Engineering Thermodynamics
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Lecture 27
Second law of thermodynamics, heat engine, cyclic devices

Welcome back, we will start a new topic here, which is on the second law of Thermodynamics. Ok?

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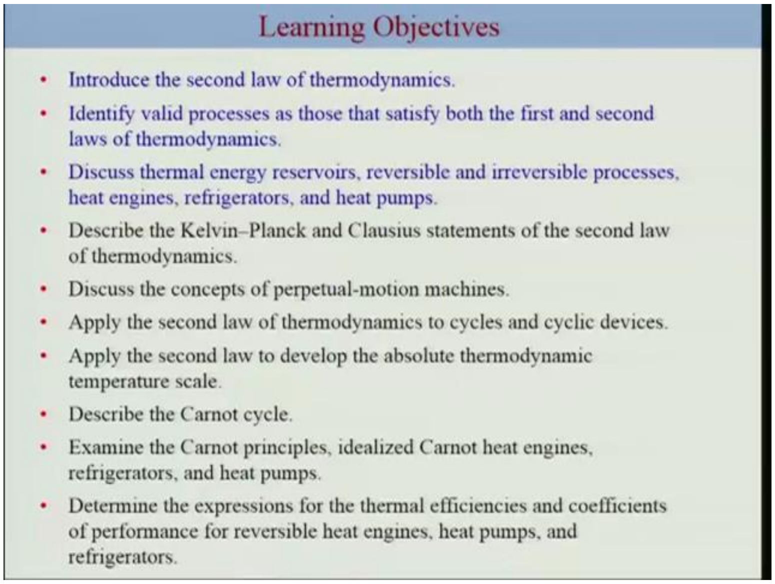

So in this particular lecture we will introduce the second law of thermodynamics and particularly discuss a bit of heat engines, ok? So let us look at some processes. So most of the processes are spontaneous, that is it has a specific direction.

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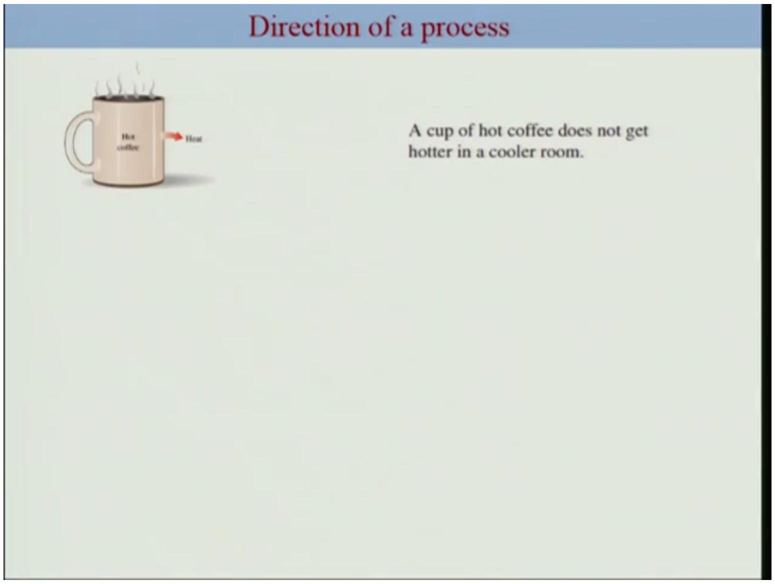

Take an example of your hot coffee mug and you put it in a cold room. What you see is a that it cools off, ok? That means that the heat transfer from the hot coffee mug to the surrounding air of the room, ok? So that is a direction of this particular process which is a nothing but spontaneous process. But take a look at reverse process, ok? Can you imagine a case where the coffee mug or the coffee itself warms up in a cold air? Does your first law violates in doing so? And the answer is no.

Ok, but as long as the energy transfer from the air is equal and to the energy received by the coffee or that particular condition is met, you should expect that your coffee may get warmer if such a process can exist, but we know that this process does not exists. So in such case, you have a specific direction of the process, ok? So in summary, a cup of coffee mug does not get hotter in a cooler room.

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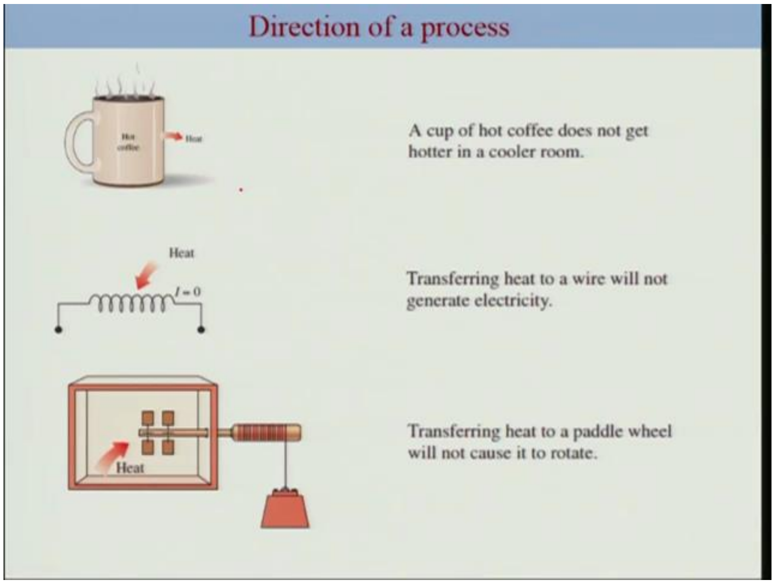

So we will take another example, and this is a example of a heat, if you supply to the particular electrical wire; a typical room heater generates heat in the process when you supply electricity, ok. But the other way around, you do not expect. So but as far as the first law is concerned, if you providing a heat efficient energy and if there is a physical process that it can get into electrical energy, the first law will be valid though. However this process is not feasible.

So in some sense, the first law do not guarantee a specific process to a curve even if it is valid, even if the first law is not violated, ok does not mean that the process may occur. So this is an example, this is a second example which we have given. This is that means transferring heat to a wire will not generate electricity. Or you can take another example, ok? In this case if you have a paddle wheel, ok, which rotates which generates heat in this particular enclosure, ok?

On the other hand if you supply heat, such that to the paddle wheel, it will not cause rotation of this wheel. So this means that there is a specific direction of a process. In all these conditions, the direction if you reverse, your first law will be valid but the process will not occur. So there is a specific direction for the process, ok?

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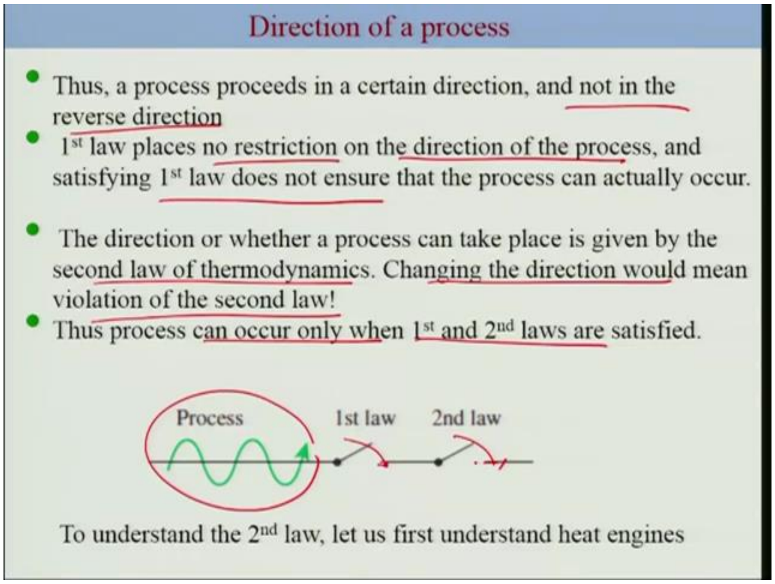

So this, let me summarize this discussion here, thus a process proceed in a certain direction and not in a reverse direction. First law places no restriction on the direction of the process and satisfying first law does not ensure that the process can actually occur. So the direction of whether the process can take place is given by the second law of thermodynamics and changing the direction would need the violation of the second law. So we will talk about that a bit.

So what we are going to learn in this particular course now is that a process can occur only when the two laws are met. The first and second law. This could be illustration of the process and in order for this first process to occur the first law should be valid as well as second law should be valid. That means the circuit should be complete, Ok?

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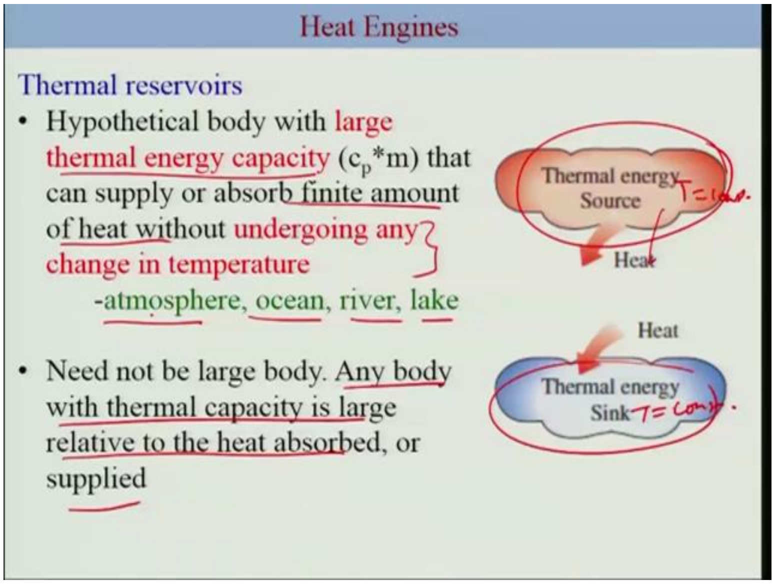

So in order to understand this second law, let us first understand heat engines and heat engines by definition, we will provide the definition later but in heat engines require something called thermal reservoir so let me first go through the thermal reservoir, which is nothing but a hypothetical body with extremely large thermal capacity, that can absorb or supply finite amount of heat without changing its own temperature.

So example could be atmosphere, ocean, river or lake, ok? So this could be a source of thermal energy which is providing heat but the temperature is fixed, ok? And this could be another thermal energy which is a sink here which receives the heat from the surrounding from your systems, ok? And but the temperature is constant, ok? Though these are the typical examples, atmosphere, ocean, river, lake, but the thermal reservoir need not be extremely large body.

Ok? You can consider this room as a thermal reservoir as long as it the heat transfer from this specific device is relatively small compared to its thermal capacity. So you can consider that anybody with thermal capacity large related to the heat absorbed or supplied as a thermal reservoir, ok? So it need not be a very large body. Though we have typical example would be atmosphere, but for solving a problem, you can consider specific body as a thermal reservoir as long as heat is not sufficiently large compared to its capacity.

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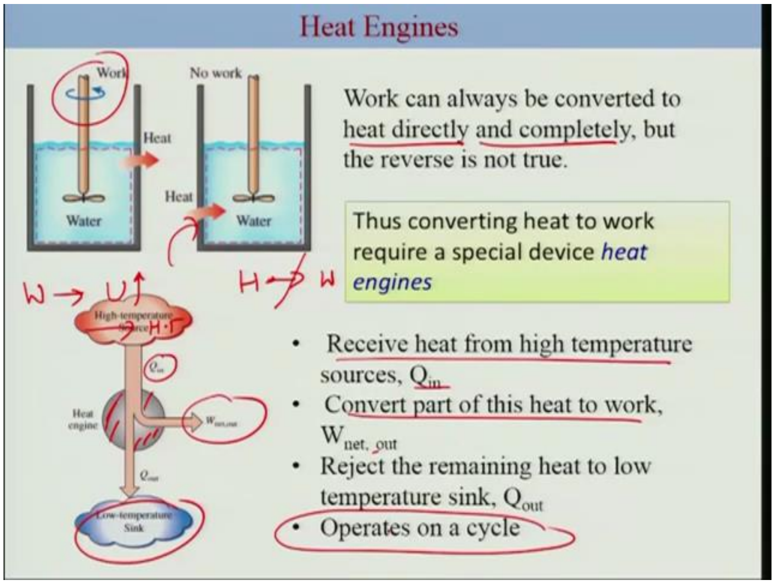

Ok, so let us consider couple of more thoughts here. So let us consider this particular illustration. Now if you do a work, let us say this is a water and you have a shaft here and if you rotate the shaft work will yield a (())(5.28) a internal energy and the temperature increase, ok? So there is a conversion of the work which we have done, ok? To effectively the internal energy will increase of this particular water and there will be certain heat transfer to the surrounding, ok?

Now if you supply the same heat transfer to the water, it will not rotate, so what does it mean that heat is not getting converted to work; on the other hand work gets converted to heat. So this is something which is very clear from this particular illustration. So that means work can always be converted to heat directly and completely but reverse is not true. In order to convert heat to work, we need a special device called heat engine. Ok?

So heat engine is nothing but a device such as this, so this is your heat engine. So this is a device which receives energy Q in from a high temperature source, ok? And does some work and the rest of the energy it passes to the or rejects to the lower temperature. Ok?

So this is a heat engine, it receives heat from a higher temperature sources, converts part of this heat to work, rejects the remaining heat to lower temperature sink and the most important aspect is it operates on a cycle. Ok? These are the important points of heat engine. So you can do a simple energy balance, we will talk about that aspect later of this heat engine.

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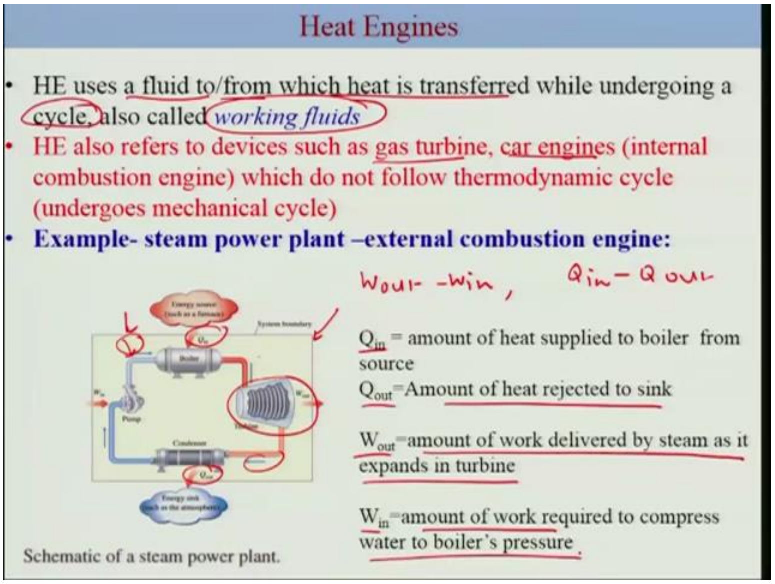

Let me point out the salient features of a heat engine. Heat engine uses a fluid to and from which heat is transferred, ok while undergoing a cycle. So according to this that cycle is important which essentially means that the whole device works on a cycle and bringing the fluid to the same initial state, ok? And this particular fluid is also called working fluid, ok? This could be (())(7.22), this could be refrigerator and so on.

Now heat engine though, works on the cycle which is thermodynamic cycle which we refer but it is in a broadly sense also consider the other devices which do not work on thermodynamics cycle. It works on the mechanical cycle such as gas turbine, car engine, ok? Which do not follow thermodynamics cycle but undergo mechanical cycle but we keep for general sake of discussion this kind of devices also as a part of your heat engine.

So let us take an example of a steam power plant which is a external combustion engine. So this is a illustration or schematic of a steam power plant. You have a boiler which takes a certain amount of heat. Its heat (())(8.02) which is of course, water considering it is a steam power plant. Ok, converts to steam here and passes through turbine which expands and loses pressure and then finally it condenses, rejects the heat to energy sink such as a close and then through pump it where the work is done in order to bring the fluid back to this original condition here, ok?

So this works in a cycle and this is our system. If you do a system energy balance which is represented by particular shaded region, we can easily show that the network done is nothing but your work out minus work in that heat supplied is nothing but your Q in minus Q out, ok?

So now these are the definition already which I have already discussed, Q in is nothing but the amount of heat supplied to work to the boiler from the source. Q out is the amount of heat rejected to sink and W out is amount of work delivered by steam as it expands in turbine. W in is amount of work required to compress water to boiler pressure, ok? So this is your net energy supplied to the system. This is your net work done by this system.

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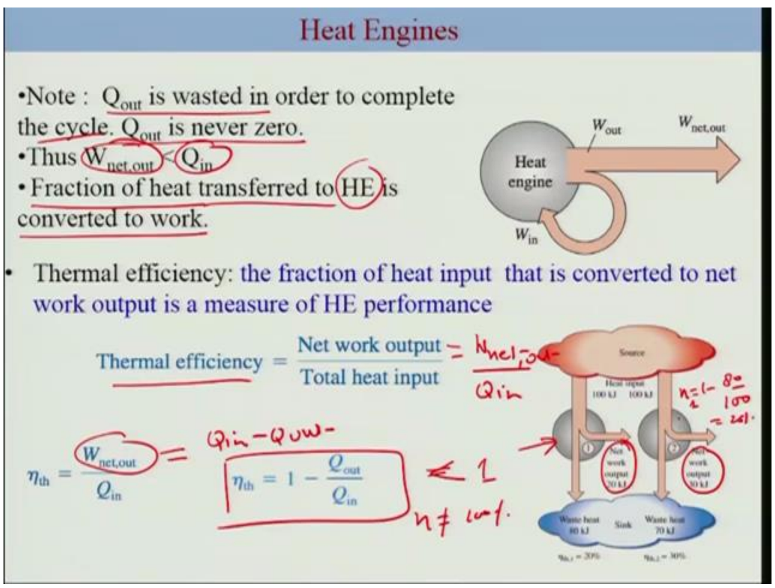

Considering that the the action is already given, the values are positive, ok? So you can represent this heat engine as the preceding slide or previous slide that this heat engine, you have this work out and the work in, part of this work out goes to the work in and there is a specific work net out which is given here, ok?

Considering that the system, there is no mass enter and exit the system, the for cyclic process the change in internal energy must be zero, ok? So which essentially means that W net should be equal to Q in minus Q out. So that something which is our energy balance will tell us. Ok, now based on this we can also identify the deficiency, but note that Q out is wasted in order to complete the cycle. Ok which essentially means that Q out is never zero which means that your Q the work net which is nothing but Q in minus Q out is much less than Q in.

Thus, we can say that the action of heat transferred to heat engine is converted to work, not all of it only a fraction of it. Thus your thermal efficiency for this heat engine which by definition in nothing but net work output divided by the total heat input that is desired output divided by required input which should be net work output divided by total heat input is nothing but W net out Q in and you can replace W net by your Q in minus Q out. Thus your thermal efficiency is given by this.

Now considering the Q out is never zero, this is less than On always, ok? So that means eta cannot be 100 percent, ok? Now this is illustration where you have same sources sink but the devices can have thermal efficiency because it depends on the net work output, ok? So thermal efficiency can vary depending on your process or the device or the particular device. But having same sources and sink.

Ok? So you can do a simple analysis here so that this eta in this case is one minus Q out. So Q out is nothing but your 80 in this case for the case of 1, eta 1 by Q in is 100, ok? So this turns out to be 20 percent. Similarly for this device too.

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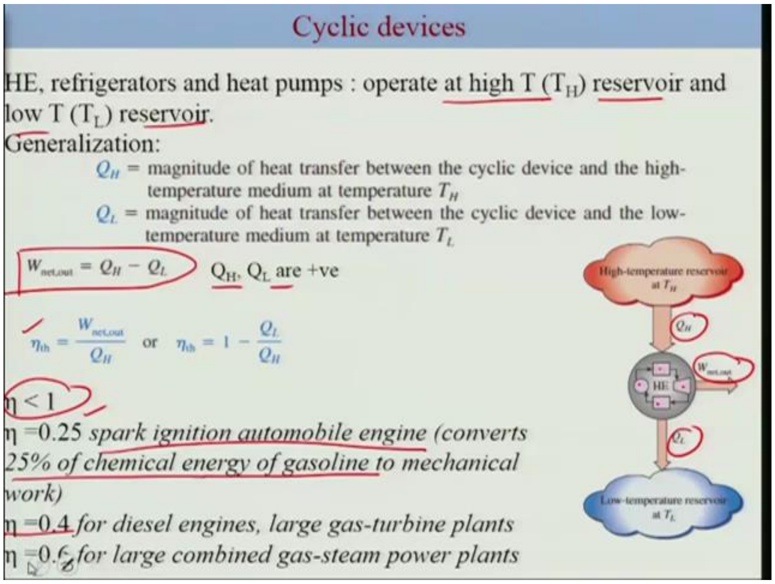

Ok, so there are other cyclic devices, we talked about heat engine but refrigerator and heat pumps are also cyclic devices. They all operate at certain temperature, let us say at high temperature reservoir and a low temperature reservoir, ok?

So they operate in this two specific reservoir and we are going to define heat transfer from the high temperature by Q H the amount of heat transfer and Q L is heat transfer or the magnitude of the heat transfer between the cyclic device and the low temperature medium; and Q H should be the magnitude of the heat transfer between the cyclic device and the high temperature medium at T H, ok?

So considering this particular heat engine schematic form, ok? So the heat engine though is represented by the circle but it includes many other devices as a part of it. So here of course you have this boiler turbine, compressor, pump, ok? But this can be all put into a simple representative form of a circle in order to represent heat engine for illustration and this is your W net out, ok?

So W net out, we know from energy balance is nothing but this. We know this Q H and Q L are positive, we are aware of eta by definition, so eta as I said is less than 1. Ok, for a typical spark ignition automobile engine which converts only 25 percent of the gasoline because this eta is round point two five. So it converts only 25 percent of the chemical energy to mechanical energy, ok?

But eta can be higher for different engines, for example in the case of a diesel engine, the thermal efficiency is 0.4. In case of a gas steam power plant, the thermal efficiency extremely large, 0.6 ok?

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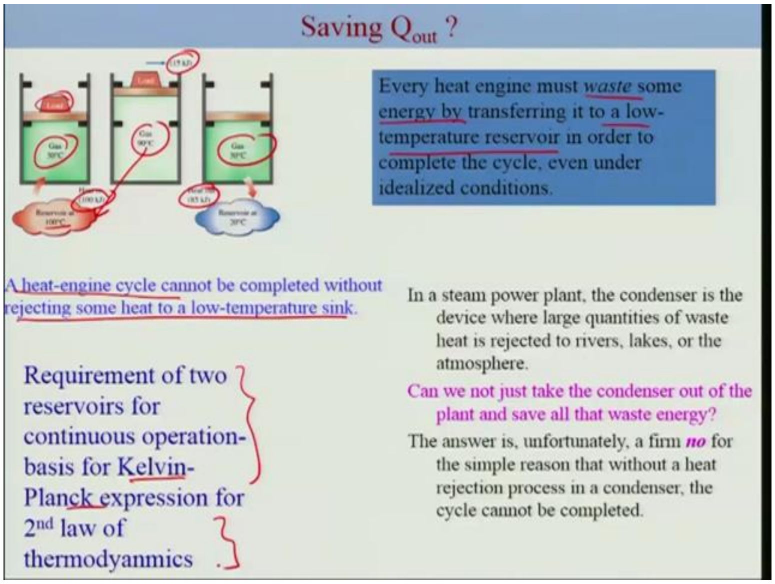

Now the question is why we cannot have Q out zero or why we need to actually discard certain energy to a low temperature reservoir. Why cannot we just make use of a single reservoir, in order to complete this cycle? So let us take an example an illustration in order to understand that that we cannot work with just a single thermal reservoir for a cyclic device.

So let us take a gas in this cylinder device. So this gas is at 30 degree celsius which takes heat at 100 kiloJoule and form a reservoir at 100 degree celsius. Now after consuming heat of 100 kiloJoules, it expands and converts some of this energy as a part of internal energy but while doing so it does work of, let us say 15 kiloJoules, ok?

And the temperature also increases to 90 degree celsius. Now which essentially means you are removing 15 kiloJoules and the rest of the 85 kiloJoules, you have to discard. Now which essentially means that in order to bring the gas from 90 degree to 30 degree in order to complete this cycle as well as the reduce the volumes such that it will go back to original state, you need to compress and by removing this 15 kiloJoules, you want this particular stint.

However we are aware of the fact that heat cannot be transferred from 90 degree celsius to 100 degree celsius because the fact that this is low temperature, this is high temperature. We know that the heat transfer from the higher temperature to lower temperature but we cannot reject this heat of 85 kiloJoules from this 90 degree celsius to 100 degree celsius. Thus we need to have a reservoir at a lower temperature to reject such a heat in order to bring the system back to original condition.

Thus every heat must away some energy by transferring it to a lower temperature reservoir in order to complete this cycle or in another word, we can say that heat engine cycle cannot be completed without rejecting some heat to a low temperature. The requirement of two reservoir for continuous operation is the basis for Kelvin Planck expression for second law of thermodynamics, ok?

So we will talk about this in our next lecture. We will discuss more of this expression so we will talk about this more a bit later. So in other words, what we are stating that for cycle you must have two reservoir, on at high temperature and other as the low temperature for a cyclic device.

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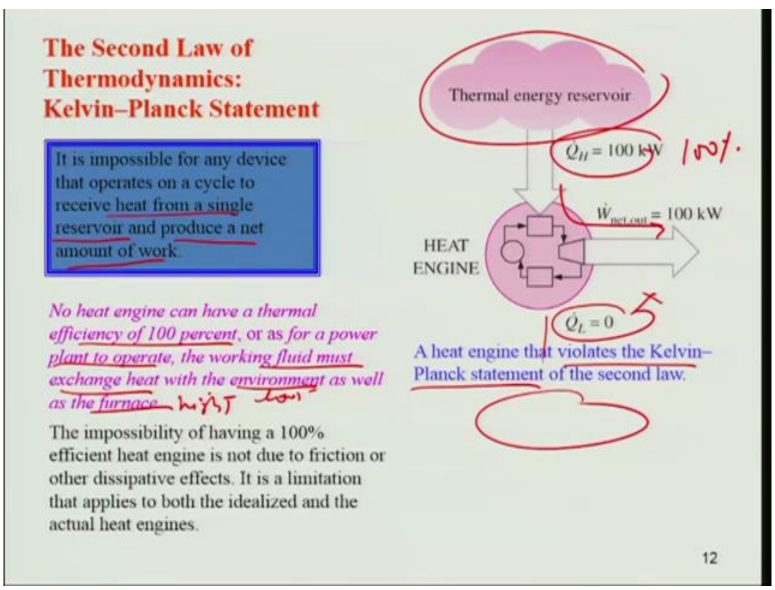

So this is a very well defined in the statement like Kelvin Planck which is equally the second law of thermodynamics of Kelvin Planck statement. It says that it is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work, ok. So this can be given illustration. It says that having just a single reservoir and converting this to the work which means is a hundred percent efficiency is impossible, ok? You need to have another reservoir of low temperature that means you cannot have this condition.

So this particular device is a violation of a Kelvin Planck statement of the second law. That means no heat engine can have a thermal efficiency of 100 percent or as for power plant operate the working fluid must exchange heat with environment as well as the furnace which essentially means low temperature this is a high temperature, ok? So it must have two specific two reservoirs, ok?

Now you may think that this 100 percent maybe because of the frictional loss and so forth. That is not the case, it is a limitation that applies to both ideal as well as actual heat engines. So we will discuss little more, take a certain examples in the next specific lecture.

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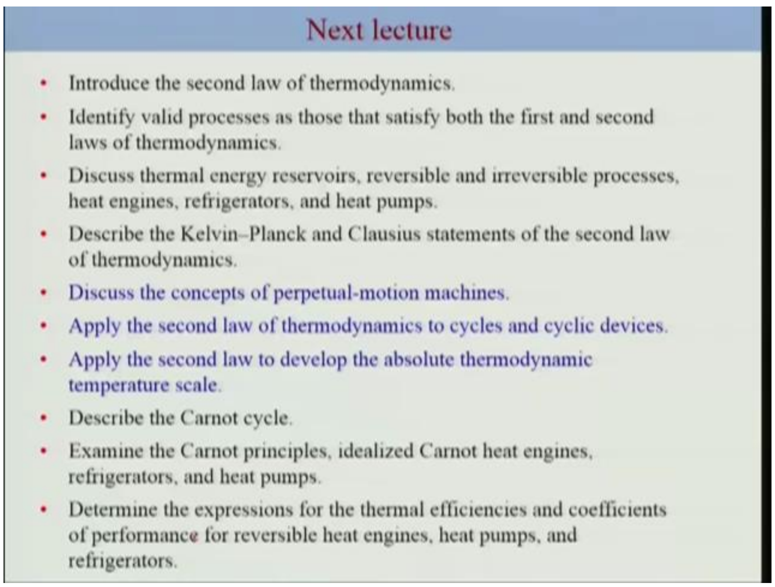

So where we are going to elaborate more on the Kelvin Planck and as well as bring these Clausius statement, ok? And as well as we going to look into more details of this second law of thermodynamics. So I will see you in the next lecture.