Applied Thermodynamics
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Module - 01
Review of Basic Thermodynamics
Lecture - 03
Second Law of Thermodynamics

Dear learners, greetings from IIT Guwahati. I welcome you to this course Applied Thermodynamics. We are in the module 1; that is Review of Basic Thermodynamics.

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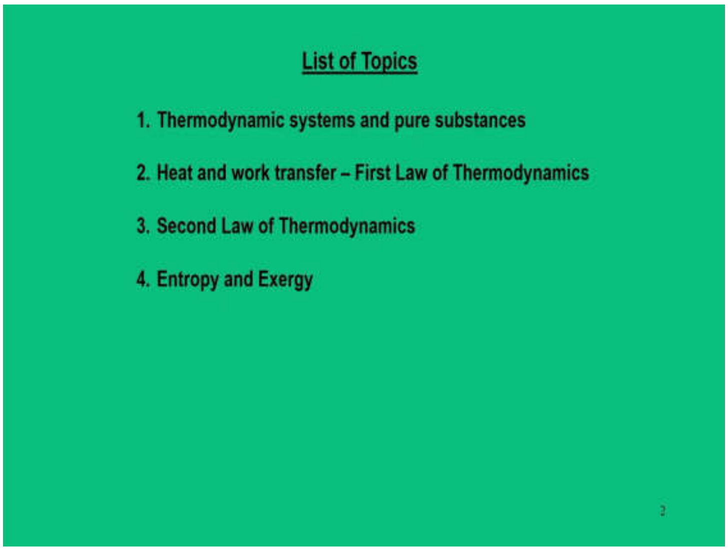

So, in the beginning of this module, it was proposed that this module will contain 3 lectures. But however, looking at the contents, instead of 3, we are proposing 4 lectures. So, basically the first two lectures which I have covered that is on thermodynamic systems and pure substance, heat and work transfer, where we focused mainly on First Law of Thermodynamics.

Now, two more lectures in this module are Second Law of Thermodynamics which we will be covering today and in the next lecture, we will be discussing about entropy and exergy concepts.

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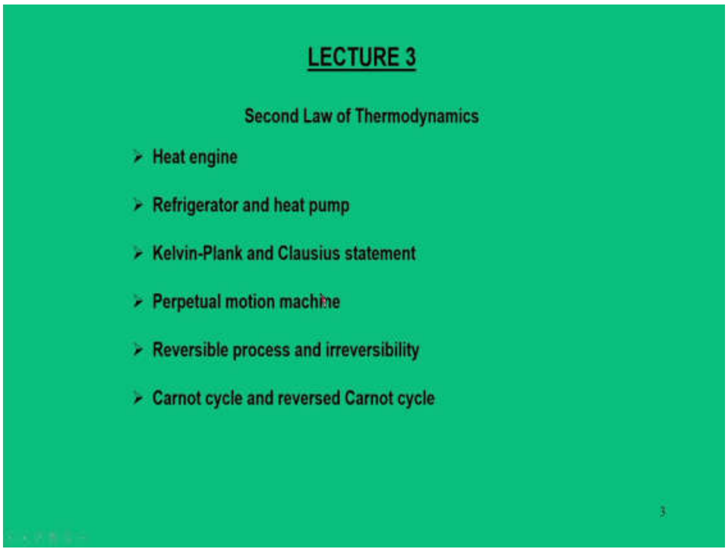

Now, let us start these contents for the lecture 3 that is Second law of Thermodynamics. So, in this lecture, we will touch upon the following topics heat engine; refrigerator and heat pump; Kelvin-Plank and Clausius statement. In fact, these are the two statements which are in the form of second law of thermodynamics and there is some concept called perpetual motion machine and next is reversible process and irreversibility.

So, this is a very important aspect as far as the second law is concerned. I will emphasize what is meant by reversible process and irreversibility; how does it affect for occurrence of any system or process and lastly, we will cover the Carnot cycle and reversed Carnot cycles.

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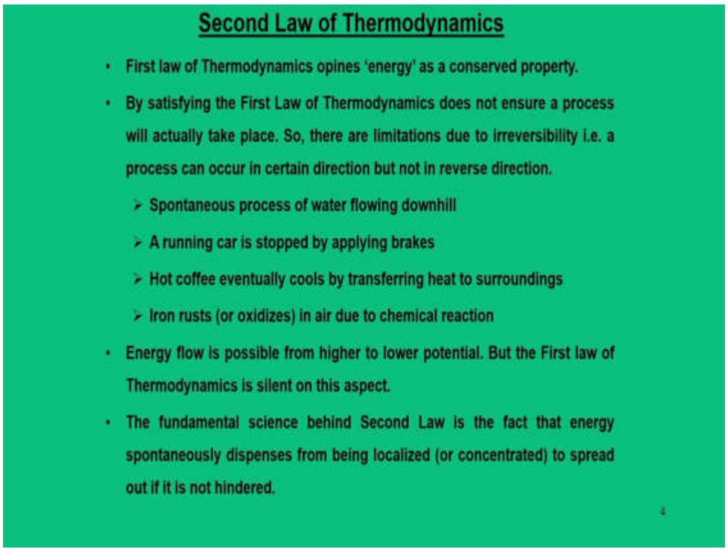

So, let me give you some brief introduction about second law of thermodynamics. So, in the first law of thermodynamics, we emphasize that energy is a conserved property and whatever change of energy that takes place or interaction that takes place in which it takes one form of energy into other.

So, there is no concept of energy creation and while dealing with energy interaction, the first law states there are two modes of heat transfer; one is heat and mass transfer and that is going to happen in a closed systems. But in a open system in addition to heat and mass transfer, there is another interaction that is through mass flow, where the flow energy is dumped into the system and that mass also carries out of the energy.

And one of the most important significant property that first law introduces is the internal energy and this internal energy is mainly for a close systems and when you deal with open systems, the flow energy gets added to into the internal energy and we call this as a enthalpy. So, this is the very basic summary of the first law.

But what is the main demerit in this first law is that first law does not take into account about the occurrence of a process. So, it just makes a energy balance or we can say it is a energy audit; whatever energy comes to the system, it goes out. So, its takes take a stock of it; that means entire energy that comes that goes out.

But in fact that is not true first of all and second aspect is that in the first law, although it says that heat and work are two form of energy; but the most important point is that both have same unit, now question comes which is high grade and which is low grade.

So, for example, if you have 10 kJ of heat and 10 kJ of work, which is at higher potential? So, these are the questions that remains unanswered whether energy has a quality or not and second thing is that if a process has to happen, although we can make an energy balance, but can a process occur the way the process occurs in one direction, can it occur in a reverse direction.

So, these are the questions that remains unanswered in the first law. So, because of this reason the second law comes into picture, where the second law has answered most of these queries. And in fact, any system that is occurring in nature must satisfy both the laws. So, this is the basic inference that we will get out of second law of Thermodynamics.

Another important aspect that the second law gives is the concept of entropy that gives the directionality of a process to occur. So, all these things we are going to cover one by one in this lecture and the subsequent lectures. So, just to begin with whatever I have explained, if I can consolidate them in some statements, then I can write like this. First law of thermodynamics opines that 'energy' is a conserved property. But by satisfying the first law of thermodynamics does not ensure that process actually takes place.

Because there are some limitations due to irreversibility; that means, a process can occur in a certain directions, but it does not occur in a reverse direction. For example, water flows spontaneously from a uphill to downhill. So, in this process, what happens? The potential energy of water at uphills gets converted to kinetic energy. So, it is flowing downhill.

Now, by some means if you want to want to accelerate the water, it cannot flow spontaneously uphill; that means, because of some limitations or restrictions that spontaneous flow from downhill to uphill is not possible.

Second example could be a running car is stopped by applying brakes. So, in this process what happens? Kinetic energy converted to the internal energy through brake shoes. Now, if you can get back the internal energy back to the car, car will not move.

Hot coffee eventually cools by transferring heat to the surroundings.So this cooling process is a spontaneous process; but reverse is not happening in nature. Iron oxidizes in the air due to chemical reaction after long time. But once it oxidizes, we cannot get the iron back. So, these are the many such occurring processes in nature that shows that a process occurs in a certain directions.

So, it is a spontaneous flow of energy occurrence in a certain direction. So, we say for example, when iron rust; so, there is a process of degradation of energy. So, this is typically quantified through the concept of second law of Thermodynamics.

Energy flow is possible from higher to lower potential. But first law of thermodynamics is silent on this aspects. The fundamental science behind the second law is the fact that energy spontaneously dispenses from being localized to spread out or if it is not hindered.

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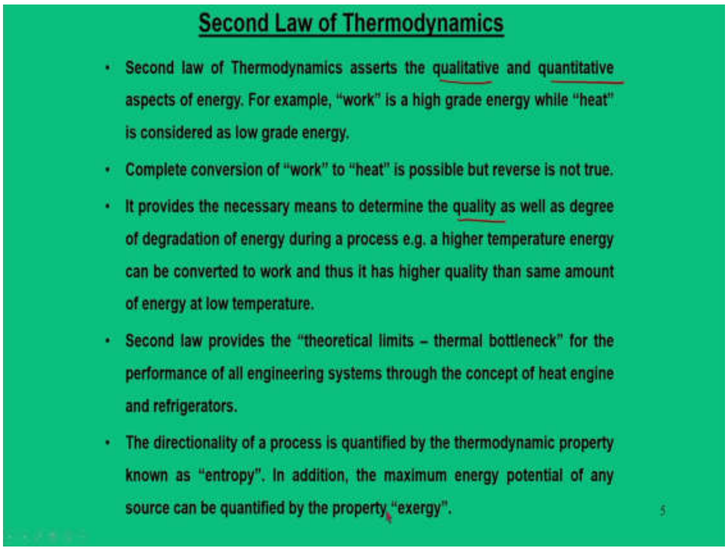

So, it is tries to spread out. The second law of thermodynamics asserts the two important things; qualitative as well as quantitative aspects of energy. So, it says first law talks about 'work and heat' that the form of energy. But second law says that "work" is high grade energy and "heat" is low grade energy. Why?

We will come back later. And so, since it is a high grade energy, the complete conversion of work to heat is possible; but reverse is not true. And the second law of thermodynamics provides the necessary means to determine the quality as well as degree of degradation of energy during a process.

For example, a high temperature energy source can be converted to work. So, they are called as high quality than the same amount of energy at low temperature. For example, if 10 kJ of energy is available at 700°C and 10 kJ of energy is available at 300°C; then, we say that the quality of energy at higher temperature that is 700°C is more. The quality of energy is more when the temperature is high. Another important aspect that second law provides a theoretical limit or thermal bottleneck. So, by introducing a term efficiency, second law says that a system has certain bottleneck or some thermal potential at which beyond which it cannot convert the form of energies.

So, we will come back to those points when we introduce the term efficiency. Another important aspect is that directionality of a process is quantified by a thermodynamic property what you known as entropy. So, we will give more emphasize on this entropy topic in the next lecture and in addition, we also have another concept what we call at exergy, which is nothing but the maximum energy potential of any given source. So, these two topics will be addressed in next lecture.

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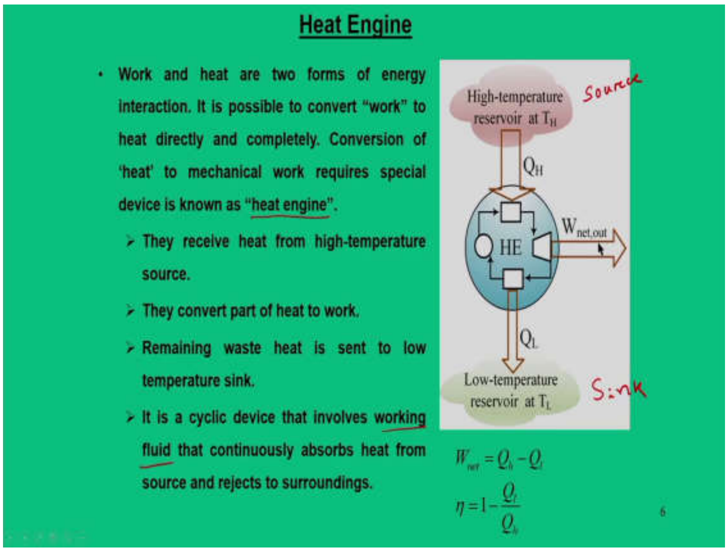

So, let me start with the first thing that we are going to talk about the different two forms of energy interactions that is 'work and heat' which is given from the first law. So, first law it has been said that whether you call it as a work or heat does not matter to us because they have same unit, they have same quantitative nature, whether they go out or come into a system, energy audit or energy balance has to take place.

But next question is that why we have to say it is a work and why we have to say it is a heat. So, those things are addressed here. So, it is said that it is possible to convert work to heat directly and completely. So, we have given many examples on this aspect, while dealing with the first law; but conversion of heat to mechanical work requires a special device which is known as heat engine.

So, this means second law introduces a heat engine and how we are going to convert heat to mechanical work. So, in that way, we can say that a concept of heat engine is introduced. So, what does this heat engine do? So, they receive heat from high temperature source, they convert part of heat to work, then remaining waste heat is sent to a low temperature sink.

And there is a cyclic device that involves the working fluid that continuously absorbs heat from the source and rejects it to the surroundings. So, if you look at this particular figure, so it is a cyclic device. So, we call this as a heat engine. So, this heat engine, what does it do? It takes a heat from high temperature source; so, it is a source.

So, when we are talking about high temperature reservoir, we call this as a source and when you talk about low temperature reservoir, it called as a sink. So, the concept of source and sink is like a sea if you add a drop of water into sea is potentially such that its mass changes negligibly.

So, that means, we can take out any quantity of water from a sea or ocean. So, we can say it is a water reservoir. So, similar thing for a source we call as a high temperature reservoir, and same concept goes in a reverse way for this sink. So, we say it is a source and it is a sink.

So, the heat engine what does they do? It takes let us say Q_H amount of heat and reject Q_L amount of heat to the sink. Now, in the process what it does is we can get a work output. So, that means, by taking heat Q_H, it gives a network output.

So, the heat engine must reject heat to the low temperature sink without which the work output is not possible. A typical example could be that we can have IC engines. So, this particular engine could be an IC engine; it could be a power plant.

So, IC engine means we are giving energy in the form of fuel, but there are about 30 percent of energy goes out as a waste heat or to the atmosphere. So, that is a heat rejection. Similarly, for power plant, the heat comes from the coal which is as input and it goes out to the through the condenser to the low temperature water or to the river.

So, this heat engine could be anything; it could be a gas power plant; it could be a IC engine or any other things. So, in this process, there is a working fluid which is involved. So, in a power plant, the working fluid is steam or water. In IC engine, the working fluid is the fuel and air mixture which we call this as a charge.

So, in this process we can get a power output in the form of shaft work for an IC engine and we get also power output from a turbine in a power plant. So, in that way, we call this as a network output.

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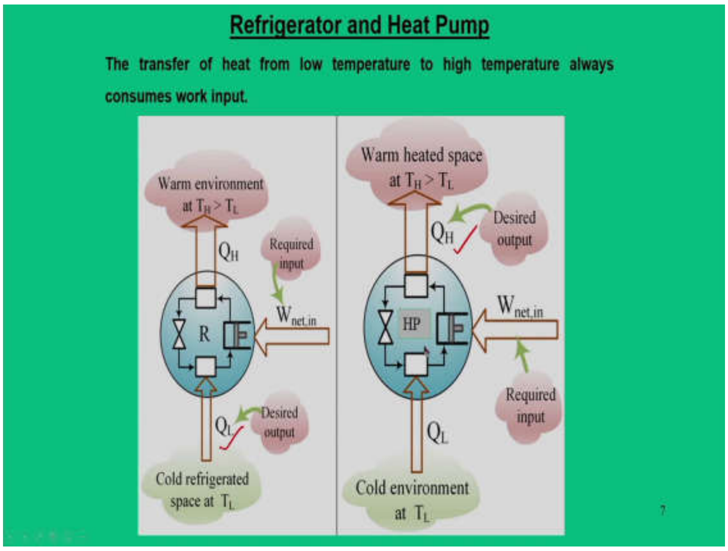

Now, another concept that drops in is a refrigerator and heat pump. Now, we said that to get work output, we have to take heat from the high temperature source. Now, the question comes is it possible that we can we can transfer heat from a low temperature reservoir or sink and reject to the source.

Yes, first law says, also second law says it is possible. But in that case, you will not get work output; you have to give work input to that machine. So, since, it is a contradicting statement, so we do not call it as a engine because engine produces power output. So, instead of that we call this as a work consuming device.

So, in a work consuming device, we have two category; one is refrigerator, other is heat pump. So, now, under what circumstances they will qualify; whether we call this as a refrigerator or heat pump. So, that is mostly decided is what is the desired effect.

So, desired effect is nothing but as user what do you want. So, if your requirement is at lower temperatures area or low temperature space, then we call this desired effect is a refrigerating systems. Now, if your desired output is required for a high temperature source, then we can say it is a heat pump. So, in a in a refrigerator what does it do?

So, here, work input is given to a refrigerator. So, because of this, we extract heat from a cold refrigerated space and typically, we call this as a low temperature sink and we can reject Q_H amount of heat to the warm environment and typically, in this case is atmosphere. And obviously, this T_H is higher than the T_L. So, in this process what happens?

We take a heat from low temperature space and rejects to the high temperature zone and through this process, we are getting work output and your desired effect is or your attention is concerned more towards this Q_L and that is your net effect or your desired output or net desired effect.

But in other case, if your attention is focused that how much we are going to reject heat to a heated space. Then, that means, your attention is towards Q_H. So, in that case you call this a heat pump. So, these are the two basic distinction that we make in a refrigerator and heat pump.

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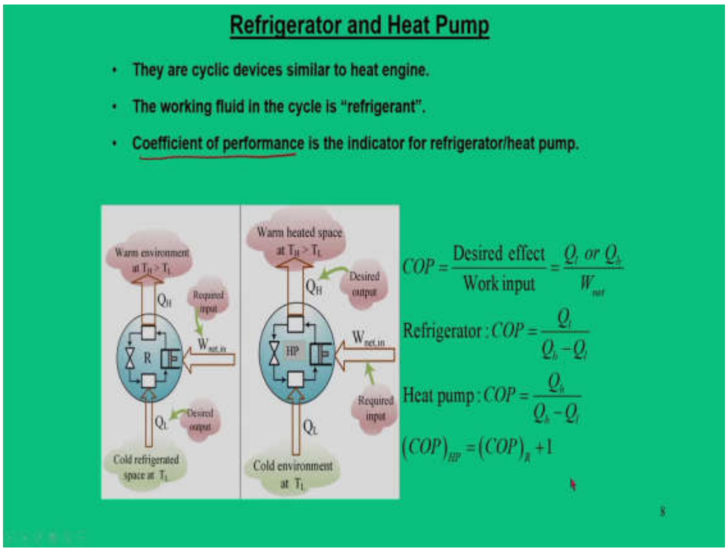

And of course, here they also qualify that they are cyclic devices and they are similar to heat engine and here, the working fluid is similar to the refrigerant. There the working fluid could be air, there could be fluid air charge or it could be steam or water in a heat engine.

And previously, when you talk about heat engine, we introduce a term efficiency which we say that whatever work we get, that divided by the amount of heat we supply will give you the efficiency. But in a refrigerator or heat pump, we define a indicator what we called as Coefficient Of Performance or in a short form, we call this as a COP.

And the COP is nothing but the desired effect by work input. So, desired effect could be heat from the low temperature sink or heat from the low temperature source. So, Q_L or Q_H; but denominator that is always work input Wnet and by doing this energy balance, Wnet is nothing but $Q_H - Q_L$. So, when you deal with the refrigerator, the COP is assigned; your desired effect is concentrated on Q_L. So, it is $COP = \frac{Q_L}{Q_H - Q_L}$.

For heat pump, the desired effect is considered on Q_H. So, it is $COP = \frac{Q_H}{Q_H - Q_L}$ and so now, by just simple addition of these two will tell you that the $(COP)_{HP} = 1 + (COP)_R$; that means, COP of heat pump is always higher than a refrigerator.

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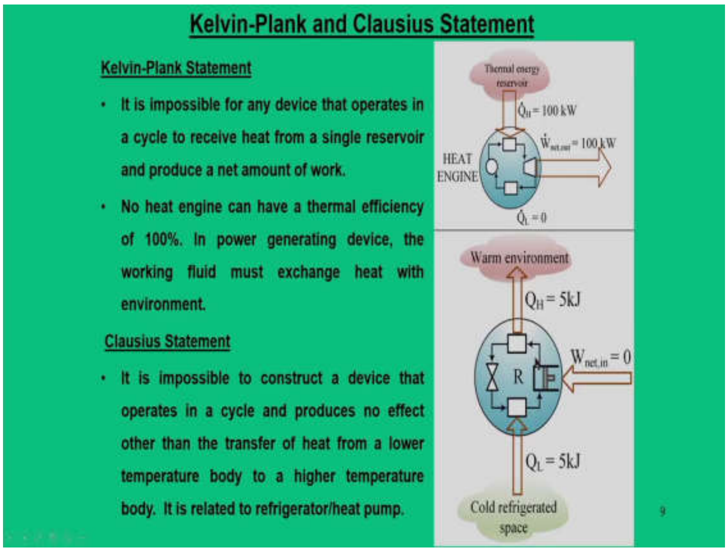

Now, having said this, now we will talk about two important statements of second law and they are called as Kelvin-Plank statement and Clausius statement. This Kelvin-Plank statement pertains to a heat engine; whereas, the Clausius statement pertains to a heat pump or refrigerator. So, what does this statement says?

So, these two statements are negative statement. So, negative statements means it is put in a negative sense. So, what does it mean that it is impossible for any device that operates in a cycle to receive heat from a single reservoir and produce net amount of work. That means, we cannot construct a device which operates in a cyclic manner; but keep on producing work by interacting it with a single reservoir.

For example, if you say it a heat engine, without rejecting heat to the low temperature sink, we cannot run a heat engine. So, for example, so when you have 10 kW of energy that comes from high temperature source and we are getting out 10 kW of work as a output, then it is not possible because in this case Q_L is 0. Although it is satisfy the first law, but Q_L is 0 means it violates the second law. So, that is what the form of Kelvin-Plank statement.

So, no heat engine can have thermal efficiency of 100 percent. So, in a power generating device, the working fluid must exchange heat with environment. That means, Q_L should not be 0; it has to have some number. Next is Clausius statement.

So, it is also a negative statement, but it is based on refrigerator or heat pump. So, what does it say? It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from low temperature body to a high temperature body.

So, what does this mean that for example, if it want to take a 5 kJ of heat from a cold refrigerated space and you are going to reject the same amount of heat by using a refrigerator, then without any work input you cannot do this. Although, it satisfy the first law; but we have to give some work input.

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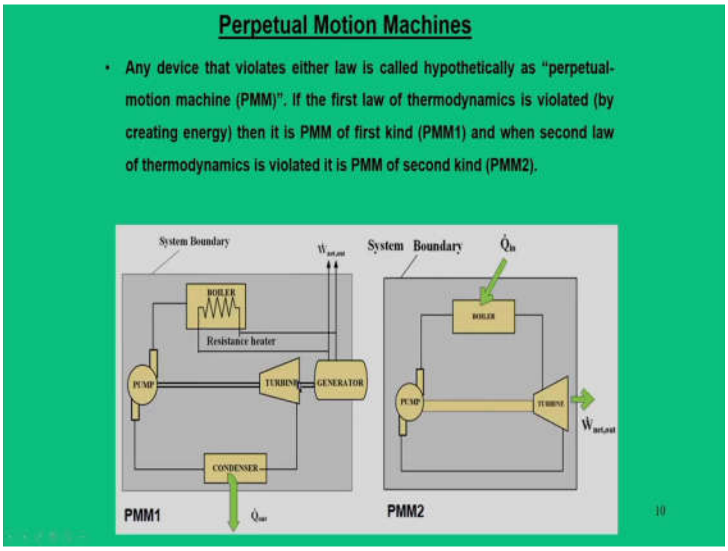

So, these are the two form of second law of Thermodynamics. But these two concept has an another role and our many books call this as a perpetual motion machines and which we call this as a typically hypothetical device; that means, till this point of time, we have been telling that when both the first law and second law are satisfied, a process has to occur. And none of the processes have violated first law or second law.

So, this particular hypothetical statement say, that perpetual motion machine which is never possible. And in thermodynamic sense, we call it is a perpetual motion machine that if anything that violates the first law is called as PMM1; that means, it can produce continuously work output. And any device that violates the second law which called this as a PMM2.

So, this particular typical concept which was introduced here that in a first case, we have drawn the schematic of a power plant which says that this power plant is operated from the power which is developed from a generator which is the net output power and from that power, we are continuously giving the input as a heat source.

So, in this process, what happens? We are basically creating energy. So, this is not true. So, in that way it violates the first law of thermodynamics. When we are dealing with another similar concept that we have a power plant which operates turbine and pump and boiler. But it takes Q_H amount of heat, but it produces work output; but there is no heat rejection that means it violates the Kelvin-Plank statements. So, we call this as a PMM2. So, these are the hypothetical machines.

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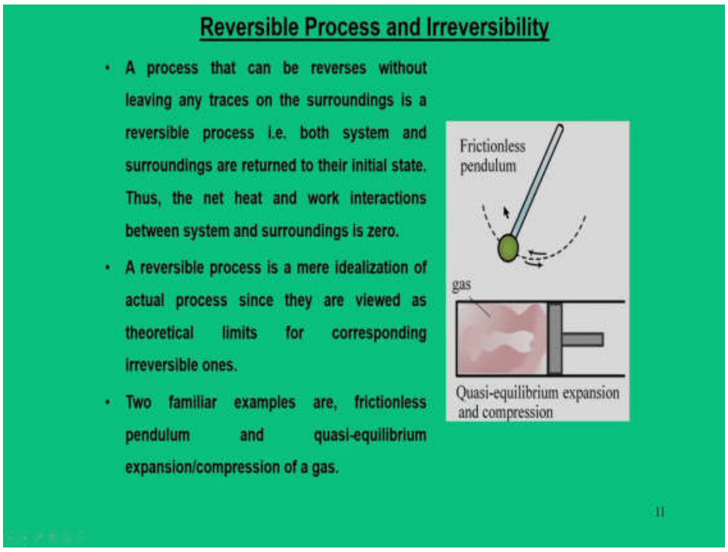

Now, we are going to introduce another important concept; what is a reversible and irreversible process or irreversibility. For example, we have been telling that a process when occurs in a very slow, that means, we have introduced a term which is called as a quasi static process where the infinite slowness is the characteristics of a quasi static process.

Now, in a naturally occurring system if some process occurs in a quasi static manner, then process occurs in one direction. But if same process can be reversed back to its original state, then we call this as a reversible process. So, a two typical examples could be a simple pendulum which always moves I mean since it is a frictionless pendulum, it has a some time period of rotation and also another example could be quasi equilibrium expansion and compression in a piston cylinder device. So, that means, this is nothing but a process which you can quantify.

So, why do you require a reversible process? Because reversible process is mere idealization of actual process. So, the second law says that there is a reversible process and there is a actual process. So, what is the distinction between these two? So, what is the upper limit that actual process can achieve?

So, it can achieve up to some extent for its corresponding reversible process. So, that means, it is a mere idealization of an actual process that occurs in a nature. So, it put some theoretical limits. So, previously, we have talked about heat engine and we have talked about refrigerator and heat pump; but we have to put some theoretical limit. So, what is a theoretical limit? So, to address those theoretical limit, the reversible process was introduced.

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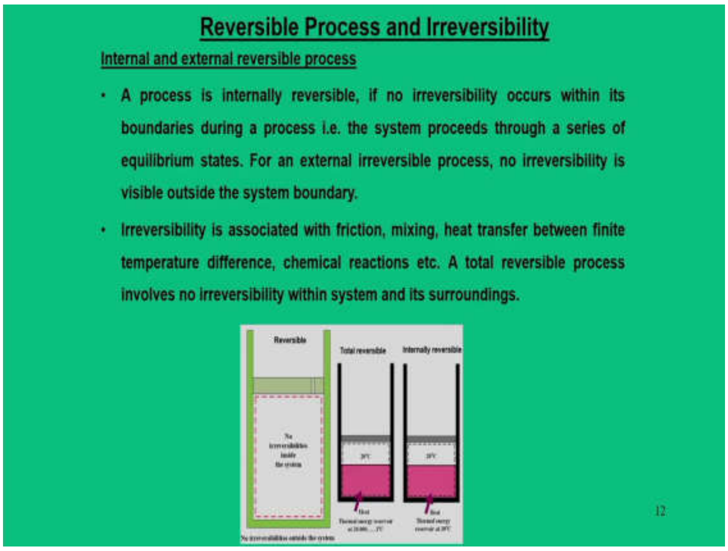

Now, moving in that line, there is another concept called internal and external reversible process. So, a process is a totally reversible process or a simple reversible process. There is a system and we have surroundings. So, when you have the system and it occurs in a very slow process, so through this slowness of process or quasi static nature, we say it is a internally reversible process.

Now, what happens at the same time? Because of this occurring process if the surroundings is not affected, that means, there is no irreversibility due to the surroundings, then we say it is a total reversible process. For example, a total reversible process can be hypothetically stated that we have a thermal reservoir which is taking heat from a reservoir and that temperature is 20.0001°C; infinite 0.1°C.

And the system itself is at 20°C. So, what it does mean that there will be a heat transfer because there is a very infinitesimally small temperature gradient in between. So, heat transfer takes place, but its occurring in such a slow process that as if nothing is going to be visible for system as well as its surroundings.

So, we call this as a total reversible process. But in the other way, we can view this particular concept is that we have a thermal reservoir which is at 30°C and from that reservoir, we are taking heat to this piston cylinder device or gas and when that heat is going into this system or to the gas, the piston tries to move slowly. So, this slowness is within the gas and this piston.

So, we call this process as internally reversible; but because of this, there is some finite change in the surroundings. So, this particular process, we call as internally reversible; that means, through this process, we are not bothered what happens in the surroundings and there are irreversibility that occurs in the surroundings.

So, because of this reason, we say it is an internal reversible process. So, these are the thermodynamic definition of a reversible process and it introduce some irreversibility that is accounted due to friction, mixing, heat transfer between finite temperature difference which is in this case, chemical reactions, these are the some of the irreversible nature that introduces the behavior of a irreversible process.

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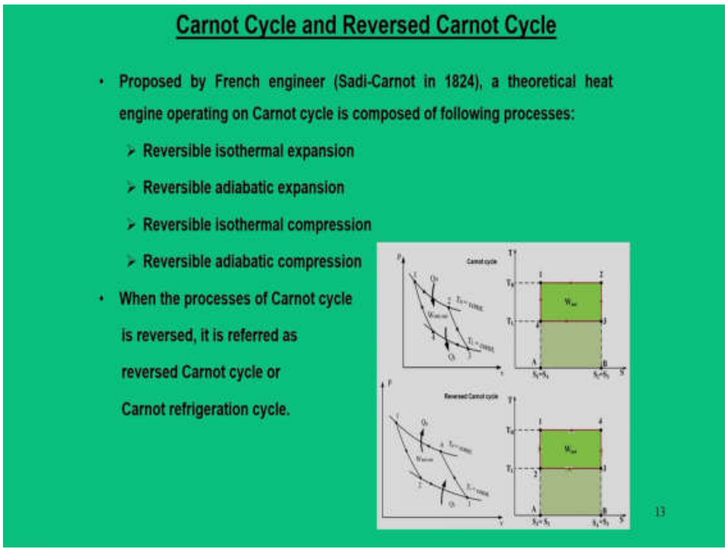

Now, having said reversible and irreversible process, we are now going to introduce the thermal bottleneck or we say theoretical limit for a actual process and that is done through a Carnot cycle or reversible Carnot cycle. What does this mean? Beginning, we have introduced a heat engine. When we are talking about a heat engine, we say that certain quantity of heat is being taken from a high temperature source and some quantity of heat is rejected to low temperature sink and by virtue of which we get a output.

And whereas, in a heat pump or refrigerator similar concept holds in, but there we are going to introduce work as a input to the system. Now, while this heat pump or heat engines or refrigerator they operate, what is the upper limit or what is the theoretical limit they can have? For example, as I mentioned that while transferring heat or work at what that heat or work is available.

To quantify this, we proved some theoretical number and that number is to be done through a reversible process and this is introduced through Carnot cycle and reversed Carnot cycles. Carnot cycle refers to for a theoretical limit for a heat engine; reversed Carnot cycle proves a theoretical limit for refrigerator or heat pump.

So, it was proposed by a French engineer, Sadi Carnot in 1824. So, for a theoretical heat engine that operates in a Carnot cycle, they are composed of the following processes, they call it as a Reversible isothermal expansion, reversible adiabatic expansion; reversible isothermal compression and reversible adiabatic compressions.

So, if drawn the cycles in a P v diagram; the process 1 to 2, it is a reversible isothermal expansion; when it goes from 2 to 3, it is a reversible adiabatic expansion and 3 to 4 goes as a reversible isothermal compression and 4 to 1 goes as a reversible adiabatic compression.

So, in this process, when we say isothermal expansion, the temperature remains constant. So, it is called as a high temperature source and when it rejects heats, it is treated as a low temperature sink. So, that means, a heat engine operates between two limits; that means, high temperature source and low temperature sink and we know their temperature because their process is isothermal and while doing this isothermal process, it takes heat from the source and rejects heat to the sinks.

So, for example, this process is such a slow process that here we are talking about adding heat to a system; but still we are keeping the temperature as a constant. So, although it is very slow process; that means, it is a infinite slow process. So, similar diagrams we can draw in a temperature entropy diagrams.

So, there the process the 1, 2, 3, 4, it is a rectangular in nature. Now, similar thing we can reverse it, so we call this as a reversed Carnot cycle or we call this as a Carnot refrigeration cycles. So, in that way, the process goes from 1 to 2, 2 to 3 and 3 to 4 and 4 to 1; but the difference that goes here that here heat is added in the process 2 to 3 and heat is rejected in the process 4 to 1. So, this is the basic difference between a Carnot cycle and reversed Carnot cycle.

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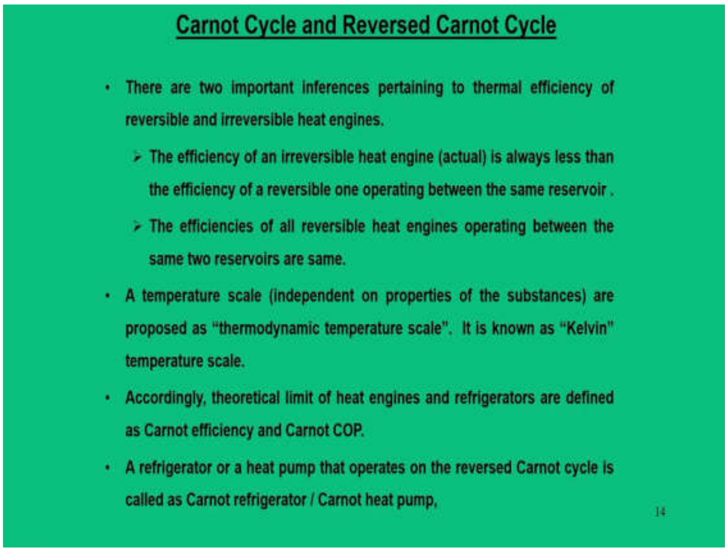

And what are the important consequence that the Carnot cycle gives us? There are two important inferences and it talks about the concept of thermal efficiency of a reversible and irreversible heat engine. The efficiency of an irreversible heat engine or actual heat engine is always less than the efficiency of a reversible one operating with between the same reservoirs.

The efficiency of all reversible heat engines operating between the same two reservoirs are same and also, there is another significant concept that introduced. It introduces a temperature scale which is independent of working fluid of substance. So, beginning when you talk about centigrade or Fahrenheit scale, it depends on the working fluid in the thermometer; but here the Kelvin scale does not depend on the properties of working substance.

So, introduce a Kelvin scale as temperature scale. And based on this temperature scale, the theoretical limits of heat engines and refrigerators are defined and we call them as a Carnot efficiency or Carnot COP. And similarly for refrigerator and heat pump, we call this as a Carnot COP for refrigerator or heat pump.

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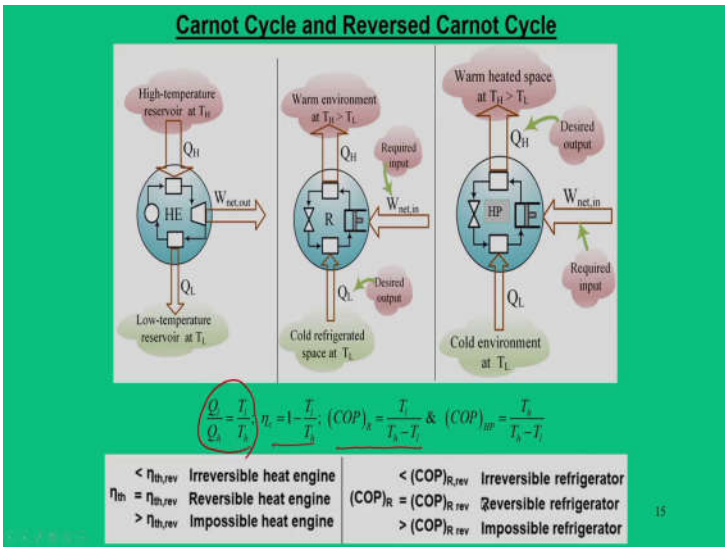

Now, how do you find this Carnot efficiency? So, one important thing that we dealt with a heat engine first. In that heat engine, we just state the introduced the heat that is Q_H, W and Q_L. Now, apart from this, we are also introducing the concept of T_H of high temperature source and T_L that is low temperature sink.

And from this Carnot cycle, when they introduce a Kelvin scale for a reversible process, a important relations that was developed that $\frac{Q_L}{Q_H} = \frac{T_L}{T_H}$. So, it is a linear relation and this linear relation is applicable when the temperatures are expressed only in the Kelvin scale.

So, that is the reason, the advantage of Kelvin scale because for a reversible process, we can relate heat and temperature in a linear fashion. By doing so and for a reversible process now Carnot efficiency for heat engine and refrigerator are defined.

So, for a Carnot efficiency, we can define as instead of $\frac{Q_L}{Q_H}$, we are going to put as $\frac{T_L}{T_H}$. So, we call this as a Carnot efficiency. So, for a heat engine, there are two efficiency; one is the actual heat engine efficiency, other is the Carnot efficiency. Similarly, for refrigerators, we have the Carnot COP, where the heat terms are replaced with T_L and T_H.

Similarly, for heat pump, we can say COP for heat pump is equal to $\frac{T_H}{T_H - T_L}$. So, now, having said this, we have two important conclusions; one for heat engine another for refrigerator. So, the efficiency of an actual engine is equal to reversible engine and for irreversible engine, it is always less than the reversible heat engine efficiency or Carnot efficiency.

But efficiency of any actual engine if it is greater than a reversible value, then such an heat engine is impossible. And similar logic is also true that actual refrigerator COP value of irreversible refrigerator is always less than their its reversible value. So, similar logic can also be framed for heat pump.

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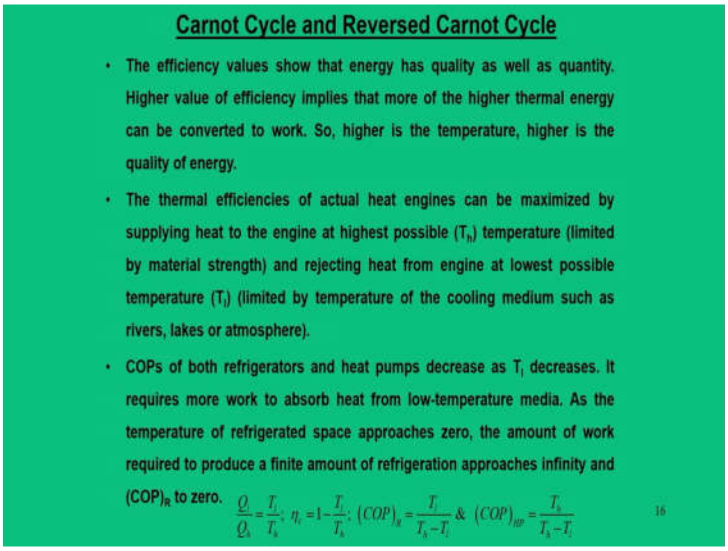

And finally, when we are going to conclude from Carnot cycle and reversible Carnot cycle, following statements can be made. First, when we are talking about efficiency, it is a thermal performance indicator that shows that energy has a quality as well as the quantity. Higher value of efficiency implies that more of higher thermal energy can be converted to work. So, higher is the temperature, higher is the quality of energy.

Second important conclusion can be derive that thermal efficiency of actual engines can be maximized; that means, for any actual heat engine, if you want to maximize the efficiency; that means, we can go up to the Carnot efficiency by supplying heat to the engine at highest possible temperature T_H.

That means, if you want to increase the Carnot efficiency either we have to increase T_H or reduce T_L so that efficiency will be more. Similarly, for COP also, we can have similar logic that COP of both heat pump and refrigerator decreases as T_L decreases and that means, it requires more work to absorb heat from low temperature media as the temperature of refrigerator space approaches 0.

That means, when T_L goes to 0, this means the amount of work required to produce a finite refrigeration approach to infinity. That means, COP of refrigerator goes to 0.

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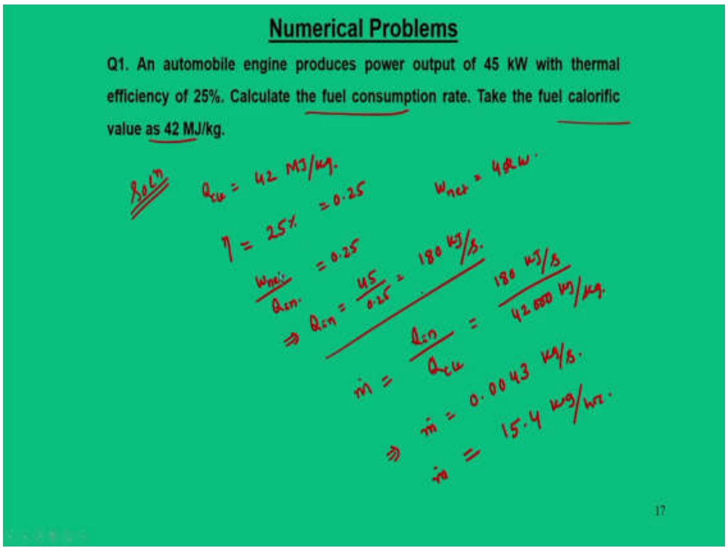

As far as numerical problems for this section is considered is just an arithmetic addition, subtraction, multiplication and the problems are very simple because the relations are also very linear. So, the first problem that we are going to talk about an engine produces a power output 40kW with thermal efficiency of 25%. Calculate the fuel consumption rate. So, we are given with fuel calorific value of 42 MJ/kg.

So, we can recognize calorific value as Q_{cv} and that is 42MJ/kg and we say efficiency as 25% or that is equal to 0.25. So, this efficiency can be written as $\frac{W_{net}}{Q_{in}} = 0.25$. So, we have Wnet is already given 45kW. So, from this, we can get Q as 180 kJ/s. Now we know calorific value; but we require fuel consumption rate. So, fuel consumption rate can be quantified as $\dot{m} = \frac{Q_{in}}{Q_{cv}} = \frac{180\,\mathrm{kJ/s}}{42000\,\mathrm{kJ/kg}} = 0.0043\,\mathrm{kg/s} = 15.4\,\mathrm{kg/hr}$

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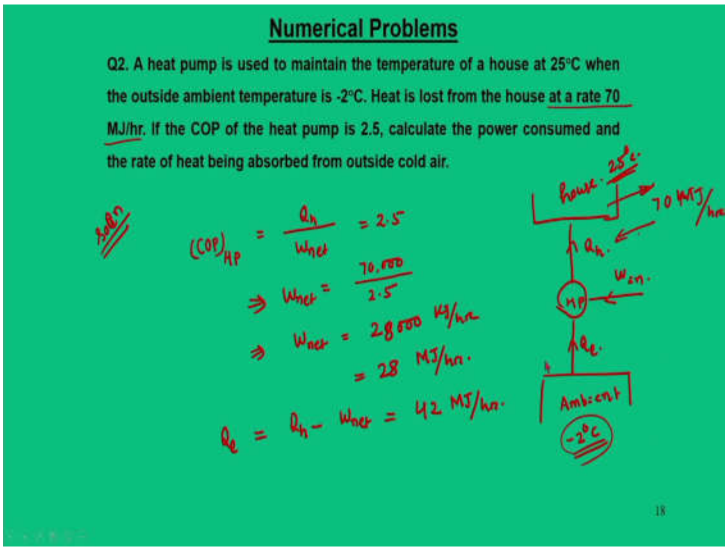

Next problem is deal with the heat pump. So, heat pump is used to maintain the temperature of a house at 25°C = 298K; whereas, outside temperature is -2°C = 271K. So, for the solution, what you have to do that we have to simply create a schematic diagram of a heat pump.

So, we are talking about a heat pump and it must reject Q_H of heat and takes Q_L of heat and it must consume see W_{in}. So, this we can say it is a house and this is what we can say ambient. So, ambient is at -2°C.

So, here we are not going to talk about to the temperature because it is simple heat pump and we are not talking about the reversible nature of the heat pump. So, temperature has no role in this problem. So, we will start with. So, what does it rejects? It rejects heat at a rate 70MJ/hr.

So, this should be same as that of Q_H. So, first thing we can start with the basic definition, $(COP)_{HP} = \frac{Q_H}{W_{net}} = 2.5 \Rightarrow W_{net} = \frac{70000}{2.5} = 28000\,\mathrm{kJ/hr}$ And then, we have to find out what is Q_L. So, $Q_L = Q_H - W_{net} = 42\,\mathrm{MJ}/\mathrm{hr}$. So, here, we have not given any kind of reversible nature. So, the temperatures has no role in solving the problems.

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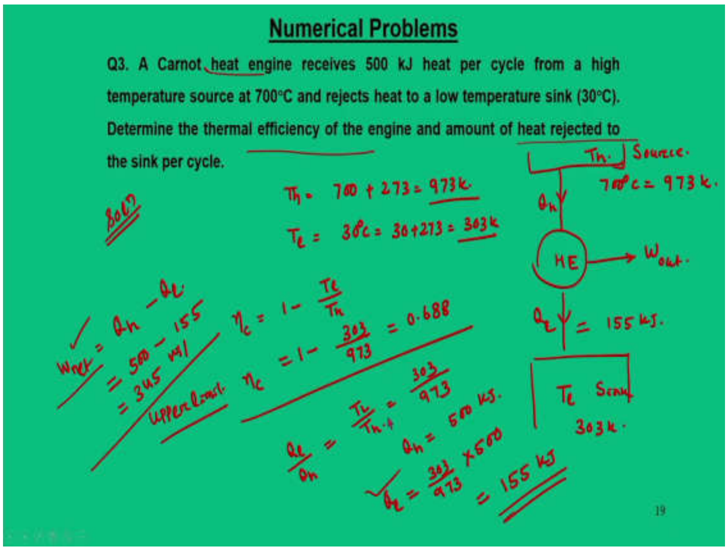

But the next problem, we will talk about a Carnot heat engine where temperature will have some significance. So, here for this Carnot heat engine, we have to also draw a similar schematic diagram. So, here it is a heat engine. So, we have a high temperature source. So, heat is coming from high temperature source T_H and source temperature is 700°C or 973 K. Similarly, T_L is 30°C that is 303K. So, these two conversion is a must. So, T_L it is sink, we can say 303K. So, heat is taken Q_H rejected as Q_L work output is W_{out}. What is asked what is the thermal efficiency of the heat engine? So, we say it is a Carnot heat engine.

So, first thing we can say Carnot efficiency, we can find out since it is a reversible heat engine. That is $\eta_c = 1 - \frac{T_L}{T_H} = 0.688$. So, efficiency of this engine is 0.688; that means this particular engine cannot have efficiency more than 68.8% that is the upper limit.

So, we say upper limit for this engine is 68.8% and when this engine operates in this limit, we are supposed to find what is the heat rejected to the sink. So, heat rejected Q_L

we can write the relations because the process is reversible, we can have this ratio $\frac{Q_L}{Q_H}=\frac{T_L}{T_H}\Rightarrow\frac{Q_L}{500}=\frac{303}{973}\Rightarrow Q_L=155\text{kJ}$.

$W_{net}=Q_H-Q_L$=345kJ . So, these are some simple problems. With this, I conclude my lecture for today.

Thank you for your attention.