Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Engineering Thermodynamics

Lecture – 20
Second Law of Thermodynamics: Basic Concepts 1

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So let us start this lecture with a thought process that is an attitude of gratitude.

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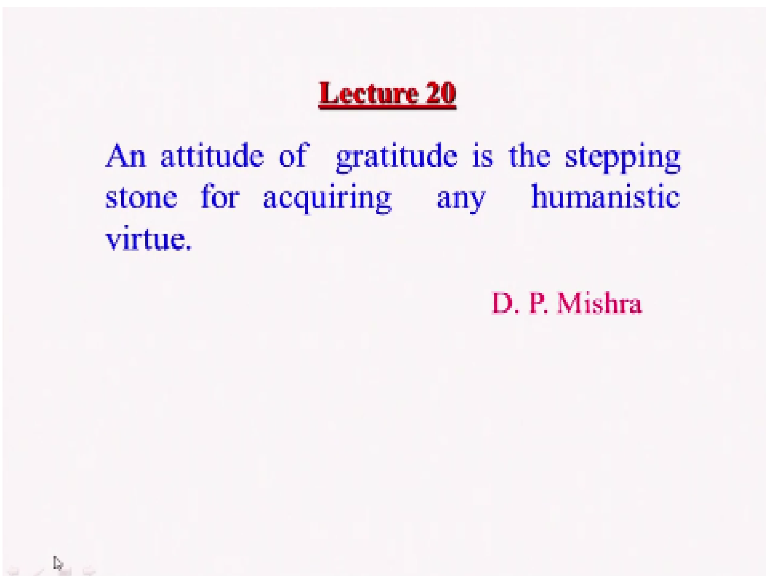

Is the stepping stone for acquiring any humanistic virtue and in the last lecture we discuss about how to use the first law of thermodynamics or reacting flows reacting system it can be flow problem it can be what you call control mass system or a control volume system it can be applied but we only emphasize on the control volume system and towards end I told that it that can be applied to the control mass system in which case the internal energy of the reactant will be equal to the internal energy of product particularly when you are calculating the adiabatic temperature that I have told.

And today we will be looking at what you call this first second law of thermodynamics pass today and first let us see that what are the limitation of the first law of thermodynamics.

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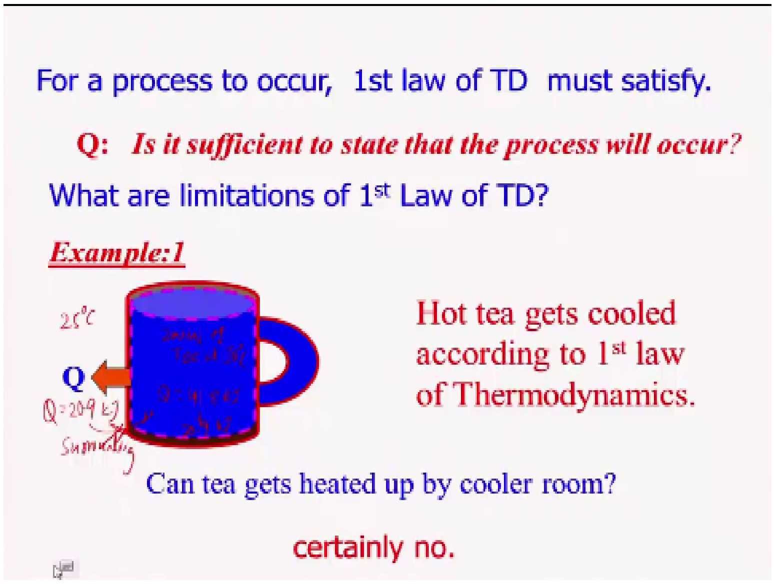

We all know that the first law of thermodynamic you know has to satisfy for a process to occur because we have seen several processes right and where we have applied the first law of thermodynamics and is it sufficient for a process to occur suppose I say that it is you know first law of thermodynamics we state that energy you know can be converted from one form to other, it can be neither created nor destroyed rather it can be converted from one form to other.

And basically first law of thermodynamics you know talks about like how the energy interaction takes place between system its surrounding, and let us take you know a few example to find out what are the limitation of first law of thermodynamics we will take our usual example of hot tea you know in a cup and if you look at let us say it this is a you know tea which is around let us say 200 ml of course little bit more but if we it is having in a temperature of something what you call 50 ^{0}C

So what will the amount of heat it will be having I am saying this is having at 50 ^{0}C and this is something 200ml 20 0ml of tea at 50 ^{0}C, so what will be amount of heat it will be containing in this cup you can very easily calculate right that if you take the 200 ml means basically 0.2 what kg you can say consider water instead of you know tea you can consider that the water the CP is

4.18 kilo Joule right, so what it will be then 4.18 kilo Joule into 0.2 in 250 that is something 41.8 what kilo Joule right.

So the amount of heat which is there with this is something 41.8 kilo joule of tea yes or no and now it is kept and the ambient in the where the ambient temperature is something 25 ^{0}C and will allow certain amount of time which is sufficient for this temperature you know tea which is from you know there will be some reach the equilibrium temperature with the ambient because the heat being transfer Q, so what will the amount of heat is going out what will be going out because this P will be reaching thermal equilibrium after you know let us say one hour or something like that okay.

25^{0}C that means half of the heat energy will be going out that is something 20 what you call 0.9 kilo Joule all right, yes or no so if it is going out that means the energy from here from the cup it has gone and what is remaining there here it will be this will be reduced to 20.9 kilo joule right yes or no. Now this amount is there in the surrounding this is your surrounding right, so this, what the first law thermo say that heat energy has gone from the hot tea to the ambient or the surrounding ambient air.

And then that energy can come back to it is it possible that is silent a first law is thermo not segment nay thing can go from here to their it can come from other way around right that means that we know from our common sense that we cannot really what you call heat the tea okay just taking the heat which is being transferred to the ambient air by itself right that means that whatever energy is there here can it get back to hear it would not it cannot be right it cannot be right.

So that is the common sense we do therefore it is not really possible for the process to take in the reverse direction that means you know from what we call to the am like you know from the cooler room to the tea okay so let us take a few more examples just to illustrate this point.

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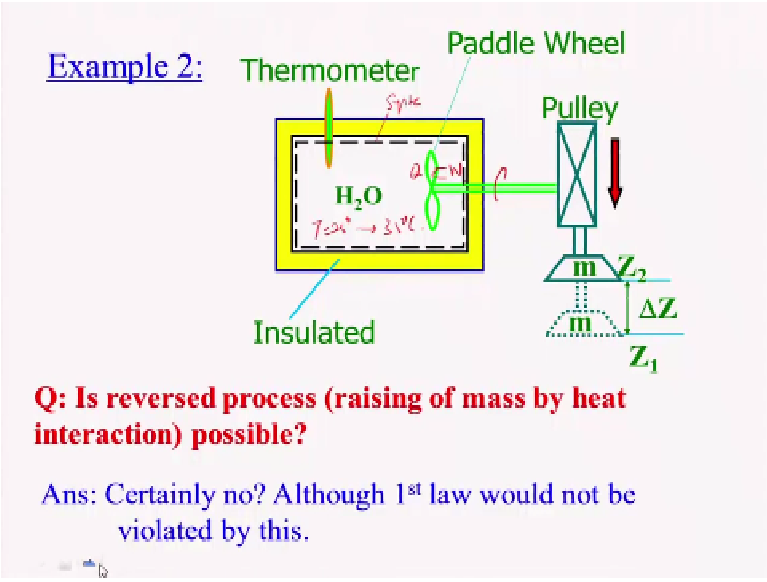

What we will do we will take a container which having certain amount of water and this is our control system I can say that is your system boundary right and then we will make the pedal wheel to run and it will be what you call the mass is being raised against gravitational field, so that means some work is done right some work is being done here as a result if it is at 25^0C and let us say it is going to the something 35^0C water you know tea right that means the work is converted basically into heat.

Whether that heat whatever the energy is there I can get the work done is it possible because now this has converted in the work is converted into heat right and can I get the use this heat to convert into mechanical energy or the work is it possible or common senses certainly know right, that means it is not possible for raising a mass by the heat interactions although the first law of thermodynamics would not violet if you say they look this heat you know can be converted into mechanical work this first law of thermodynamics is not violated by this right.

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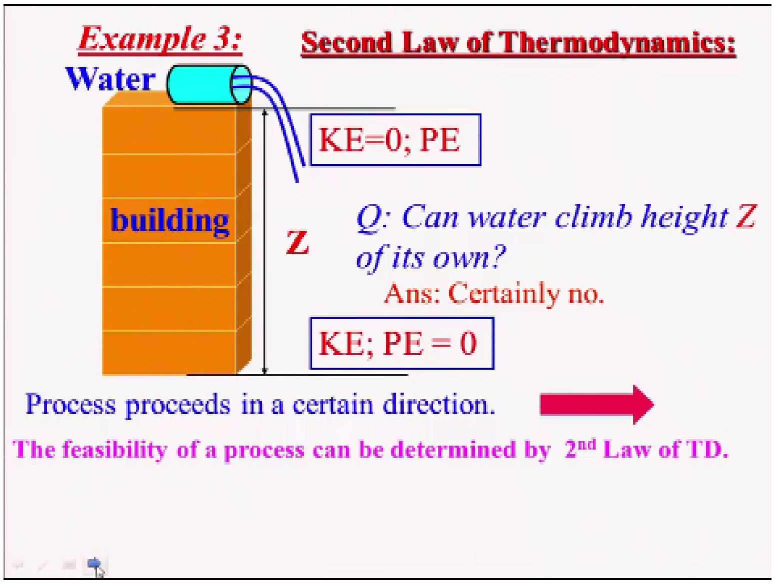

So let us take another example that means you know water store in a high rising building or any building rooftop and it will be you know again release from that and it will come down and there at the certain height Z delivering potential energy that is converted into the kinetic energy right, and of course at the ground level right and we cannot really get back this water into the tank which is placed on the rooftop again right.

So that our commonsense says that it is not possible right that means from these examples right what you can see that process proceeds in certain direction only right yes or no I will give an another example which is just crossing my mind like suffer example you are now youth right may be around something 17 or years back or 18 years back you people are toddlers you know moving around trying to walk trying to talk and other things right, and after few years you become middle-aged and then after you know many years you become old person right.

And whenever you talk with your grandparent they will say look my childhood was very great today I do not know why it is everybody wants to go back to a childhood right because that is the beautiful part of the life what people say, so now is it possible you can go back can anybody go back to the you know your childhood or maybe suppose your old to the middle age or to the youth no you cannot it is one directional.

Similarly you know that is the thing that means feasibility of a process basically can be determined by the second law of thermodynamics, so for a process to proceed that means you know both the first and the second law must satisfy it is not that fast learner that means the first law is necessary for any process to occur but that does not mean that it is sufficient but when you apply both the first law and second law that means the process you know will be possible.

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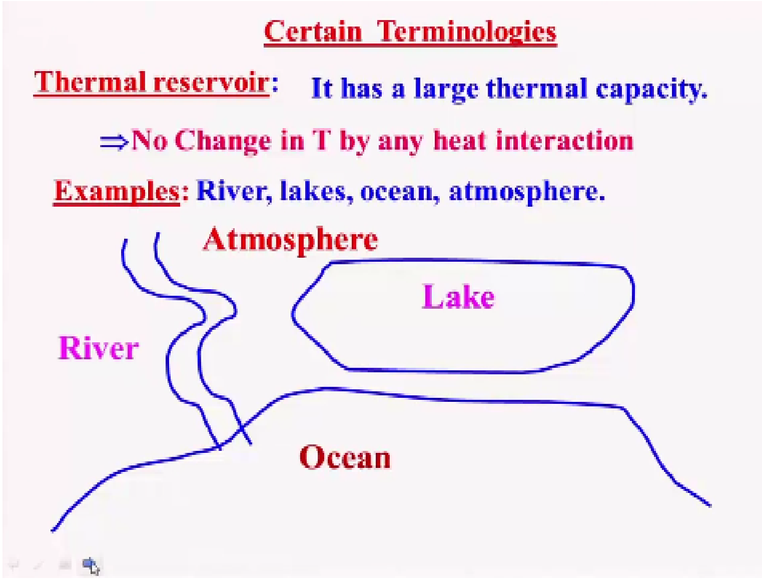

So let us before really delving into the second law of thermodynamics we will define certain terminologies because that is very you know important to get acquainted with the terminology of course you will be knowing that we will be using thermal desirable, so what do you mean by this reservoir basically it will be having a large thermal capacities right you know let me give an example of that right reserve means you know always we say reserve means water reservoir right is not it what are the server like if this is a very big lake is there right and I will take maybe you know let us say few thousand liters from that water.

That water level would not really change let us say I will take something let us say 10,000 liters you know but you might take a 10,000 liter from a what you call well then the height of the what you know water in the well will be reduced that means it is changing right and the therefore the reservoir is basically you know can be several thing that means the thermal reservoir which one in which no change in temperature will be taking place by the heat interactions right that means it will be very large amount let us say there is a thermal reserve right.

Let us say a combustion is taking place and you will take some amount of heat from that which is very less let us say boiler it is something megawatt you take some few kilo watt there would not be any change in temperature that right and the examples of reservoirs are River, Lakes, ocean and atmosphere right these are the examples of the reservoir as a told but this reserve also contains a large amount of the thermal energy.

If you look at yes or no even if you take let us say ocean you know it is a large amount of quantity of water and then it is having let us say something even if you take 25^0C it will be huge amount of thermal energy right okay of course that cannot be you know utilized as a source like we will divide this thermal reserve into two kinds.

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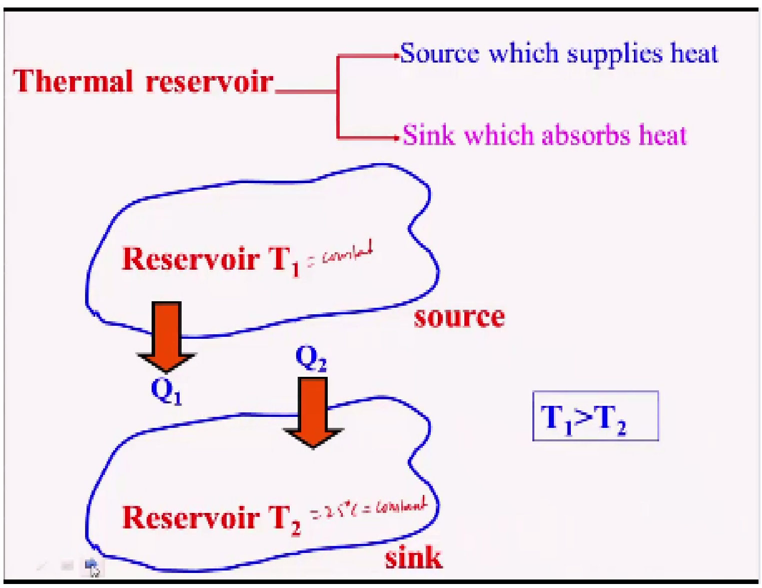

One is a source, other is sink that means that it is ever we supplies the heat to any system or engine that we call it as a source right and sink a which observe the amount of heat like kind of things so if you look at like your nowadays you know you take some money or the resources from your father, father is a source for you and you are giving to the you know staffs and other thing they are the sink right.

Suppose you are buying certain items and giving to a soft keepers are the people then that is a sink and your father is a basically source and you are utilizing it, so sink which observe the heat you know that we call it as a sink so reserve basically as I told that the source which is having a temperature t1if you take certain amount of heat Q this temperature would not change right this will remain constant right.

This will be remaining constant temperature would not be changing of that reservoir and similarly the sink if it is at certain temperature let us say if it is 25 degree Celsius right so if it is 25 degree Celsius right and if you are giving certain amount of it let us say it is a lake kind of things and you are giving some amount of heat to it you know so this temperature will be not remaining we will not be changing will be remaining constant so this will be right it would not be affected by the heat interaction.

Generally the source temperature will be much higher than the sink temperature right so the examples of the reservoir will be.

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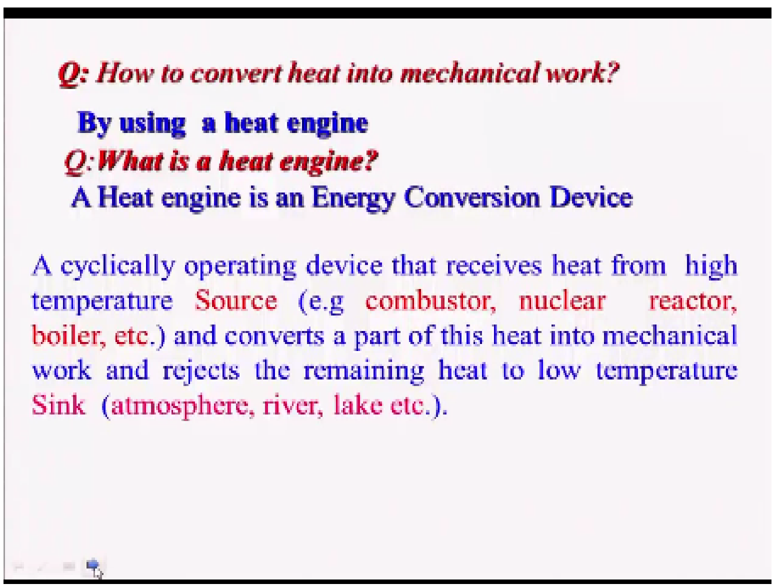

Basically as I told there will be combustor seven nuclear reactors and then boilers and other thing for the source and the sink will be you lake river and your what you call pond and then see that is why you know we are using the basically or environment or the you know air itself so we are giving large amount of heat into that therefore that is a increase in the temperature you know kind of thing.

So basically we will have to say that how we can convert the heat into mechanical work, so that is by using a heat engine and heat engine is basically a energy conversion device that takes at an amount of heat from the thermal reservoir that we call source and then it will be giving some amount of feed to the sink and also produce certain amount of work done so therefore heat engine can be defined as a cyclically operating device.
That receives certain amount of heat from high temperatures source that is the thermal reservoir right high temperature and the example as I told combust a nuclear reactor boiler any other things one can think of and converse a part of this heat into mechanical work and rejects the certain amount of it or the remaining amount of it too low temperature what we call it as a sink low temperature sink and it can be atmosphere the sink you know it can be river it can be lake and other things.

So if you look at like there are you know that is the way how it has to be done that heat engine operates.

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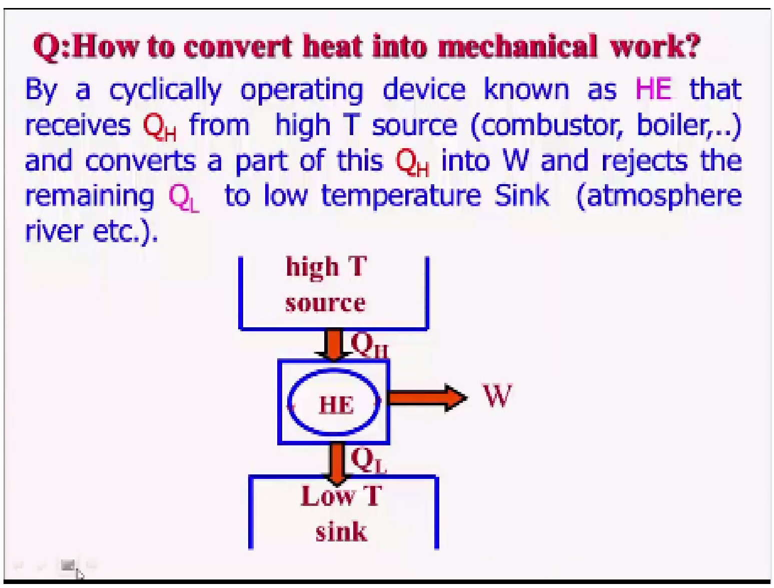

So question is how to convert heat into mechanical walk so what we will do like we'll have to as I told earlier that will have to take certain amount of heat that is QH from the source high temperature source and this is a cyclically operating device heat engine and it will be a certain amount of this observe read from the source will be converted into work and certain amount will be rejected to the sink. So by this way one can really what we call convert the heat into mechanical one.

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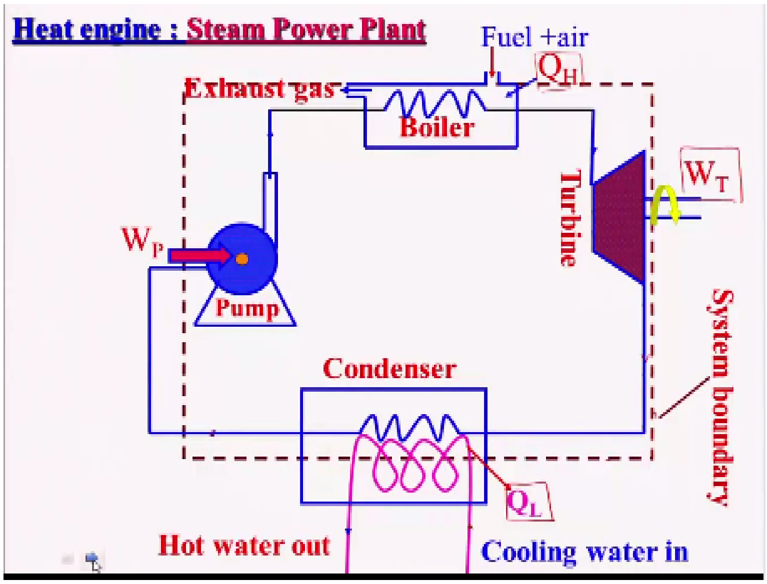

So let us take an example like in heat engine and this example is steam power and there are several kinds of heat engine steam power plant is one of them, in this case if you look at this is the what you call the boiler which is basically last amount of heat being generated and from this the fluid will be taking certain amount of heat QH and then it will be going to the turbine which will be expanded and then the work mechanical work is being article obtained.

And then that fluid will enter into the condenser where it will be rejecting the heat to the cooling water right which is cooling water will be coming and then going become a heart so then again this fluid is basically getting into pump and this pressure will be raised again it will be entering into the boiler so if you look at this is a closed cycle right it is a closed that means fluid is not going out therefore if I want to analyze this what I let me use.

Whether the control volume or control mass definitely it will be the control mass system and this I have taken it is your system boundary right this is your system boundary now you keep in mind that what is happening here, here the boiler to the system boundary certain amount of heat that is QH is entering and the certain amount of heat is going out from the system boundary to the your cooling water that is QL right and work is being produced that is by the turbine this is WT. And you will have to supply the work for the pump what is the net work done then here that will be WT - WP is you net work done.

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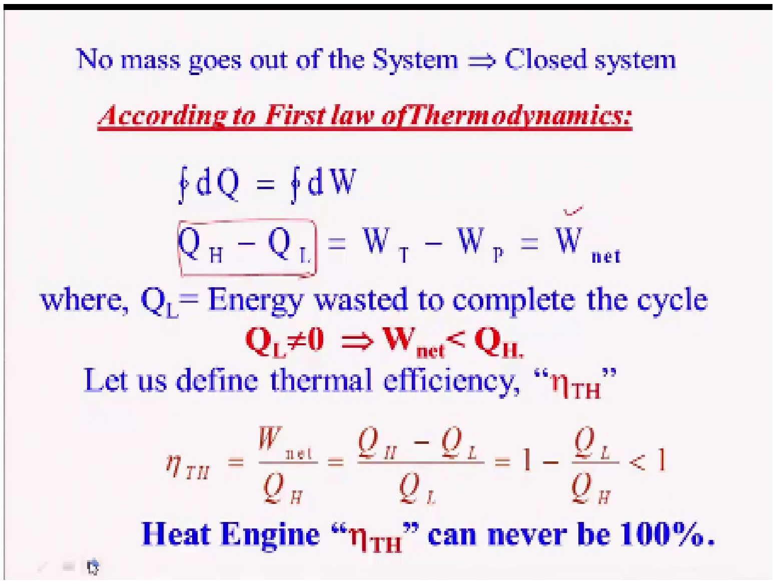

So what we will do as I told no mass is going out from the system boundary right so therefore we are using a closed system and according to the first law of thermodynamics the cycle integral of DQ is equal to cycle integral of the DW that is the work and we have seen that the amount of heat which is entering into the system by the source is QH and QL is the amount of heat is going to the sink and is equal to the amount of work produced by the turbine.

And you will have to supply the amount of work to the pump and that is your net work done right and this is just you are applying the first law of thermodynamics for acyclic process because this steam power went works in a cycle and as this QL cannot be 0 right certain amount allowed to give therefore the network is always less than QH the amount of heat which is observed from the source is always will be higher than the amount of work produced by the turbine over the network.

Basically it is the turbine work minus the pump that is the network what you will get because from the turbine you will have to give some amount of work to the pump to be operated so therefore we will define a term to characterize how good it is that we call it as a thermal efficiency that is by definition that is ηTH = W net / QH and what is this w net, w net is nothing but your QH – QL that is your w net.

So QH – QL/ QL = 1 QL/QH keep in mind that QL will be some finite right so therefore the thermal efficiency will be always less than hundred percent that means all the heat cannot be converted into the one right, so that is the things what we are looking at it so heat engine basically efficiency can never be you know hundred percent it will be always less than one hundred percent right.

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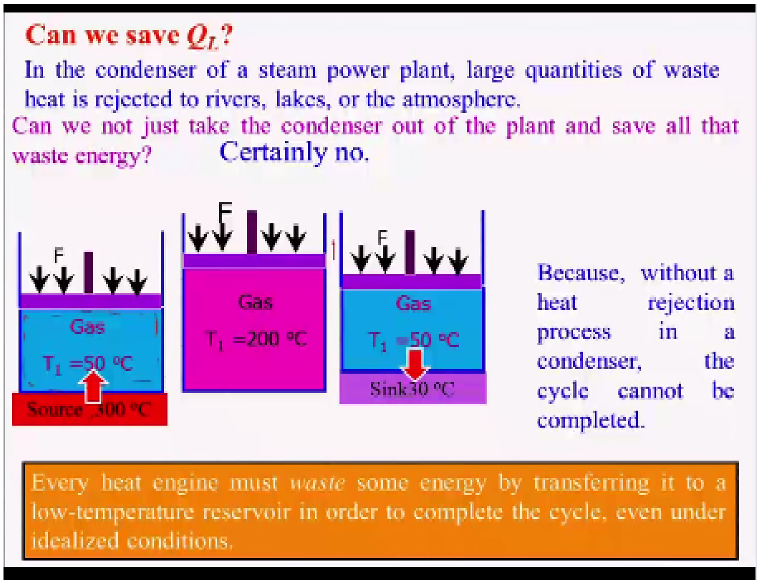

So is there any way we can you know minimize this heat which is going to the sink you know it being lost to the sink so in a condenser we have seen that a steam power plant large quantities of waste heat is rejected two rivers lakes and atmosphere therefore you will find the temperature is being what you call the places being increased and then Marine life also being affected because you are producing a large amount of putting it not only that pollution also you know water pollution so another things comes into picture.

And so can we just not take the condenser out of the plant and save all the waste energy because the Waste is it possible that I can utilize those heat which is going to the condenser for some other purposes so that you know I can enhance the efficiency right so that is the challenge what is being done and the people have trying to eat use it but I will be not discussing about that and but however you know you cannot eliminate it you can minimize you can reduce it but you cannot make it zero QL.

Why it is so let us look at that we are having a gas you know at let us say 25 degree Celsius to start with right and it has been connected you know what you call if you look at like it is having I can take this as my system right and it will become connected with the source which is at 300 degrees Celsius and then what will happen like it will be gas temperature will be increasing right and when it will increase let us say it is going to 200 degrees Celsius that means the work is being done right.

Piston is moving up in this case now right so then after that it has reached the state 200 degree Celsius let us say of course you can increase this further to the 300 degree Celsius and giving suburbs are certain amount of heat into the gas but now I want to get it done because it has reached a state where it cannot come back again unless sit is that means I will have to put into you know what you call into a seeing to make it cyclic to work it continuously right.

So what else you I will have to give this gas what you call bring a sink here and then put that thing so that heat will be transferred and then the piston will move back to again original state that is what you call 50 degree Celsius and then so that again it will go as a cycle otherwise you can get the work done you know for a certain period of time after that you cannot so it has reached the state.

So therefore it is very important to that you know without heat rejection process in a condenser the cycle cannot be completed right if it is not completed you cannot really get the work in a continuous manner you will be getting the work in a discreet manner right so therefore it is important to reject the heat so we can conclude every heat engine must wear must waste certain amount of energy by transferring heat it to a low temperature is ever in order to complete the cycle even under idealized condition right. So therefore it is very important you know that heat engine has to reject certain amount of heat to the sink.

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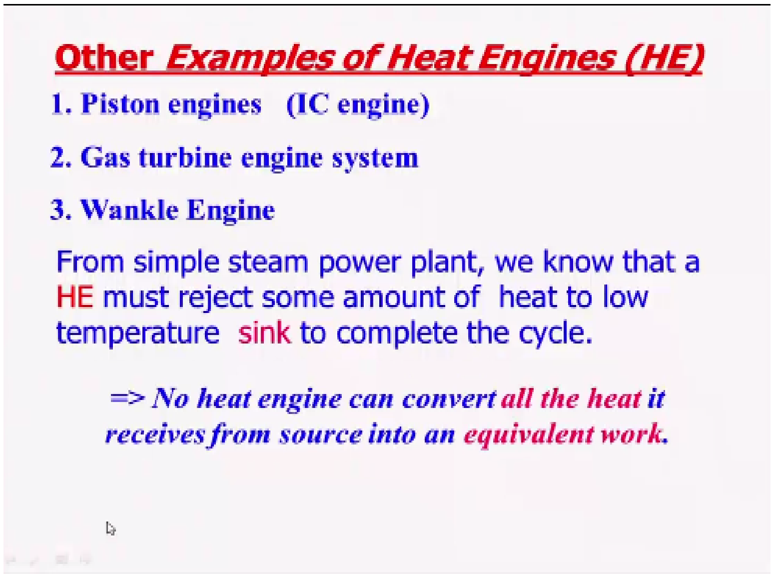

So other examples of heat engines upwards the piston engines like what we use in automobile and gas turbine engine Wankel engines and but from a simple steam power plant we know that heat engine must reject certain amount of it to low temperature sink to complete the cycle right. So therefore we can say that no heat engine can convert all the heat it receives from the source into equivalent walk. So it is impossible to observe certain amount of heat from a source thermal reservoir. You know and do the equivalent amount of work.

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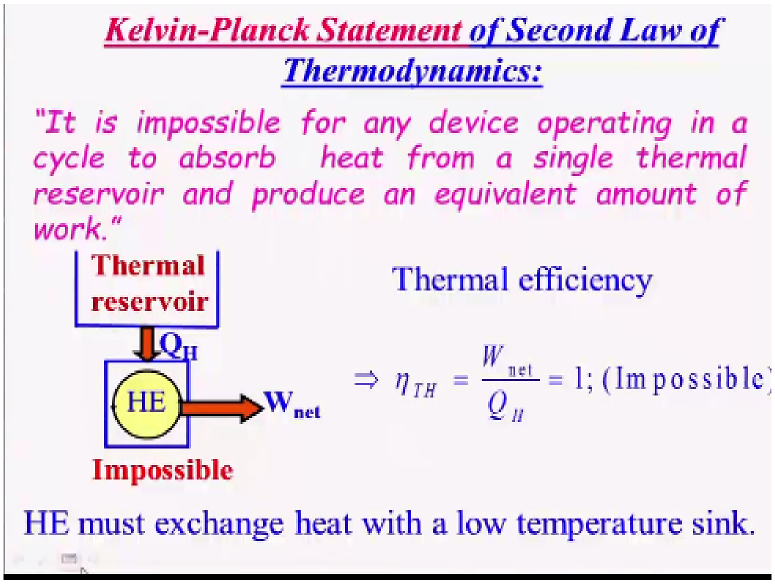

So that is basically the Kelvans plank statement and of the second law of thermodynamics that we states that it is impossible for any device operating in a cycle to observe the heat from a single thermal reservoir and produce an equivalent amount of work. That means if you look at you know schematically that is it is impossible to have a you know cyclic operating device heat engine certain amount of Qh and converted you know that fully to the work mechanical work.

That means the thermal efficiency of this heat engine you know can never be equal to one hundred percent it will be impossible up to that kind of engine which is having one hundred percent efficient thermally thermal every one hundred percent efficient thermally. That means heat engine must exchange heat with a low temperature sink.

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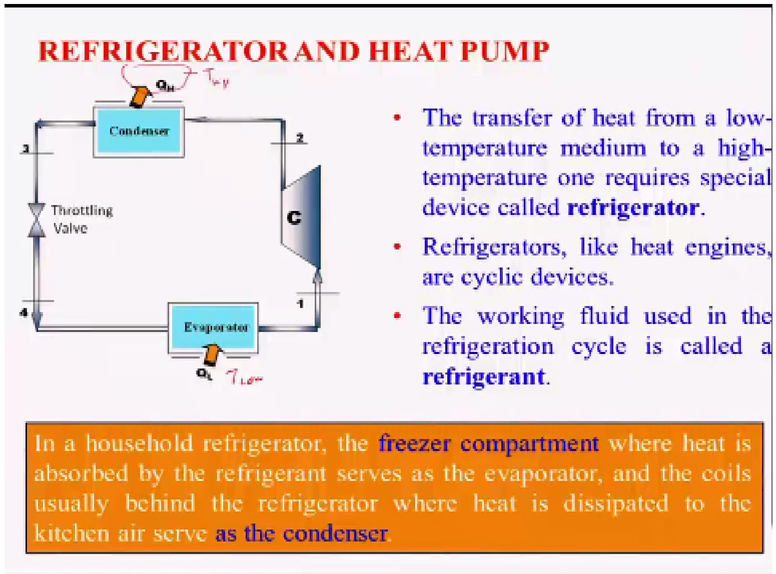

So let us look at refrigeration and heat pump. The basically if you look at what we have seen it heat engine which will be absorbing certain amount of heat from the thermal reservoir and giving certain amount of heat to the sink and doing the same amount of work but there is another application where the heat has to be taken from the low-temperature medium to the high temperature. And of course you will have to give certain amount of work that is you know like for example you are doing the air conditioned.

Right and in which case the heat has to be basically taken from the low temperature medium and leaving. Let us say from this room this is the low temperature and then it will be transferred to the surrounding that is the ambient air which is at higher temperature that we call it as a refrigerator. And refrigerators like heat engine have to be operated in a cyclic manner right it is basically a cyclic device.

So let us consider the how it operates and what it will be doing it will be basically taking certain amount of heat you know in evaporators' right and then it will be compressed and again in the condenser which will be you know certain amount offered has to be rejected to the high temperature surrounding. So if you look at the surrounding will be at a high temperature you know like you know higher temperature high temperature and this is your tea low temperatures kind of.

And then it has to expanded in the throttling valve which we have discussed in the maybe few lectures I mean like back kind of things that where we told we have found out that this is an isenthalpic process right and where the temperature will be reduced and then it will come back. So if you look at this operates under cyclic what you call way. So working through it you know will be used and that wit in this reference cycle is known as the refrigerant there are various kinds of refrigerants will be being used and some of them are toxic in nature also and it gets.

So in the household refrigerator if you look at the freezer compartment where heat is observed by the refrigerant serve as a evaporator right and the coils usually behind the refrigerator where heat is dissipated to the air of course if were kept the your refrigerator in the kitchen that is the kitchen air serve as a condenser. You might have seen that is quite hot you know like of course nowadays the people are covering it and done has to keep this refrigerator properly you know otherwise it will not function properly. Why because the heat has to be dissipated.

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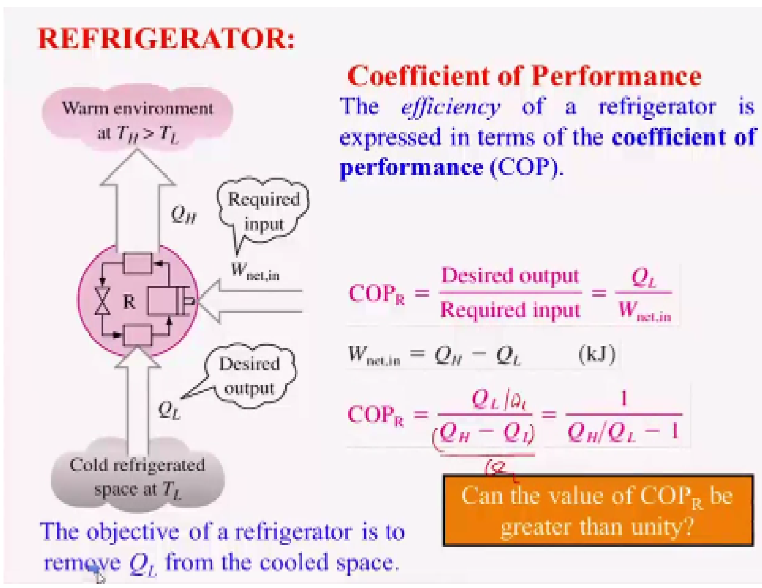

So let us look at that you know how to you know evaluate or the its performance for example this is a refrigerator which is taking certain amount of the heat that is q l at from the cold refrigerated space that is you are basically evaporator. You know kind of thing at T L is a lower temperature and then certain amount of work is being done right put into this and then you will be transferring Qh amount to the warm temperature that is TH is greater than TL.

That means you know this temperature is basically you know is higher than the low temperature now. If you look at this is your that means always will have higher amount of this heat which will be extracted so that the temperature will be maintained at particular low temperatures were fixed or it will be worth. So therefore we will have to you know define a term which is known as the coefficient of a month's right and is basically a ratio of the desired output by the required input.

Right that is the co p we call coefficient of performance that is Ql / a net input work input. So the net work input will be nothing but QH - QL and CEO p is basically Ql / Qh - QL if you look at if I can divide by this I will get the ratio basically if I / Ql here and this l I will get 1 over Q h / q l-1. So this is the way how it will be you know you can evaluate how good it is and is it this coefficient of performance will be greater than 1 or less than 1 what it will be.

We have seen the heat engine is basically always will be less than 1 right we have seen in this case what it would be what it would-be right it will be always greater than one right is not it and if you look at why we have not used the efficiency thermal efficiency here for the refrigerator why you have really divide the coefficient of performance why because we have already defined you know thermal efficiency cannot be greater than 1 if we will define that way that means it will add to the confusion. So therefore we use a new terminology known as coefficient of performance.

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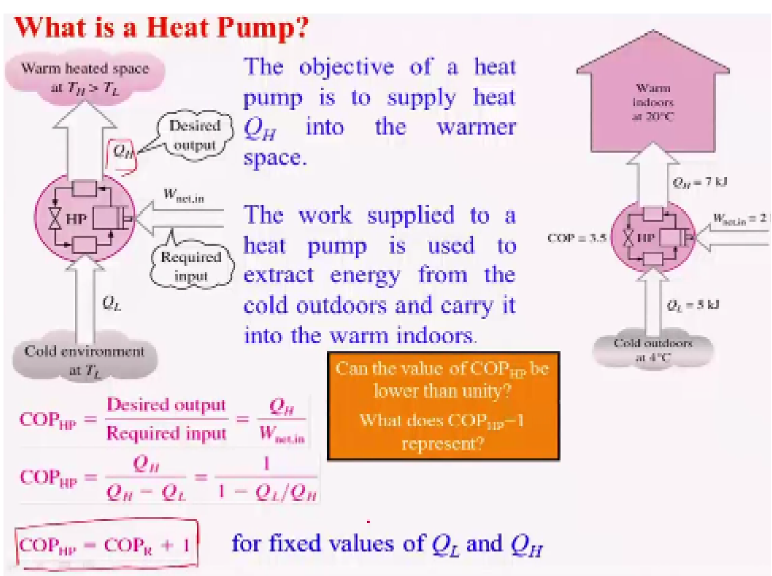

So what let us look at a heat pump and heat pump is basically we use in the winter season right where you will have to supply the heat you know to the your room which will be at higher temperature as compared to the ambient will be lower temperature right kind of things to anything. So in that case it is just the application what matters right so as I told the objective of the heat pump is to supply heat QH into warmer space and the work supply to the heat pump is used to extract energy from the cold outer and carry it into the warm indoors.

For example like if you look at this is the heat pump and which takes the heat from the cold environment temperature. Let us say in the ambient air in the winter season QL and then certain amount of work is done input is given and then it is the certain QH amount of heat has to be go to the you know warm heated space. So if you look at in this case the desire what you call output is QH in case of refrigerator what was that desire output is the QL.

Just opposite you know so and let us take you know like a an example like warm like warm indoors will be you can try to maintain at 20 degree Celsius and whereas the outer you know temperature which is at four Celsius. That means you will have to take certain amount of heat from this low temperature you know let us say five kilo Joule then you add something to kilo Joule of work input.

Then you have to supply the amount of q h 7 kilojoules of course and in this case the cop is something 3.5 kind of things this comes you know if you just do that. So this is basically the heat pump what we call and CEO p of heat pump can be defined as a ratio of desire output divided by the ratio of desire output and required input that is QH/AW net and that is co p is basically QH/ QH – QL.

So we can say that it is1 by q 1 minus QL by QH so for the same input you know heat input ratio like sorry for the same QL /QH whether the co p of HP will be same as that of the refrigerator or it will be different how it can be related let us see that and before that we will see that that the value of the co p you know lower can it be lower than the unity certainly know.

It will be higher than the unity as I told in the refrigerator case and what does Co PHP equal to 1 it basically it says that whatever the you know energy if I say this is equal to 1 right-eo p is equal to 1 means what that means the QL right whatever it is going it will be from the cold temperature it will be getting into the warm heated temperature without any work input you know that is really not possible

So you can from this one can say the co PHP is equal to c 0 PR + 1you can derive that expression right that means which says that COP for the same ratio the EOP of refrigerator you know will be lower than the GOP of the heat pump for the same what you call heat interaction right for a fixed values of Qln - Qh. So keep in mind that the COP of the HP is higher and generally the coefficient of performance of the refrigerator you know is being arranged something maybe around two to three kinds of things.

But if you use letups say you want to store your ice cream you know at a very low temperature so that it would not melt down then therefore you will have to you know there you want freezer kind of things or you want to store the meter fees in a low temperature then that co p of the refrigerator is very low.

It will be around something 12 to kind of things now when you are designing you know you will have to take care like what is the application but if you combine that both together you want to have then you will always having a very low c co p and loco p means the cost of the things will be very high right so what I am saying this performance parameters helps to a tailor your design depending on the application so let us consider that like you’re basically a engine like heat engine kind of things reverse heat engines.

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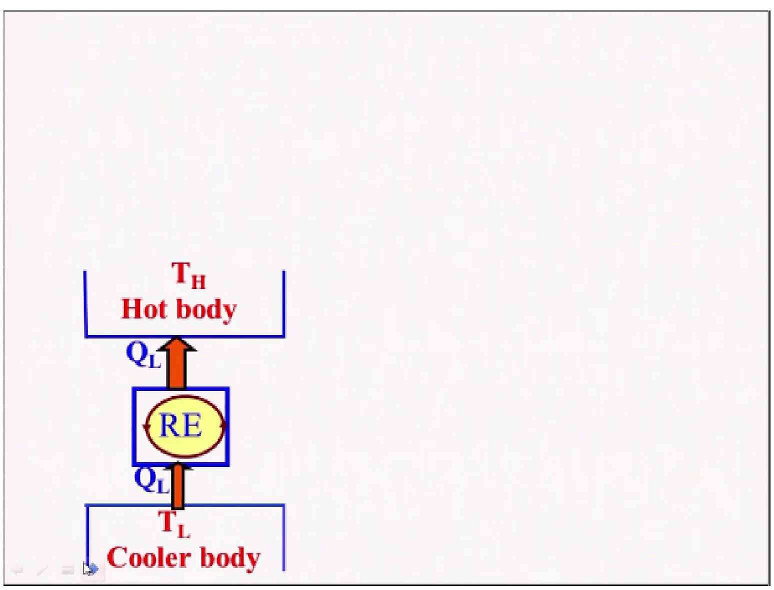

That is we say that it takes certain amount of key well from the cooler body and also gives the certain amount of weed the same amount of it you know to the water bodies and which is really not possible because no spontaneous flow of heat is possible from cooler book body to the hotter body by its own we have seen you know like and that is nothing but your classiest statement we say that it is impossible for any device operating.

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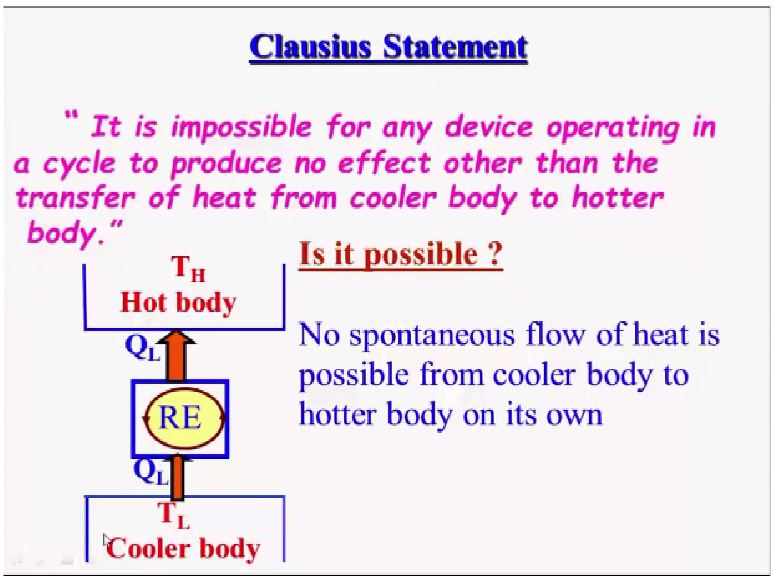

In a cycle to produce no effect other than the transfer of heat from cooler body to the hotter body if you look at Kelvin plank statement is about basically the heating and the classiest statement is basically about the refrigeration system or the heat pump right so now question arises you know like we'll have to see that another words it says that it is impossible to construct a refrigerator without any external walk.

And co p of refrigeration is infinity you know is impossible rather always see will be greater than 1 and second love Amanda based on experimental evidence till now no experimental evidence exists to disc prove this statement right to kind of things so therefore you know it is there and it is similar to your first law of thermodynamics and there might be one question coming to your mind like is this Kelvin plank statement.

Same as that of the ecclesia statement right because one is 48 engine and other is for the your if you look at class a statement is for the your aviator is it same or different so what we will do we will look at it.

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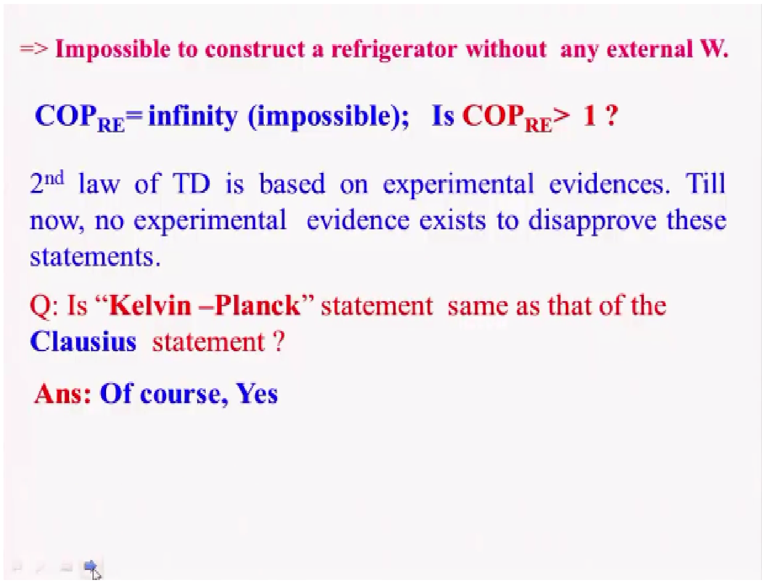

Of course the answer is yes but can we prove it what we'll be doing we'll be taking a deduction route to say that it is true that both the statements are you know same so let us assume that Kelvin plank statement is incorrect right what that means what that means there is a heat engine reversible heat engine that takes at an amount of heat and does the equivalent amount of works that is the thing what I was telling that the thermal.

From thermal reservoir there is a heat engine which takes at an amount of heat that is q1 and it does the same amount of work hypothetically you were saying it is true now let us take this that Is another reversible heat engine that is your refrigerator which takes at an amount of heat all from the low temperature reservoir thermal reservoir and certain amount of work is done and as a result it gives this reverse heat engine.

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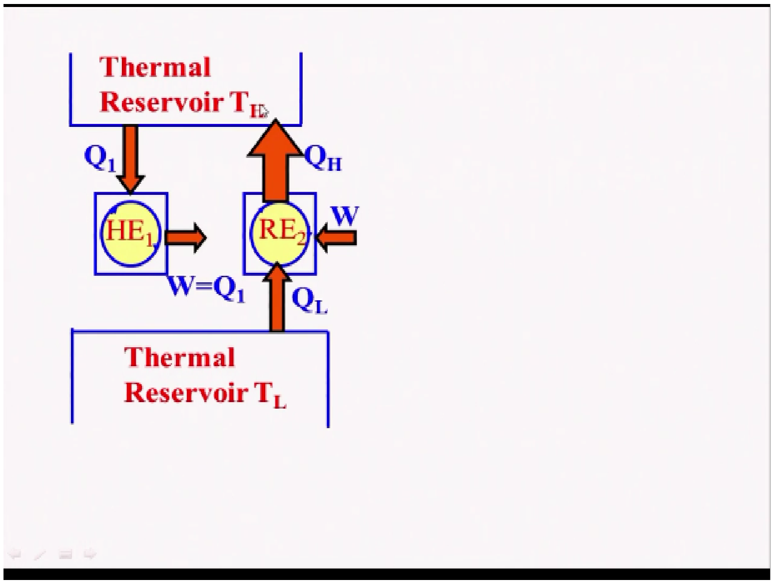

That gives the q h amount of heat to the thermal reservoir right that is a source and will dowel can say that this basically q l and this amount instead of these what will say we will take from here from what you call this amount of heat is taken from here instead of this you know kid one right it basically take this amount of heat q1 and then it is not taking from thermal reservoir as a result what happens that it gives if I take this as a my you know combined a system or this thing.

That means it takes at an amount of heat all and it is giving the same amount of it to the thermal reservoir at high temperature that is called source right it takes from the sink all amounted it this is your sink right and it gives to the same amount of feed to the what you come to the source that means it violates the classiest statement okay that means what I can say violation of Kelvin plank statement leads to the violation of statement.

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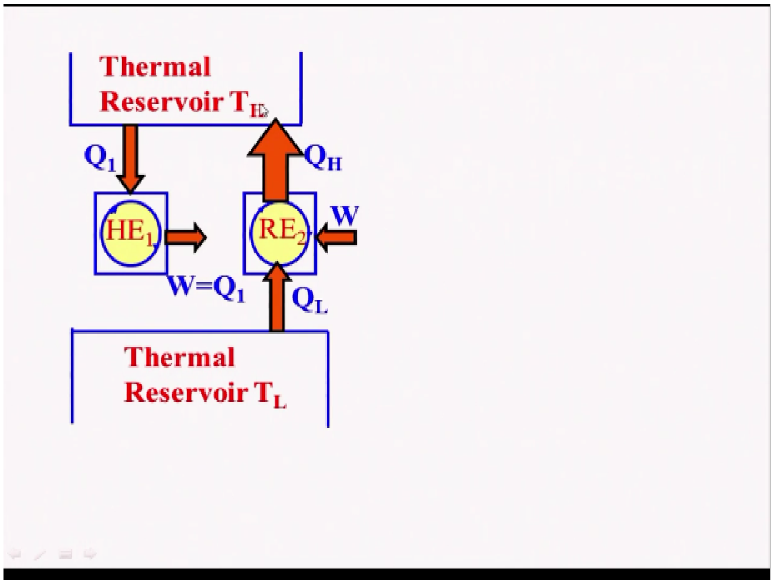

So let us look at other way around we will say that classier statement is actually violated right that means I will say that there is reversible heat engine which observe ql amount of it and also giving the same amount of all to the source which is at higher temperature than the sink so then what we'll do we'll again consider the another heat engine which observe qh amount of heat and it does certain amount of work and leaves certain amount of he that is Q well into the sink.

Now we will combine it right and together that means this amount of heat is going here what we call all instead of going tithe thermal reservoir this is going to this place all right and this ql instead of going here you give to this place you know so what will happen the whole system says that that means this system the new system when you combine it takes q h minus QL amount of heat from the thermal reserve right and does the same amount of work that is q h minus .S state that that violation of class statement.

Leads to the violation of Kelvin statement therefore that classy statement is equal to Kelvin plank statement so we have seen that both the Kelvin plank statement of the second law of thermodynamics is same as that of the Clauses statement of second law of thermodynamics on we have seen so we will stop over here and we will consider the other aspect of second layoff thermodynamics in the next class you.

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