Engineering Thermodynamics

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Week-05
Lecture-25
Second Law of Thermodynamics

Welcome to the part 2 of 2nd law of Thermodynamics. In this lecture, we will discuss about refrigerators and heat pumps. And then we will discuss about the clauses statement of 2nd law of thermodynamics. It is related to the Kelvin-Plying statement. We will talk about it in one way but in different ways. We will discuss about thermal efficiency and coefficient performance which is used to extract heat from heat pumps and refrigerators. Let's understand the principle of refrigerator and how it works and what different devices it uses. So, this is a schematic diagram of the motor which represents how the refrigerator works. Of course, like in other heat engines, we used some fluid or in steam engines also we will use fluid. There is also a fluid in this which runs through the cycle. This is what we call working fluid. Usually, this refrigerator is called fluid. and it is a fluorine based. Of course, nowadays it has become important that with environmental concerns, the way it damages ozone layer, this type of fluorocarbon-based fluid has become a goal to change it. research groups and countries are interested in the alternative of these refrigerated fruits. But this is not the topic of this lecture. In this lecture, we will try to understand the principle of how to get the power of any system. This is your cycle The main purpose is that if you are interested in refrigerator then this will be your refrigerator space which you will want to keep between 5-5 degrees If you want to maintain that space then you will have to remove this much heat regularly You will remove some heat and start the temperature is maintained so the heat goes here and this fluid when goes into the evaporator unit so with this heat here this saturated liquid will be there and we will get sufficient heat to make it a saturated vapor Once saturated vapor is done, you notice that the temperature is fixed and the pressure is fixed. So, this is a saturated liquid phase, liquid vapor region. Here the fluid moves forward and here we use compression is that we apply the work on this particular fluid and by compressing we create high pressure and higher temperature Now this was a vapor, now it is a superheated vapor. Now we will condense it. Condensing means that we will throw the heat in the surrounding medium. So, we will throw the heat in the kitchen. So, you will have a condenser behind the refrigerator. The condenser has thrown the heat in the kitchen. And what has it thrown? Heat. That's when you will notice that you are standing behind the refrigerator. So, you will feel the warm air. It has condensed, which means it has reached the liquid phase. But it is at high pressure, and it is at 30 degrees. After that, we take an expansion valve, and it expands it so that it reaches low pressure and low temperature. This way, your cycle is formed. Now let's talk about the capacity of this refrigerator. Have a good day. In this form, we can put the four devices in a circle. This circle represents a cycle. These are the four devices in this cycle. This is the compressor, condenser, evaporator and expansion valve. And this is the evaporator. We call this R. Now how will we get the power of this? No, Conversion capacity, yard, In general, the capacity of our engineering devices is Desired output divided by required input. Now, when we talked about the heat engine, we used ETA. In the case of ETA, the thermal efficiency was the desired output. The total work we have done with the engine and the required input was the heat we had given. So, this was the ETA efficiency. But here, our purpose is to keep the cold space at a low temperature. Later, we worked on the remaining heat energy and had to work to run the bike. We left it at high temperature, at warm environment. So, what is the required input? Required input will not be adequate in this case. It is Win, because it will have to work to complete this cycle. So, this thing, The definition is the same as we did there. But since we will use it for the refrigerator, it will not be eta. Because its term is different. That's why we call it as CAPR. Yeah, I'll do it. QL by W net in so this is the COP so the coefficient of performance.

$$(COP)_R = \frac{Desire\ Output}{Require\ Input}$$

$$(COP)_R = \frac{Q_l}{W_{net,in}}$$

$$= \frac{1}{\frac{Q_H}{Q_L} - 1}$$

Now, if you balance the energy of the system, then Wnetin will be Qh-Ql. We can write it like this. Now, the thermal efficiency of the heat engine of ETA is less than 1. Because it was clear that the part of the QH input will be Wnetout. And definitely, we also said that it cannot be 100% as per the Kelvin Plan. ETA cannot be 1. 100% efficiency cannot be possible. So, it will always be less than 1. Because we will have to leave something behind. But here it is the opposite. Here we are taking out the energy from the low temperature space. That's why we call it QL. And we are throwing it at high temperature. That's why we call it QH in this case. In such cases, the ratio becomes important. Because according to this, your COP value comes out. is greater than 1. So, this greater than 1 can be. It's not that it can't be. Even if it has to be 1, then to get 1, you have to get 2. And in such cases, your QH, which means Went,in, should be the same as QL. So, it depends on how much your Went,in is. Wnet in cannot be 0. This statement is about clauses. We will try to understand how Kelvin-Plank statement and clauses statement are equivalent. It is the same thing. Let's discuss about it. This is a refrigerator system and we have understood it today. And from here, the QL is being taken out. Rate of heat 360 kJ per minute. This is taken out of the refrigerator system so that your food compartment can be kept at 4°C. To do this, you have to work this much. 2 kW. We have to reject the heat and waste it. And where is it going? In the kitchen space. Now the question is that you have to remove the COP of this refrigerator. so to remove the CU we know that this is QL by W net in we can put dots in rate form and this will come out as 360 kJ per minute divided by 2 kW and 1 kW will be 60 kJ per minute so this is your 3 Now the second question is what is the heat rejection value? So, we can balance the heat rejection value by taking out the system So we will get the heat rejection value 60 kJ per minute and add 360 kg per minute so it will be in your per minute form and it will be 480 kg juice per minute ok so this is your overall example you can understand how to use it Now let's talk about heat pump. There is no difference between heat pump and refrigerator in devices. But the purpose of it is different. Like the purpose of refrigerator is to maintain your cold environment at that temperature. The heat that you extract from the cold refrigerators system That was yours and the purpose of heat pump is that you have a room or you have to heat it So what will be your desired output? The heat that you are putting in that particular space The space that you are putting in, like you have to heat the room So the room becomes your space You have to maintain it at a specific temperature Which you consider as TH and the outside environment of the room is cold which is why TH is greater than TL but it will be more than TL so you have to put a certain amount of heat in the room so that the temperature of the room can be maintained in TH so that's why when we say heat pump the desired output is different that is QH earlier we took QA for the refrigerator Notice that there is no difference in the diagram. This is the same evaporator, this is the compressor, this is the condenser, this is the expansion, this is the wall. And the same is true for this too. The required input will be Went,in. So, the COP of the heat pump can be seen again as the desired output. by recording. and this is the result Now we will balance this, and we will get QH-QL This is 1- QL. We are taking the QL from the outer space and adding the required input to get QH. So, in this we can write 1-QL by QH and let's try to understand this So I have written this because this part is usually in case of heat pump it is less than 1 and COP and ETA are always positive and COP HP and COP R have a relation because notice that COP is R will be equal to QL divided by QH minus QL. So, COPHP is equal to COPR plus 1. This is the relation.

$$(COP)_{HP} = \frac{Desire\ Output}{Require\ Input}$$

$$(COP)_{HP} = \frac{Q_H}{W_{net,in}}$$

$$= \frac{Q_H}{Q_H - Q_L}$$

Now, if we take an example of this, it is warm indoor, which should be maintained at 20 degrees. In winter, if the outside temperature is 4 degrees, if you want to maintain the room temperature at 20 degrees, then you will have to use this heat pump. Like these days, it is also connected to the AC. Both can function. So, imagine that you have a heater. But if it is in the form of a cycle, then it is a separate refrigeration system which works like a heat pump. So W19 is 2 kJ, COP is 3.5 and QH is equal to 7 kJ. You can also check that this is the right information. If you have a COP 8.5, then you will have to open the desired COP output, developed by required input. desired output is QH because we will put this amount which is 20 degree is maintained and the required input is 2 kg, 2 kilo joules, sorry, so this is 3.5, so this 3.5 is your definition is correct. So the question is that can the value of Hb be less than 1? To get a lesson 1, you have to write 1x1-qlxqh and for this you have to write 1x1-qlxqh or ql by qh less than one So for this you have QL by QH less than 1-1 means less than 0 and this is not possible Have a great day. So, you can get this from simple definitions.

Let's move forward. Let's take another example. This is a heat pump. Now it has a COP of this device. What we have been told is that this house has to be maintained at 20 degrees Celsius, but it has a heat loss. It is losing so much energy. And QH, we have to keep it at 20 degrees Celsius. So, we have to keep it at 20 degrees Celsius. So we have to the I don't know about Wnet and QL QH is not given, the question is that heat pump is used to maintain at 20 degree celsius and the

day your air temperature is minus 2 degree Celsius that day the heat is losing 80,000 kJ per hour If its efficiency is 2.5, then you have to get power consumption by the heat, which is power consumption. And the rate at which heat is absorbed from the outside, that means the rate you are getting out and absorbing is this. So, this question is asked to you. This will be taken out. So, the question in this is that the rate at which heat is absorbed means that how much you are getting out of this air. So, take the definition of the total HP of the COP. What does it mean? This is your desired output. In this case, the output is your QH. and what is the desired input on it which will Wnet. The value of COP is already given. Now the question is that how much QH happened? So, if QH is saying that if your heat loss is 80,000 then to maintain 20 degrees, at least you have to give QH this much. The heat that came in the steady state is the same. So, we can say that QH is your... You have to put this much. So according to this if it is 2.5 then Wnet will be 80,000 So this is 32,000 kJ per hour And QL is simple What is the QL? QH- So the rest will be out. 80 minus 32, It's a simple exercise.
Let's move ahead The heat pump that we normally use is the one that has a COP of 2-3 This is the one that is used these days, which is also called a heat pump This COP comes between 2-3 And you always use a heat pump where the outside temperature is coated Like now in winter That's why you call it an air source, sometimes a heat pump. Its capacity decreases as the temperature drops below 0 degrees. And sometimes in such a situation, you can use a ground source as well. Because if the temperature is high in the ground source, then the heat pump can use the geothermal heat pump in such situations. So, in such situations, It is used as a heat source for the ground. But it is very expensive to install. It is very costly and difficult to install. This is a cartoon that shows that if you reverse one condition, it can work like a heat pump. Talking about refrigerator, you refrigerate the building in which you are refrigerating. A condition is that it is like a simple refrigerator. Because it is doing air conditioning to the room, so it is refrigerating it. The second thing is that the CO2 in refrigerator decreases. the temperature of the refrigerator will decrease. So, the CO2 of the refrigerator will decrease. Because you will have to take out more QL for it. To maintain it. is not good at low temperature. That's why it is not very efficient. If you reduce the need, then the refrigeration system will decrease its capacity. So, you should pay attention to this on the Aam Toa, what temperature you need in the room if you want to use it properly on an additional scope.
Let's move ahead to the discussion. Now, one thing you will remember, that in the last lecture we discussed that this is a Kelvin Plank that relates the heat engine. And the important thing that we proved is that it is impossible that your device operates on a cycle and takes heat from the same reservoir and produces only one work. without heat rejection so that is impossible we discussed this in the last lecture what I mean is this part that you took the heat engine you took QH from reservoir which is on TH and directly connected so this is impossible you have to reject this at low temperature on environment this is a thermal reservoir at high temperature similarly on the basis of refrigerator Clausius gave this statement It is impossible to work on a cycle and only work on heat transfer from low to high temperature without affecting the environment outside. This is impossible, as the Colossus statement said. It is related to the refrigerator. That you take QL and transfer QH directly. This is not possible. They are maintaining the low temperature. This is your surroundings. This is the environment which is at high temperature. This is not possible. You have to work. No effect other than means that you cannot do this work without any work. And this is what is written in this. Without any effect on the environment or any surrounding, you are throwing heat from low temperature to high temperature. That is not possible. That is impossible. So, this is your Clausius statement. And this is your Kelvin Plank. And these two are

equivalent. So, this diagram is saying the same thing. This particular diagram is saying that you cannot do this. This refrigerant is a violation of the clauses statement, which is the statement of the second law. This is the same statement. This and this are the same thing. It also shows that this 5 kJ is taken out of the cold refrigerant system and 5 kJ is made in the warm. And W net is zero. This is impossible. Both these statements are equivalent. That's why we will try to understand how they are equivalent. It is a high temperature reservoir. So, it is extracting heat from here and giving it to the heat engine. Let's assume that this is a heat engine that is violating. If it violates, then it means that its thermal efficiency is 100%. So, this Wnet will be QH. Wnet will convert it. So, this violates the Kelvin Plank statement. If it violates, then we will show that it violates the Calcius statement as well. So, if any statement is violated, then it violates the other statement as well. This means that this statement is equivalent. Whether this statement is used or that statement, both are statements of the second law. Now, what we will do to prove this is that it will be taken out in QL at a low temperature and I will increase the same again by taking out QL and working it again it will go back to high temperature which is your high temperature reservoir And this is at low temperature. Now, this will be your QL plus Wnet which is your QH so let's remove it and let's say that QH Now, we have to pay attention to the QH which we extracted from the TH we have put it back in front of us so, if we look at the whole system then it is internal so, we can write it like this TH is reserved, high temperature is reserved So, the QH is returned to the original state So, this is the internal state, so we can represent this as well because it is inside the original state So, the only thing left is the QL If the state is like this, then we can write the whole system like this. and since it went inside, you can't see the WETF in it because the whole system of Wnet and QH is balanced, so it gets cut off and since both are absorbed, this particular thing is gone so what is left? Only R is left and QL came out from here and went back So this is your equivalent system. If you assume that the Kelvin-Plank statement is validating, then this equivalent system will also be validating. Because, as we said, if we use this and put it back in the refrigeration system, then the equivalent system of this comes out. And what is this? It validates. closest it You can't throw the same energy from low to high temperature without changing the environment. And how the environment is changing, you have to put your work in it. So basically, there is no work in this, there is no essence, so this is your violation of the clauses statement. I hope you understood this in this whole discussion. You must have understood the connection between calcius statement. You must have also understood the discussion about the refrigerator heat pump. You will understand how to use it in the assignment through the example. In the next lecture, we will study Carnot Cycle, Perpetual Motion and Reversible and Irreversible Process. Till then, let's meet again. Till then, bye.