generating heat. So, the heat is transferred from the work. And if the container is like this, then the heat will also be transferred outside. So, it means that the heat can be transferred very easily from the work. Because you worked, the temperature of the molecule increased gradually and that means the temperature of the molecule increased T is more than the surrounding T of water is more Now because the surrounding temperature is less and the temperature of the water inside has increased So from here, heat transfer is done Because let's assume that it is not adiabatic This wall can be transferred energy If it is not insulated then heat transfer. So, it means that work can be converted into heat. As you may remember, we have already talked about this. Heat and work are always a boundary event. Until there is a boundary, we cannot identify it. So, since energy will be transferred, it will be in the form of heat. That is why we say that work is transferred into heat.

Now, take another example. You may think that we have put heat in the system, so it should rotate on its own, but it doesn't work. Here, there is no heat transfer, no rotation work. That's why we say that work can always be converted to heat directly and completely, but the reverse is not true. It means that your work can always be converted directly to heat, but the opposite is not true. So, you can understand the direction of this Now if we want to convert work from heat, then what should we do? How to do it? And here comes your heat engine That means if we want to convert work from heat, then we need a special device Which we call heat engine Now the heat engine is an engine in which many small devices will be connected Overall, we will call it a big heat engine. What does this heat engine do? So, like we made a ball, there will be many devices for it, which we will discuss later. But it's not like this is a simple box, it must have much equipment inside it. and it will be connected later. But what is the purpose of this heat engine? Because we said that converting work from heat is very important. And this is very important, as your engine runs, whether it is your car engine, still your heat comes out because you burn the fuel, you burn it, and the fire comes out from there or the energy comes out, so the rest of your work is done from there. So now to understand this, we will take the example again that we take a thermal reservoir, which is high temperature. which is working like a source from where we will extract energy and this is given by heat engine and this is called network so this heat engine's work is given by network and some part of the energy of the q-in has to be left behind and that is the low temperature sink which is your thermal reservoir but its temperature is low the upper one is high temperature and this one is low temperature you can understand it like this suppose this is a furnace from where your fire has been burnt where your temperature rises and this is your environment i.e. the atmosphere outside now you understand so this is a kind of a representation of a heat engine you try to understand this so in summary this heat takes Q in from high temperature reservoir and some part of it converts to work It goes through the low temperature sink. And the special thing is that it works on the cycle. It is continuously working. That's why we are showing this circle that it works on the cycle. Cycle means this way. So, this is one important thing that is it a thermodynamic cycle or a mechanical cycle? We will discuss this later. So one important thing is that there will be many small devices in the heat engine and there will be a fluid in the heat engine which works For example, you can understand it as In the car, like in the automobile, the gasoline or petrol there that is your fluid So what is being used continuously or what is being used continuously and mechanically completes a cycle. So, the heat engine that uses the fluid in this cycle, which is exercising through the cycle, we call it working fluid. your steam engine has water, your automobile industry has petrol, diesel etc. Heat engines are not just one type of engine, there are many types of engines. Like gas turbine, car engine, internal combustion engine, etc. They follow mechanical cycles and not thermodynamic cycles. We will discuss about this later. We will try to understand from the examples that the cycle is not a thermodynamic cycle. But mechanically it is not a thermodynamic cycle. Mechanical cycle does not mean that it is a thermodynamic cycle. We will discuss that later.

So, steam power plant is also a heat engine. Let's take an example of what happens in this steam power plant. This is your heat engine. If we use a circle and a square, this is your heat engine. This is your Win and Wout. There are four devices used in this. Wout is connected to the turbine. and Win is connected to the pump. It means that if there is a liquid in the pump, then you worked in the pump, and increased the pressure. After increasing the pressure, you took the fluid to the boiler. It is heating up at constant pressure in the boiler. The fluid is heating up at constant pressure and the temperature is increasing. But the heat comes from the furnace. Finally, the high temperature comes out and expands in the turbine. When it expands, the shaft works, which comes out. And this will go to the generator. And the rest of the low-pressure fluid comes back here. Condensed with the condenser. And when it is condensed, vapor phase condenses and releases some energy which goes into the sink which is atmosphere. So, this is a complete cycle. This is your schematic power plant. Please note that Q in is coming from the furnace like energy source. This is high temperature reservoir. So, all these values are given in a positive direction. So, this is a positive value. W in is going to the pump, W out is coming out of the turbine. So, this is a kind of a heat engine. Let's move forward. If you simply balance it, note that W net out will be Wout minus Win. So if we simplify this, it is done like this This is your heat engine From here your Qin Finally we are saying that Because we can connect Win and Wout We say that this whole thing is Wnet out And something went in our Qout So this is a small version of your heat engine In which we hid the rest of the devices So the same thing is shown here This is your Netout and because the energy will be balanced so if you balance the whole square considering the system so note how you can do this because your E in minus E out will become zero because it will be in a steady state it is continuously running in the cycle You can write e in and e out later as well. Qin plus Win is equal to Qout plus Wout so if you rearrange this then you will get Wout minus Win is equal to Qin minus Qout and this is Wnetout so Wnet out will be Qin minus Qout So this is a simple concept of your heat engine. Now let's understand it further. What we have come to understand is that Win minus Wnetout equal to Qin minus Qout. This is less than Qin. I got it.

This expression also tells us that some fraction heat that we have taken from the furnace we have to lose some part of it. We have to put it in the sink. This means that some part of Qin is converted into work. That's why this is given as equal to. The ideal would be if this was the case, then this would be very If Qout was 0, then it would have been more work. But it does not work. Because you will understand this in the next video. That Qout cannot be 0. So, some part of the Q-in is converted to W network. So, in the energy engine, only a part of the energy can be converted. Now, let's try to understand this more. That's why we say that if we can convert only a part, then it means that the heat engine will have different performances. To measure that performance, we define thermal efficiency. Which is called Tapia power. We are using thermal power. And this is the definition of the power. Total network that we have done. That is our interest. That is divided by total heat input. Total heat input is Qin. So, W net out divided by Qin. So, engine power or thermal efficiency we can write it like this Now let's understand why this is important. Now there are two types of engines here, 1 and 2. And the source is the same. Both the engines are 100 kJ Qin. Both the engines are extracting 100 kJ. But the first engine is only 20 kJ is its network output. And the second is 30 kJ work output. and the difference is that the internal devices in the engine will not be efficient and the other loss is that 80 kJ is left in the sink and in the other case it is 70 kJ so if you ask the borage of this, then tell me how much is the thermal efficiency of the first one and how much is the power of the second one So you will take out eta from here. Here you know that it is 20 kJ divided by 100. So, this is 20% of one. And in the second case, this is 30 divided by 100. Why 100? Because it is 100 kJ. Which is the initial input of energy. So, this is 30%. So, this is how you can get the efficiency of the engine. This is an example of a heat engine that takes energy at a rate of 80 MW. And so much heat is wasted. So how much will be the net power output of this? and how much is the thermal efficiency? So, net power output means As I know, we have already done Qin minus Qout So Wnet is out Qin-Qout So this is 80 minus 50 Now we have to calculate the thermal efficiency of this heat engine. So this is the heat engine. It is also called ETA Th. Th means it is from the Thermal efficiency. So, this is done. Netout divided by Qh because Qh is your Q in H means high temperature, L means low temperature, So this is 30 divided by 80 So this is 0.375% is 37.5% Okay Let's move ahead. These are all cyclic devices. Like the heat engine. Similarly, there are refrigerators and heat pumps which we will read in the next lecture. This works between high temperature reservoir and low temperature reservoir. Now I understand. We can use Qh and Qin You can use Ql or Qout. But in some books, it is written that when H is present, it is Th. That the reservoir is a high temperature reservoir. The temperature on TH is static. It is the same. Because when the reservoir is being transferred, the temperature does not change. Its body is so big. It has a heat capacity. and this is low temperature reservoir where temperature is TL so we have discussed about these values QH, QL because we have given direction that it is coming from here to here so all of you will be positive and we have already discussed about this we have discussed about this so this value of eta of course it is seen that this will be less than one eta value because the definition But what is the range of it? What is the typical range of it? If you talk about the Spark Ignited Automobile engine, which is the typical engine in which the petrol is used and the engine is used by the spark, what is the efficiency of the engine? Which converts the chemical energy into mechanical work. That is approximately 25% of the engine capacity. Of course, new engines are coming and getting more efficient. And the diesel engine capacity is around 0.4. And the same gas-steam turbine is around 0.6. So, this is usually a range you must have understood about this. Now the question that should come to your mind is that if you want to increase the efficiency of QL, then what should you do? If you want to increase the efficiency, then the first thing is that if this QL keeps decreasing, then the efficiency will keep increasing. Or if your QH is too much, then the efficiency will keep increasing. So, this is your one. So, the question is, can you do this? Can you do this? Can we save QL, Q So to understand this, we take the same steam engine that the loss that we are throwing, wasting energy, that comes out in the condenser. So, the question that arises is, can we remove the condenser? Can we remove the condenser from the system and run it in the cycle? So that we can save all the energy that is being wasted. So this question arises. It means that your device is at Th from high temperature thermal and this is your heat engine and this QH is directly connected to W network Is this possible? This question arises So to understand this, let's take an example This is gas, there is a load on the gas. And this is a piston cylinder. Here the heat is taken from a reservoir, which is a high temperature reservoir. 100 kJ heat is taken from here. And this reservoir is 100 degrees. And in this 100 kJ, 15 kJ is used to lift the load. And the remaining 85 kJ is used to increase the temperature of the gas. 30°C to 90°C. So, this means that the internal energy has increased. We will call it as internal energy. So, the question is, if we want to cycle it, we have to bring it back to the same state in which we started. So how can we do that? We removed the load of 15 kg from here. But the rest 85 kg, sorry 85 kilojoules, how can we remove that? How can we take 85 kilojoules back from here? So how can we take this heat transfer? Because it is at 90 degrees Celsius, and this is at 100 degrees

Celsius and we were talking about direction that this direction of any process so from low temperature to high temperature the heat will not be able to flow or how will the energy flow? So, this is not possible because the heat transfer is only of low temperature from the high temperature. As we have written here. So, similarly, it is not possible that the energy that we had used to mix the 30°C and 90°C of the gas can be transferred to the temperature of 90°C and transferred to the temperature of 100°C. So, this is not possible. But this is possible. to bring So the first thing is that you have to remove the heat loss and the second thing is that it will be at a low temperature. So, one reservoir will not work. You have to have two reservoirs. One is high temperature, and one is low temperature. So now the question is, can you remove the condenser? Can you bring this condition? The answer is no. You need a low temperature sink. This is necessary. It has to be done. You can't remove it. You have to keep the condenser. to make the heat to be rigid because the cycle has to be completed without the cycle, the engine will not be able to work the work will not be done you continuously means that you are continuously working in steady state, and you are transferring heat to the work so to do that you need condenser to. In summary, each heat engine has to be transferred to a low temperature sink to complete the cycle in ideal conditions. This is your statement of Kelvin Plank expression. So, this statement is the basis of the Kelvin-Plank expression. Finally, it was impossible for any device to operate on a cycle to receive heat from a single reservoir and produce a net amount of work. Any device that works on a cycle can't work with one reservoir. It's impossible. For that you have to have two. So, it is said that any cycling device can't work with one reservoir and take heat and network the whole network. The capacity of any heat engine cannot be 100% Even if it is not ideal There is no friction or anything like that, So it is very important to understand this, So this system violates the second law And this is your second law That you need a source, a scene This is necessary to operate the cycle. If you don't have it, then the cycle cannot operate. So, if you want to make a heat engine, then one reservoir will not work. So, this is your basic concept that no engine can be 100% efficient in the power plant. And the working fluid, whether you take water or any other fluid, will exchange heat. environment So let's hope that I was right in explaining it to you. Now we will read about the process statement and then we will move on to the concept. Till then, I take your leave and see you in the next lecture.