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Basic Thermodynamics

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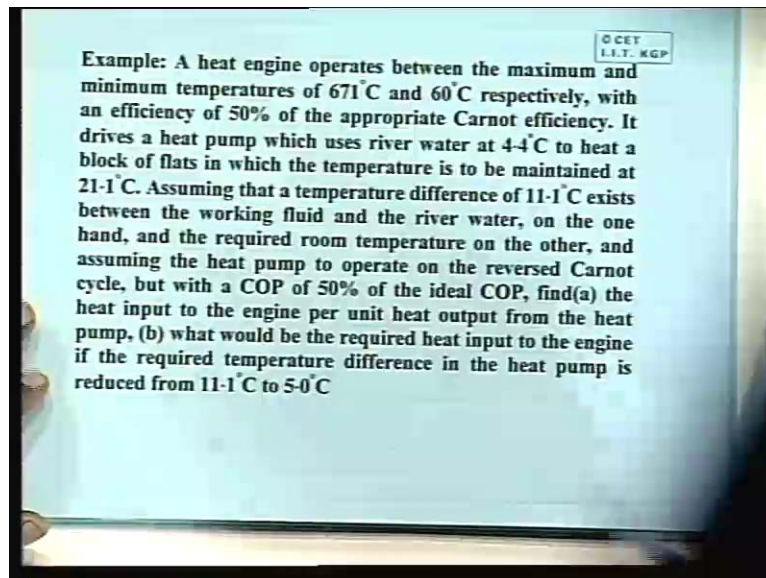**Indian Institute of Technology, Kharagpur**

Lecture - 10

Second Law and Available Energy - I

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Let us start with that example problems then I will start a new section.

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As I told earlier, the concept of availability, but before that we will go through these example problems.

First example: A heat engine operates between the maximum and minimum temperatures of 671 degree Celsius and 60 degree Celsius respectively, with an efficiency of 50 percent of the appropriate Carnot efficiency. That means, a heat engine is prescribed which is operating between the two thermal reservoirs, 671 degree Celsius and 60 degree Celsius, but it is an irreversible heat engine where the efficiency is 50 percent of the appropriate Carnot efficiency. This heat engine drives the heat pump which uses river water at 4.4 degree Celsius that means from this temperature of 4.4 degree Celsius that of the river water, heat is been extracted by the heat pump to heat a block of flats where the heat is being delivered in which

the temperature is to be maintained at 21.1 degree Celsius that means for heat pump the two thermal reservoirs are 4.4 degree Celsius where from heat is being taken and 21.1 degree Celsius where the heat is being delivered. So, from low to high temperature, this is because the heat pump operates like that where it takes work from surroundings that is in this problem from this heat engine which is working between these two (Refer Slide Time; 02:53 min) temperatures.

This is definition of the problem apart from that there is another thing. Assuming the temperature difference of 11.1 degree Celsius exists between the working fluid, it is very important, and the river water on the one hand and the required room temperature on the other that means when the heat pump operates, the working system temperature, the system executing the cycle when it rejects, exceeds is not 4.4 degree Celsius. Similarly, when it delivers heat, it is not 21.1 degree Celsius, there is a difference between the temperatures of the working system in the heat pump with the thermal reservoirs on both the sides is 11.1 degree Celsius. Assuming that a temperature difference of 11.1 degree Celsius exists between the working fluid and the river water, on the one hand, and the required room temperature on the other, and assuming the heat pump to operate on the reverse Carnot cycle, but with a COP of 50 percent of the ideal COP.

The reverse Carnot cycle means the ideal or a reversible heat pump. So, this heat pump is an irreversible heat pump and that can we can very well recognize that there is an irreversible heat transferred because of the finite temperature difference of the 11.1 degree Celsius. This is one of the reasons.

This COP of this heat pump is 50 percent of the ideal COP. So, this is the case. We have to find out the heat input to the engine per unit heat output from the heat pump, and what would be the required heat input to the engine, that means the same thing heat input to the engine per unit heat output, if the required temperature difference in the heat pump is reduced from 11.1 degree Celsius to 5 degree Celsius that means this one (Refer Slide Time: 04:49 min) is reduced to 5 degree Celsius. This is the difference in temperature on both the sides of the reservoirs, between the working fluid and both the reservoirs, that 4.4 degree Celsius and 21.1 degree Celsius. This is the problem. So, now let us see, how we can solve this problem.

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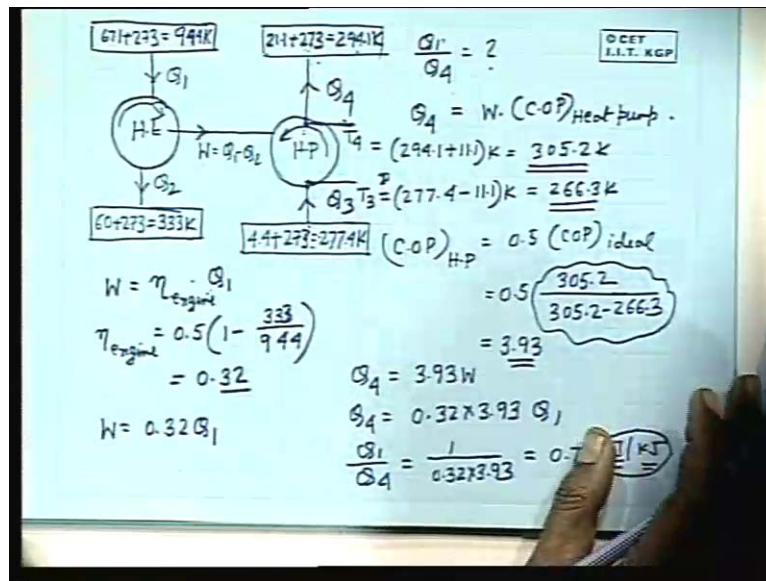
Now the problem again if it is defined is like this. There is a source temperature for a heat engine. This is 671 degree Celsius that means it will be absolute 671 plus 273 is equal to 944.

This heat engine operates, this is the heat engine on a thermodynamic cycle and it delivers heat to the temperature 60 degree Celsius that means 60 plus 273 as we know this is the conversion from Celsius to Kelvin that will be, how much? 333 Kelvin.

This heat engine delivers what?(Refer Slide Time: 06;16 min) Now, this is the heat input Q_1. Let the heat rejected out of the engine is Q_2. So, W is delivered which is definitely is equal to Q_1 minus Q_2, but this drives a heat pump that is the problem. This is the heat pump which operates on a reverse cycle and here the temperature (Refer Slide Time: 06:45 min) is like this from which it takes the heat that is 4.4 plus 273 is equal to 277.4 K and what this temperature, where heat is being is? Let this heat taken be Q_3 and let this heat rejected be Q_4. So this temperature to which heat is being delivered is 21.1 plus 273, what is this?

294.1 K. Now, we have to find out, what is Q_1 by Q_4. Now you see the efficiency of this engine HE is 50 percent of the Carnot efficiency. Therefore, work is eta engine into Q_1. So, I always try to induce the parameter Q_1. So, I will use the formula which always involves Q_1,

because we have to find out Q_1 by Q_4. So, my first job is to find out eta_{engine}. What is eta engine then? eta_{engine} is 50 percent of the Carnot engine efficiency

Carnot efficiency is 1 minus 333, we know the Carnot cycle, if this could have been a reversible heat engine. So, this efficiency could be equal to that is the Carnot efficiency.

1 minus T_2 that is the temperature of the thermal reservoirs where heat is rejected divided by T_1. It is a thermal temperature in thermodynamic absolute scale of the reservoir from where heat is being taken that means eta_{engine} is 0.5 into 1 minus 333 divided by 944 and if we equate this value, this will come to 0.32. Therefore we can write W is equal to 0.32 Q_1. Now, this W drives the heat pump. So, what will be Q_4?

Now, Q_4 by W is the COP, so Q_4 is W into COP of heat pump because this CPO of heat pump is defined as heat delivered to the high temperature reservoir where this machine is acting as a heat pump. So, this Q_4 is the output parameter of our concern divided by the input to the machine which is the work. What is the COP of the heat pump? But here on catch is that there is a thermal irreversibility that means the temperature of the working fluid here in HP, let this temperature is T_4, let this temperature is T_3 (Refer Slide Time: 10:04 min). Neither T_4 equals to 294.1 K nor does T_3 equal to 277.4 K. So, what is first T_3?

There is a temperature difference of 11.1 degree Celsius that it is defined in the problem. So, heat is coming from here that means this temperature will be less than this which means T_3 is equal to 277.4 minus 11.1 Kelvin is equal to 266.3 K. Similarly, what is T_4? T_4 heat will go from here so, that will be 294.1 plus 11.1, what is this value?

Heat has to be first transfer to the working system here. So, working system will have to be a lower temperature to take the heat in natural process of heat transfer. Heat is ultimately transferred from lower to higher temperature, but first heat has to be transferred to this fluid then it is transfer from here (Refer Slide Time: 11:28 min). There are other processes going on. One of the processes is the heat taking up from this reservoir. One of other processes is that heat given by the heat pump to this reservoir. So when heat addition is taking place to the working fluid of the heat pump, the heat pump working fluid is of the temperature 266.3 Kelvin, so that this temperature gradient can transfer heat from this temperature to the working fluid or working system (Refer Slide Time: 11:52 min). This is one of the processes of the thermodynamic cycle executed by this system.

Similarly, one of the processes in the thermodynamic cycle is the heat rejection by the working system which has to reject heat to this reservoir with 294.1 Kelvin temperature. So

the temperature of HP has to be higher than this temperature. So, this way we have to say. So what is this temperature 294.1 Kelvin plus 11.1? It is 305.2 K. <mark>So, is it clear?</mark>

Now, we have to find out, what is the ideal COP of the heat pump? COP of the heat pump is equals to 0.5 into COP of the ideal heat pump. What is the COP of the ideal heat pump? It can be written as, now COP of the ideal heat pump, we have to consider a heat pump which is ideal then the reservoir chosen by the heat pump has to be of the temperature 305.3 K so that it can reject heat to this temperature.

Similarly, it can take heat to this temperature 266.3 Kelvin, so the heat pump will be a reversible one when the external heat reversibility will be reduced. The temperature of the reservoirs should be like this so that we can write this, 0.5 into 305.2 devided by 305.2 minus 266.3. So, this is the ideal COP.

Why this COP is less? Because of internal irreversibility and the external irreversibility, because of the finite temperature difference, heat transfer, so COP comes out to be 3.93. Then the problem becomes extremely simple. Q_4 is 3.93 W because this is the COP of the heat pump.

Now again W is 0.32 Q_1, so Q_4 is equal to 0.32 into 3.93 Q_1 and which gives Q_1 by Q_4 is 1 divided 0.32 into 3.93 is equal to 0.79 Kilojoule by per Kilojoule. This Kilojoule per Kilojoule means Kilojoule of heat input per Kilojoule of heat output. We may or may not write it, because the quantity Q_1 by Q_4 is unit less that means this is the amount of heat delivered to the heat engine per unit amount of heat delivered to the <mark>block of plates</mark> by the heat pump.
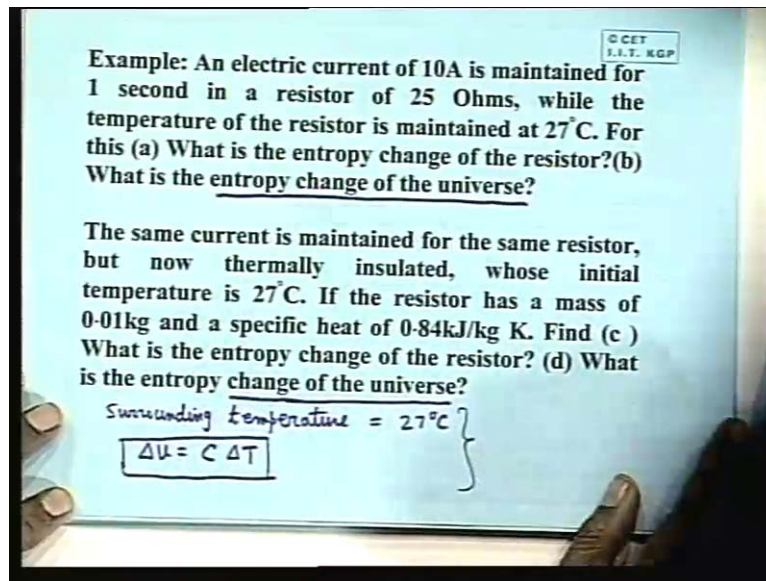
Next problem is also very simple, but interesting problem. This is relating to the entropy change, a very simple problem, but with entropy change. An electric current of 10Ampere is maintained for 1 second in a resistor of 25 Ohms, while the temperature of the resistor is maintained at 27 degree Celsius. When an electric current is passed through a resistor which is having some resistance, heat is an energy which comes in trance, if the internal energy is increased, so its temperature should increase, but temperature of the resistor is maintained at 27 degree Celsius in this problem. This resistor is cooled in such a way that the generation of internal energy because of this electric current must equal to the energy out of this resistor so that temperature is maintained at 27 degree Celsius.

This is very important in this problem that while the temperature of the resistor is maintained at 27 degree Celsius. The temperature is constant for the resistor while the current is passed through this during a time of 1 second and that temperature is 27 degree Celsius. For this,

(a) What is the entropy change of the resistor?

(b) What is the entropy change of the universe?

The same current is maintained for the same resistor, but now thermally insulated that means no heat is allowed to flow from the resistor which while allowing a current to flow for some time and it has a resistance may increase its temperature, but heat is not being allowed to flow out of the resistor. The resistor's initial temperature is 27 degree Celsius. If the resistor has a mass of 0.1 kg and a specific heat 0.84 Kilojoule per kg K. This is the unit of specific heat. Find (c) what is the entropy change of the resistor? (d) What is the entropy change of the universe? So, we have to find out what the entropy change of the resistor is and what the

entropy change of the universe in both the cases is. One case, the resistor is not insulated rather it is cooled simultaneously while the current is flowing through heat. It gets hot and it is cooled so the temperature remains constant and in other case it is not cooled, but thermally insulated. So, the temperature will increase, its initial temperature is 27 degree Celsius. Its mass and specific heat is given, but one thing is missing in this problem.

Whenever you are asked in any problem to find out the entropy change of the universe, so to find out the entropy change of the universe, you have to know, what the surrounding temperature is, which is very important. You have to take the surrounding temperature which is not, but how then you can equate the entropy change of the surrounding? Surrounding temperature equals to 27 degree Celsius which is very important for this problem. If it is not mentioned you can take any value of the surrounding temperature, but it should be mentioned.

Another thing which has not been mentioned in this problem, the way I have taken it that for this resistor, consider the change in the internal energy is given by specific heat of the resistors time T, delta T. This is another important thing that the change in internal energy of the resistor equals to specific heat times the delta T. That is the temperature difference so these two will be required for solving this problem.

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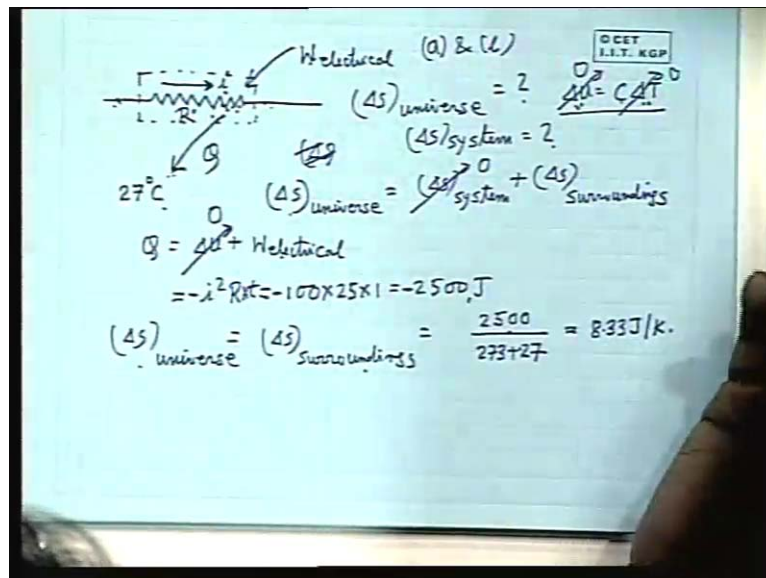
Now let us find out the delta $S_{surrounding}$. There is an electrical resistor through which an electric current i is flowing because of some potential difference applied across the resistor. So, the resistor is maintained at constant temperature which means there is a heat transfer from the resistor. In this case, I can represent the resistor as a system. When the electrical

current is allowed to flow through this resistor which has a resistance R, there is a potential difference across the resistor which means from thermodynamic view point that electrical work is being transferred into this system, W electrical, and since the temperature is maintained constant, some heat is also being coming out of the system Q. So, this is the problem from first law of thermodynamics. Thus resistor has a system receives electrical work and rejects heat to the surrounding which is at a temperature of 27degree Celsius.

Now, if we consider the problem like this then we have to find out delta $S_{universe}$. What we know is that delta $S_{universe}$, first part of the problem that is a and b. We have to find out not only delta $S_{universe}$ but delta S_{system} also. One thing is that if we have to find out delta $S_{universe}$, we have to find out both delta S_{system} and delta $S_{surrounding}$. That is why, it automatically comes. Delta $S_{universe}$ is delta S_{system} plus change in entropy of the surroundings that is delta $S_{surrounding}$. In this case, what is the delta S_{system}? Delta S_{system} is 0 because resistor is at the steady state. So, no property is changed for the resistor.

Now, if I write the first law of thermodynamics, I can write Q is equal to delta u plus W electrical. Since the resistor is maintained at constant temperature and if this relationship is giving that delta u is related like it equals to specific heat times the delta T. So, when the temperature remains constant that means delta T is 0. So delta u is also 0. This has to be known, otherwise the question will come that how do we know that if the temperature remains constant and the internal energy also remains constant. We have to know this. So, we can write that Q is equal to $W_{electrical}$.

What is the electrical work transfer? It is the voltage difference times the current, but voltage difference is not giving. We can relate this in terms of resistance also with use of ohms law that we obviously know. So, Q is i^2 into R into t that is the electrical work which is being transferred.

So what is happening physically? This electrical work is transferred to the system and because of electrical irreversibility, (Refer Slide Time: 22:08 min) these electrical work is being converted into internal energy, first. Then, immediately the heat is being coming out because of the increase in the internal energy which is because of the electrical dissipation of these electrical works, and immediately the heat will come, so that the internal energy is restored to its initial value. So, this is the step. Therefore in this system, the electrical work is ultimately coming out in the form of heat to the surrounding. So, the i^2R is the electrical work. So, this becomes is equal to 10Ampere that means 100 into 25.

So, i^2Rxt is equal to 100 into 25 into 1 that is 2500. What is the unit of it? It is Joule, i is ampere, R is in ohms, t is the duration then it gives the amount of energy. It is for 1 second. So as far as the result is considered, if we do not write T, it will be the same, but it is definitely contextually wrong, because i is the ampere with a rate is there. So, this will imply the power. So, we have to multiply it with time. So, this is the Q. Therefore delta S_{system} is 0. So, delta $S_{universe}$ is delta $S_{surrounding}$. So we can write, delta $S_{universe}$ becomes equal to delta $S_{surroundings}$. What is this? Surroundings receive heat at a constant temperature, so this will be positive quantity.

Yes, I am answering this question, but before that, here one thing. When we write this thing Q is equal to delta u plus $W_{electrical}$, so Q and W, though numerically all right, but we have to follow the sign convention. Here, this electrical work is negative, Q is positive. So, we can write that minus i^2Rt is equal to minus 100 into 25 into 1. This is minus, so that Q will come as minus which means that heat is coming out from the system with reference to the system is minus. With reference to the surrounding, it is a heat which is taken by surrounding. So deltaS $_{surrounding}$ is positive. So that is why delta $S_{universe}$ is positive and that value becomes equal to 8.33 Joule per K. <mark>Do you have already solved this problem?</mark>

<mark>Now what is your question?</mark>

<mark>Sir, how can we understand that the delta S_{system} is 0?</mark>

<mark>Delta S_{system} is 0. I tell you that</mark> it is written that delta u is C delta T. This is given in the problem. Why it assume?

Delta T is 0. So, delta u is 0. Delta u is the property, delta u is 0 that means all the properties remain same that is this resistor is at a steady state, the temperature remains same. Its internal energy also remains same that means all other properties remain same, that means this is at a fixed state. That is known as steady state. So, entropy is a point function. So, entropy remains same.

So it gives heat and it takes work, not that always a system gives heat or takes heat, its entropy will remain same. If it gives heat and takes heat, at the same time, it receives work,

work interaction. We have to consider whether its property state point is changed or not. Not necessarily we take heat, there is a system which takes, there is a net heat transfer from the system that means it gives heat or it takes heat. At the same time, there is a net work transfer to this system. If these two things balance so that system remains at the fixed state that the entropy will be same. Entropy will not change. Do not consider that whenever there is a heat transfer that the entropy will change. Entropy will change or not depend upon whether a system changes from one state to other state because entropy is a property, as a point function, state variables. It has given some heat, so this entropy should have decreased, but at the same time it is taking work from the outside so that its entropy will increase, that will balance. System is kept at a fixed state.

In next problem, it will be clear that there is no heat transfer, but still there is a change of entropy this is because this state point is changed. It is not always that heat has to be taken in. I told again categorically, I earlier also told that whenever there is a change of the state, there is an entropy change that means that change is possible by a reversible process only by heat transfer. Do you understand? If we consider a process where the change of states is possible by no heat transfer in a reversible process then only entropy will remain constant that is an isentropic process.

I gave that example. For example, you take water in a bath and stir it, heat the electrical wire or an electrical conductor by insulating it. Its temperature increases, but there is no heat transfer. It is only work transfer that works by virtue of some irreversibility. In case of stirring of paddle wheel or stirrer in a liquid, it is the mechanical irreversibility friction raises its temperature and changes its state. In case of insulator electrical resistance, it is the electrical irreversibility which changes this work into intermolecular energy and changes the state. So, in that case, there is a change in entropy. Why? This is because the change state can be connected by a reversible process which demanded heat that means that change in temperature can be executed by addition of heat to the process, so that there is an entropy change.

So, for a natural process, whether heat added or it is not added, that is not the question of change in entropy, whether this system, state as change or not and that change in system is associated with a heat transfer process definitely by a reversible process, if entropy changes there. But in an isentropic process, there is a change of state by a system which is possible without heat interactions in a reversible way. That is why a reversible adiabatic process is an isentropic process.

There may be two states which can be connected by a reversible adiabatic process, where heat transfer is 0 and the process itself is reversible. So, there will be no entropy change. Their entropy changes are due to irreversibility.

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Now, next part of the problem is this. The system is insulated that means electrical resistor is now insulated.

<mark>You can ask this type of fundamental question. I will appreciate.</mark>

Now, work transferred is there, $W_{electrical}$ which is equal minus 2500 Joule, but what is Q? So, according to first law, 0 is equal to delta u minus 2500. Now you see that there is a delta u, 2500 Joule that means the internal energy has increased. As we know that delta u is equal to C into delta T, that C is the capital C.
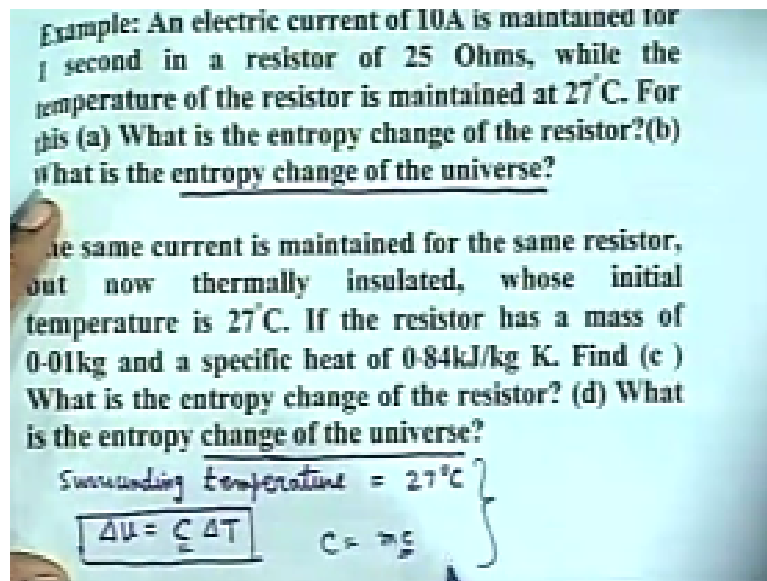
delta u is equal to C into delta T, that C could have been written by mass into c specific heat (Refer Slide Time: 29:45 min). This is the capital C, so actually this C is m into small c, specific heat.

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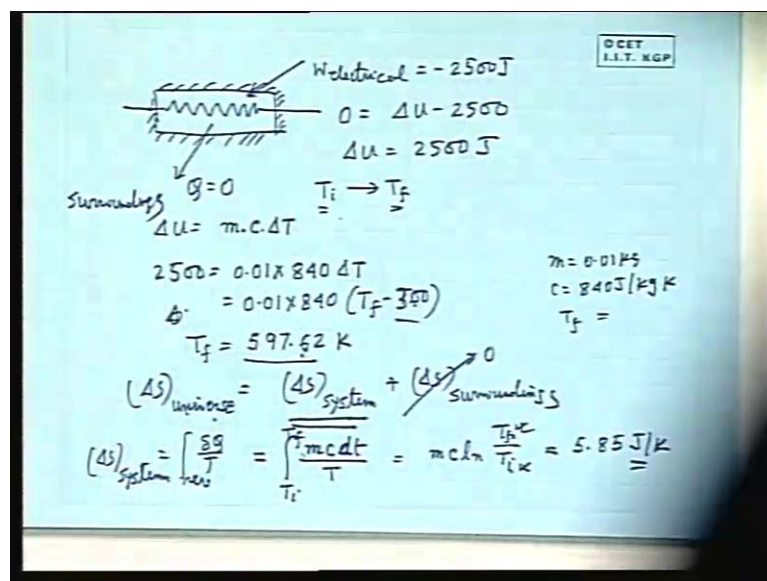
Therefore, we can write delta u is equal to mass into specific heat into delta T, according to this relationship. So, then we can write 2500 is equal to mass, that is 0.01 kg, into specific heat 0.84 Kilojoule that we have to transfer to Joule, that means 840 Joule per kg K times the temperature difference delta T, that has to be found out.

So, this gives delta T, delta T I can write rather straight forward. Let T_f is the final temperature that means it starts from T_i, initial temperature and reaches T_f, final temperature. T_f minus T_i. What is Ti?

T_i is 300 K. So, if we do this calculation, we get T_f equals to 597.62 K

Now question comes up delta S, now here also I write delta $S_{universe}$ is equal to delta S_{system} plus delta $S_{surroundings}$. Clear? Now you tell me fast what is delta $S_{surrounding}$ here? Delta $S_{surrounding}$ is 0 because there is no heat interaction of this surrounding. This is surroundings (Refer Slide Time; 31:34 min).

Delta S_{system} is there, which is not zero obviously, otherwise the principle of increase of entropy will be valid at delta $S_{universe}$ is greater than 0. System entropy changes because of the change in its state which is manifested through this change from the temperature of 300 K to this which could have been possible by a reversible heat transfer, but as because it is an irreversible process, the temperature change is possible if we need out heat transfer, but in the reversible process, the temperature change is never possible without a heat transfer.

If temperature change is possible, it is only possible by a reversible heat transfer. Only in isentropic process temperature change is possible without a heat transfer process, only by expansion and compression process that is reversible adiabatic process, that will again make clear afterwards.

Therefore, this is enough. So delta S_{system}, we can write as I have done earlier, that if I consider a reversible heat transfer process. So, this will give mcdt is the delta Q because delta S_{system} precisely, this is the thing is nothing, but integration of delta Q divided by T reversible.

Now, this reversible process heat addition is mcdt, small temperature difference, you give a reversible heat transfer, so that magnitude becomes mcdt. So, this will be integrated from T_i to T_f (Refer Slide Time; 33:01 min). This is a very important concept which gives mcln T_f by T_i.

Now, the change in entropy is connected between the states. So, if one knows T_f, T_i even if the process is irreversible where the heat has not been given by this amount (Refer Slide Time: 33:19 min), slowly, but by some means the temperature is changed from T_i to T_f. So,

entropy change is same whether it is reversible or irreversible, but to calculate it, we will have to use the equation for the reversible process and it comes as mc ln T_f by T_i.

If we substitute the values, m is equal to 0.01 kg, proper units, C is equal to 840 Joule per kg K and T_f already we have found out - 597.62 Kelvin and T_i is mcln T_f by T_i. We get delta S_{system} is 5.85 Joule per K. Joule per Kelvin is the unit of the entropy change. So, that becomes equal to delta $S_{universe}$.
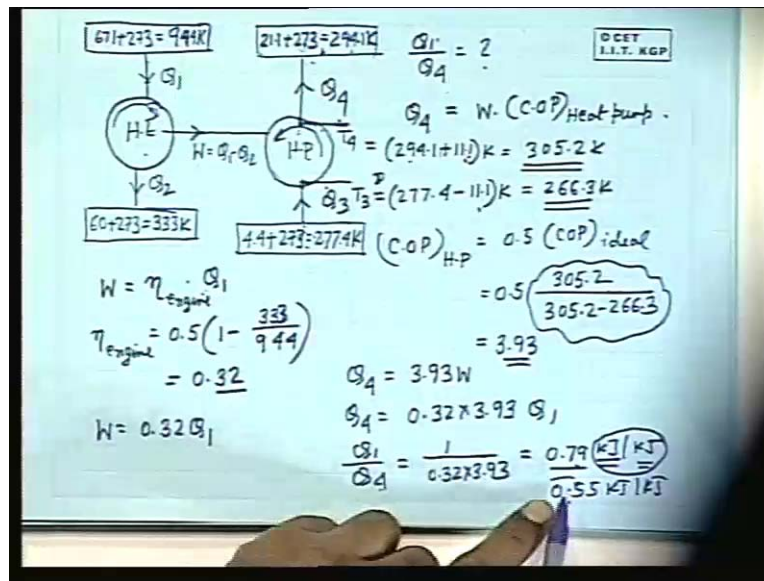
Another thing, I forgot to mention that in the last example.

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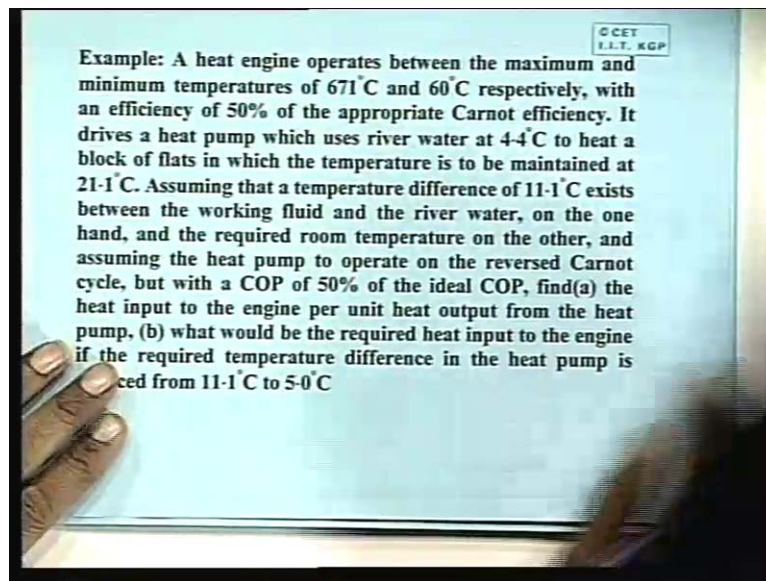
I only solved the heat input to the engine per unit heat output from the heat pump (Refer Slide time: 34:20 min). <mark>Another task is there that is left to you as an exercise.</mark> When this 11.1 degree Celsius is changed to 5.0 degree Celsius that means I am coming back to the earlier thing.
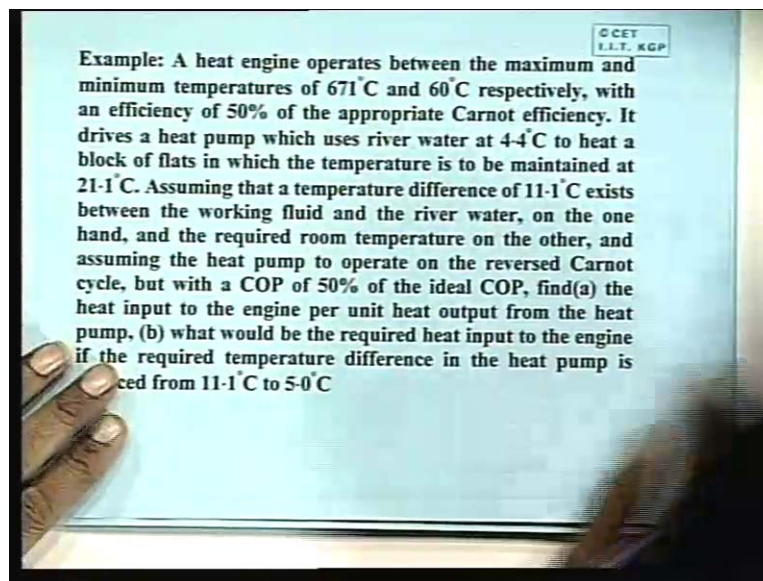
That means this temperature, 305.2 Kelvin, will change then system temperature by 5.1 here at T_4 and minus 5.1 at T_3. Exercise this thing as a routine exercise and you will see that results will be reduced that means that value will be reduced and the result will be in this case, 0.55 KiloJoule per KiloJoule.

Now you can ask me, sir, what does it convey?

A simple routine calculation, just you change, just like a kinder garden student. Just change the value of 11.1 to 5, but it will give an idea that means if we go on reducing this temperature gas (Refer Slide Time: 35:04 min), this COP is ultimately going close to the, what is the that this value not COP obviously COP is going close to the, ideal COP and this value. Q_1 by Q_4 is reduced. This heat engine will require less heat per unit heat output from the heat pump to the block of flats, so this value will be reduced.

Example: A heat engine operates between the maximum and minimum temperatures of 671°C and 60°C respectively, with an efficiency of 50% of the appropriate Carnot efficiency. It drives a heat pump which uses river water at 4·4°C to heat a block of flats in which the temperature is to be maintained at 21·1°C. Assuming that a temperature difference of 11·1°C exists between the working fluid and the river water, on the one hand, and the required room temperature on the other, and assuming the heat pump to operate on the reversed Carnot cycle, but with a COP of 50% of the ideal COP, find(a) the heat input to the engine per unit heat output from the heat pump, (b) what would be the required heat input to the engine if the required temperature difference in the heat pump is ...ced from 11·1°C to 5·0°C

So, this is the exercise for which the second part that when it is reduced the temperature difference is reduced to 5 degree Celsius that you can solve. So, these two problems will give you an immense idea about how you can apply the entropy change formula for a problem. There are number of problems, if I get the opportunity I will solve.

Now I will come to the next section that availability, available energy and exergy. Before I start, I must tell these things. Very few books write this sentence straight forward and boldly. Sometimes that a very higher stage, I tell from my experience, this is been asked at different levels, even at a higher level, at the recruitment level of a senior faculty positions also, it is asked that what is the difference between availability and available energy, what is the difference between availability and exergy? These are the terminologies.

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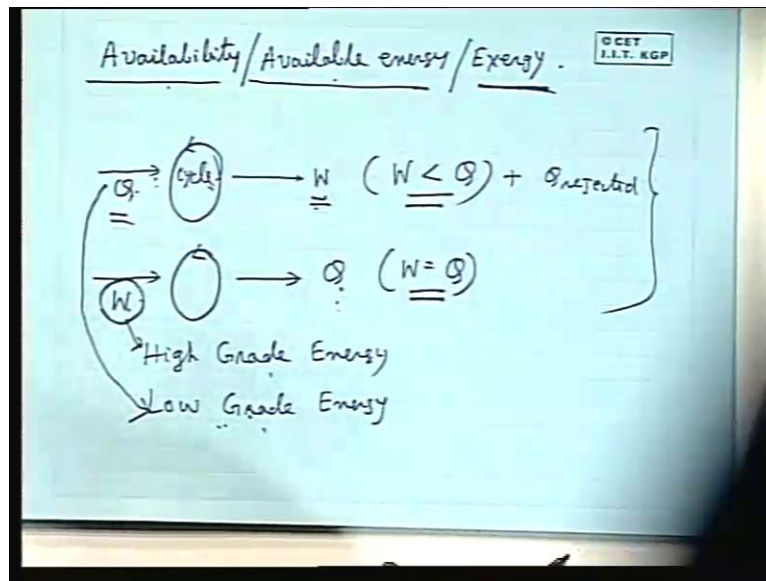
It will be met clear afterwards, but before that I must tell that these are synonymous terms, just like three names of a person. The same person, identical person, they are called by three names as and when required. In his house, his parents call by certain name. His roommate call by another nickname and his professional friends call by another name. It is like that. So, as and when required according to the convention used, we will use the terminology. Therefore, I must tell these three terms, what these are will be explained afterwards. But first write this availability, available energy or exergy. They are synonymous terms. Sometimes I will be using availabilities, sometimes I will be using available energy and sometimes I will be using exergy. I will use these depending upon the common convention that is followed. Now what is available energy and availability?

This is one of the very important aspects of second law. The way entropy was defined as one of the very important aspect of straightforward consequences of the second law. Similarly, the available energy is another important consequence of the second law. Before that again I brush up, sometimes in teaching up thermodynamics particular things has to be told repeatedly, 10 to 20 times. Again I tell the first law of thermodynamics, if this question is asked, what new information about the quantity energy has been given by the two laws?

First law of thermodynamics gives the two different status of energy, one is this point function status, and another is the path function status. So, heat and work are identified as path function energy which are only defined in transit between the systems or system and the surrounding, but they are energies which are properties of this system and their energy with point function property which can be stored within this system and are ascribed as the system

properties and therefore they are point function. These are internal energy and first law tells the difference between the heat and work interaction in a process is that energy which is stored in a system which gives that as a point function.

So, first law of thermodynamics gives the birth of two status of energy as point function and path function, but second law of thermodynamics, because I told at the beginning, in this class, we are only concerned with the heat and work, so all first law second law aspects will be defined in terms of heat and work. So, second law gives a directional constraint as far as the mutual convertibility between heat and work in a continuous cyclic process. What is that? Heat can never be converted completely into work continuously in a cyclic process whatsoever the cyclic process may be, even in an ideal case we cannot do it, but work can be continuously converted into an equal amount of heat that means this gives the directional constraint.

If you write this second law concept on the constant of mutual convertibility of heat and work, I can show it like that, that if heat is being converted into work in a continuous cyclic process because this cyclic process is required for continuous conversion work (Refer Slide Time: 40:05 min). We know that the result is that the W is less than Q. Some of the heat energy has to be rejected, cannot be converted. Everything cannot be converted.

While if you want to convert work into heat, so you can definitely convert the entire work into heat, W equals Q. This does not valid the first law (Refer Slide Time: 40:30 min), accordance with the energy conservation, but it is not because some portion of heat is still left here, $Q_{rejected}$. So, this is the basic foundation on which we define the two grades of energy, high grade energy and low grade energy.

Do you know then what is high grade energy?

High grade energy is that energy that, do not tell it is work. High grade energy is that energy which can be continuously converted into low grade energy, but low grade energy is that energy which cannot be continuously converted into high grade energy. If we make two energies now in transit work (Refer Slide Time: 41:18 min) and heat if we see that heat cannot be completely converted into work whether work can be completely converted into heat.

This is the reason for which work is defined as high grade energy whereas heat is defined as low grade energy that means the low grade energy can never be converted into high grade energy with an equivalent amount whether the reverse is true, but this is not always true for

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heat energy. There are other forms of energy as I told that internal energy stored in a system, there is a point function.

This internal energy, again come back to the earlier discussion, I have two divisions, one is the mechanical form of the internal energy that is kinetic energy, potential energy, if we leave aside that form, the other form of the internal energy is intermolecular energy, this is because of the temperature of the system, because of the chemical bound energy of the system. We know that within a fuel, there is an internal energy which sometimes we ascribe as chemical energy. When we come to the thermodynamics of the reactive system, these things will be clear.

These are all internal energy stored within the system. So if we keep aside the mechanical form of internal energy that means kinetic energy and potential energy then we are left with this intermolecular energy which is manifested to its temperature, that chemical bondage energy. This energy is stored within the system as a point function. These energies are also low grade energy. If we want to convert it to a useful work, the full amount we cannot convert. This will be conceiving this way, slowly it will come.

If a system is at an elevated state compared to its surrounding. I have told when the system properties are exactly same with that of the surroundings, the system is known is a dead state. System cannot perform any process with the prescribed environment of surrounding, but if the system is at an elevated state because of its stored internal energy from that of the surrounding always an opportunity exists to develop some work while the system is allowed to come into equilibrium with the environment. So, in that process, there is an opportunity to get some work, but that work can never be equal to the total stored energy within the system. That is why the stored energy within the system apart from kinetic and potential energies is also termed as low grade energy. So henceforth, we must know the low grade energies, either the energy in transit or the energy stored in the system are those forms of energy which cannot be completely converted in a cyclic process than equivalent amount in the form of high grade energy, if they are exists such type of energy which can be converted in the reverse way with the other form of energy.

In fact, work is that energy which is the high grade energy which can be completely converted continuously either in heat which is the transit form of the energy or in the stored internal energy which is the point function or stored form of energy. So that is why work is high grade energy and heat and the intermolecular energy stored within the system is low grade energy.

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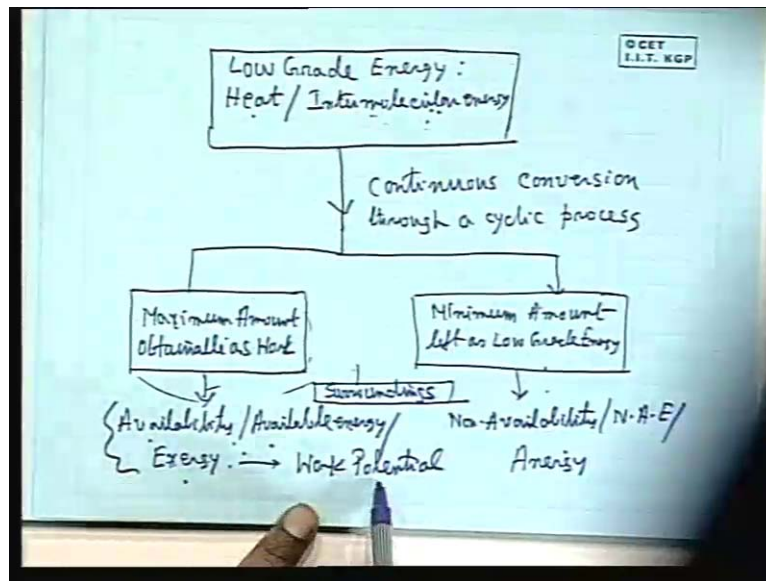
So, then I tell you a thing that this we can now show like this (Refer Slide Time: 44:40 min). Low grade energy, <mark>this is the information first I tell you the information then logic and deductions will come</mark>, <mark>information is very important</mark>. Low grade energy specially, <mark>now a days, there are information technology, generation information, its communication and all these things are very important.</mark>

Low grade energy which comprises heat is a transit form of energy or stored intermolecular energy. If you want to convert this continuous conversion through a cyclic process then we will see that we cannot have the entire energy converted. There is a restriction. There is a maximum amount of this energy (Refer Slide Time: 45:57 min) that can be obtainable as work that is the high grade energy. Obviously, these two are dependent. A minimum amount, so there is a minimum amount when this obtainable one, there is a maximum conversion possible as a work which means automatically. There is a minimum fraction or minimum amount left as, <mark>what?</mark> Low grade energy. <mark>Very Good.</mark>

<mark>[Conversation between Student and Professor – Not audible ((00:46:31 min))]</mark>

The maximum amount obtainable as work is defined as availability, available energy or <mark>exergy</mark> of the low grade energy. Similarly, the minimum amount left as low grade energy is known as non availability, non available energy and energy. These are the terminologies. There is a minimum part which has to be rejected and there is a maximum part. This is the second law. This is an axiom which can be converted. This availability, available energy of this low grade energy symbolizes the work potential of the low grade energy then what is the work potential of the low grade energy?

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Low grade energy as this work potential that means that is a maximum amount of work which can be extracted from it (Refer Slide Time: 47:35 min), under any circumstance, even in the ideal case. This is an ideal criterion whereas there is a minimum amount of which has always to be left as low grade energy. This serves as work potential, this is another terminology, but not very frequently used. This is the work potential.

These are all ascribed to this low grade energy, but here one thing has to be understood, very important. These are all referred to a surrounding because whatever will be the maximum work obtainable from a given low grade energy at a given prescribed state that means if I tell heat from this thermal reservoir because it is energy in transit. This is the intermolecular energy stored in a system which is prescribed at certain state then if this question is asked what work potential is or what is its available energy, availability, exergy and in the maximum work that can be obtainable in an ideal system?

The next question will come then with respect to which surrounding, because surrounding is very important, surrounding has to be prescribed, because we know the Carnot efficiency does not depend only on the thermal reservoir where heat is being taken. It depends upon the temperature of the thermal reservoir or heat is being rejected. So with respect to a given surrounding, these values (Refer Slide Time: 48:50 min)depend. So the availability, available energy or exergy, that is work potential of a low grade energy is defined when the low grade energy and the state is prescribed with reference to a given surrounding which is sometimes known as availability, available energy or exergy reference surroundings or environment.

<mark>This information is clear to you.</mark>

<mark>[Conversation between Student and Professor – Not audible ((00:49:15 min))]</mark>

Surroundings, this is because last part of the surrounding I explained that the maximum work that is obtainable from this low grade energy will depend upon the surroundings.

For example, we have an elevated system that means at some pressure and temperature or some property with reference to its surrounding. So the maximum work that we can get from this system, there is an opportunity of developing work. Till the system comes to dead state that depends upon the surrounding. If a system at its pressure, temperature, volume and if I tell what will be the maximum work can be obtainable before it comes to dead state today, is much different. What it could have been done in first week of January in when the ambient temperature was 4 degree to 5 degree Celsius.

So, you can very well understand, the ambient plays a major role that will be clear afterwards.

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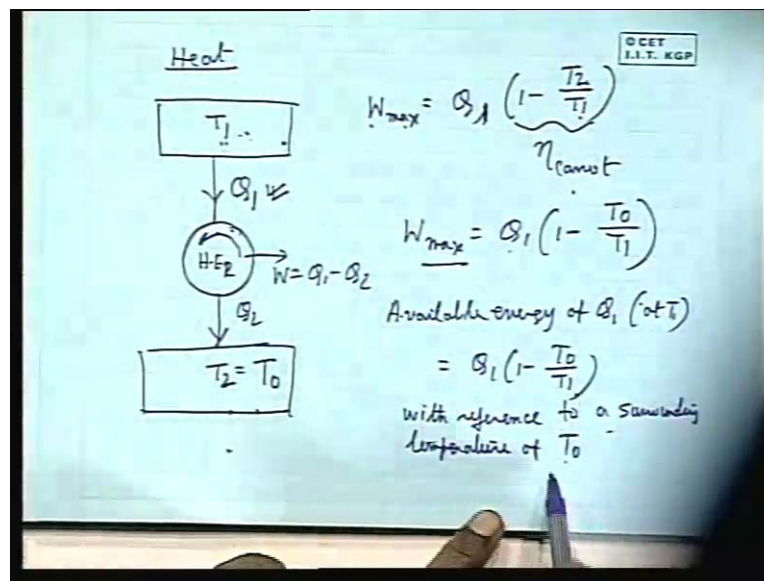
Now, let us find out heat in transit. Let us consider that heat is available from a temperature reservoir T_1. Now you tell me if I pose this problem that heat is available at Q_1 at T_1, what will be the maximum work obtainable?

We know for maximum work, we have to use a reversible heat engine that is Carnot's engine. We will have to search for a sink where the heat has to be rejected because otherwise we cannot get the work. Let this sink temperature T_2. We know the maximum work of this given heat at this temperature Q_1 into 1 minus T_2 by T_1. 1 minus T_2 by T_1 is eta$_{Carnot}$.

Now we see, this is the efficiency (Refer Slide Time: 51:12 min) for a given heat input to an engine, the work developed depends upon the efficiency. Efficiency is maximum for a reversible engine. So this maximum efficiency depends upon T_2 T_1 more is the temperature for the given heat input, more is the efficiency, more is the extraction of work.

Similarly, lower is the sink temperature of heat rejection more is the efficiency and more is the work extraction. Therefore, our main motto will be to have a higher temperature and as soon as possible sink temperature, heat rejection temperature. If this temperature is prescribed that means, we know a temperature T_1 where from we had Q_1, that means Q_1 of amount of heat is obtainable from the temperature T_1. Then, we will have to search for the minimum T_2 available, so that we can get the maximum work.

What is the minimum T_2 possible without any other effort? That is the ambient temperature which is commonly symbolized as T_0, so the ambient temperature. If that is true, so the maximum work is Q_1 into 1 minus T_0 by T_1. So, we see the surrounding comes into picture depending upon the T_0.

So, for the same amount of Q_1 at T_1, the availability here which is much less than the availability, very close to the poles because they are the T_0 which are very less. Therefore, the ambient comes into picture in this simple example. Therefore we see that this $W_{maximum}$ is the available energy so, available energy of Q_1 at T_1 equals to Q_1 into 1 minus T_0 by T_1, with reference to a surrounding temperature of T_0, this we can take here also (Refer Slide Time: 53:26 min).

So, now, the available energy depends both on the surrounding and on the temperature from which T_1 obtainable.

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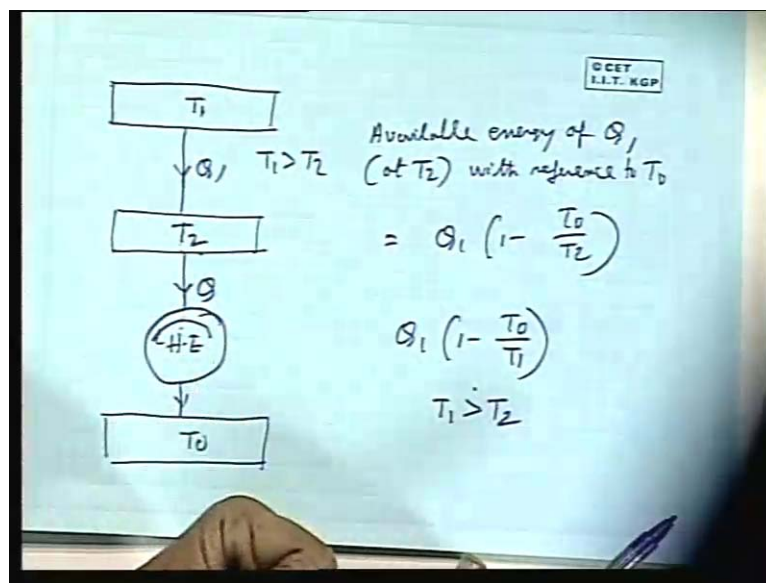
Consider that let T_0 is fixed ambient temperature. Instead of getting the heat from T_1 temperature, delivering the heat from T_1 temperature to the engine, I deliver T_1 as a designer, as an engineer that this heat, I will first transfer to a lower temperature. There may be some difficulties also. The heat engine is unable to accept this temperature. There is some practical problem where heat engine cannot take heat from there. I just transfer it, by a natural process means T_1 is greater than T_2 and this same heat is now given to the heat engine, consider a reversible heat engine to the heat engine at T_2 and it rejects the heat.

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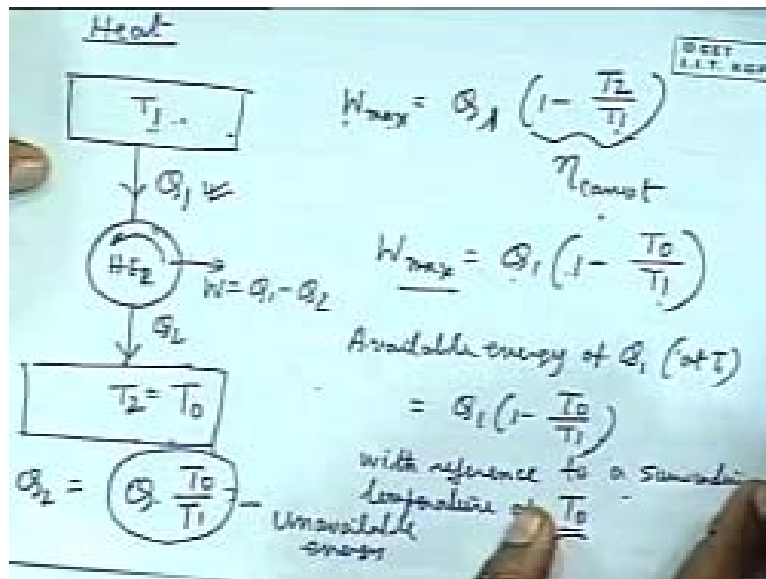
Now see here this is the heat rejection Q_2 (Refer Slide Time: 54:33 min), Q_2 is Q into T_0 by T_1 because this $W_{maximum}$ is Q_1 into 1 minus T_0 by T_1 is the heat rejection. This Q into T_0 by T_1 is the unavailable energy. Therefore, Q_1 comprises of two, one is the available energy plus the unavailable energy; so, available energy is Q_1 plus unavailable energy.
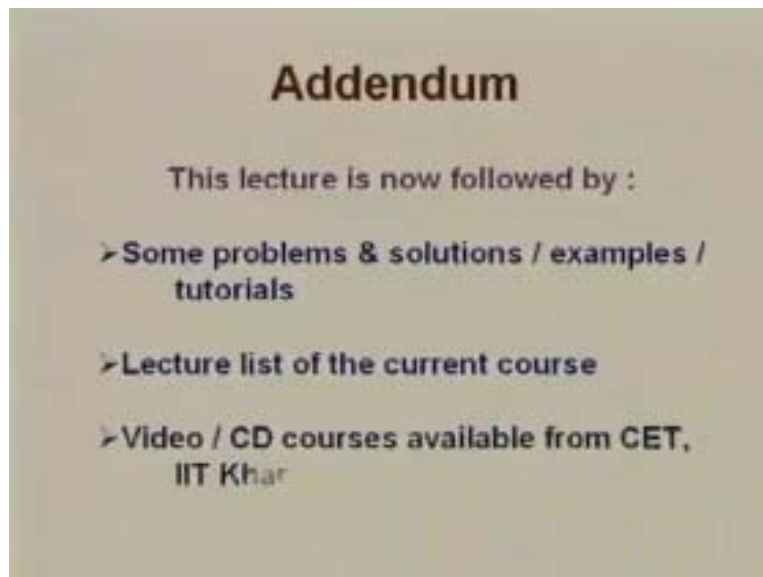
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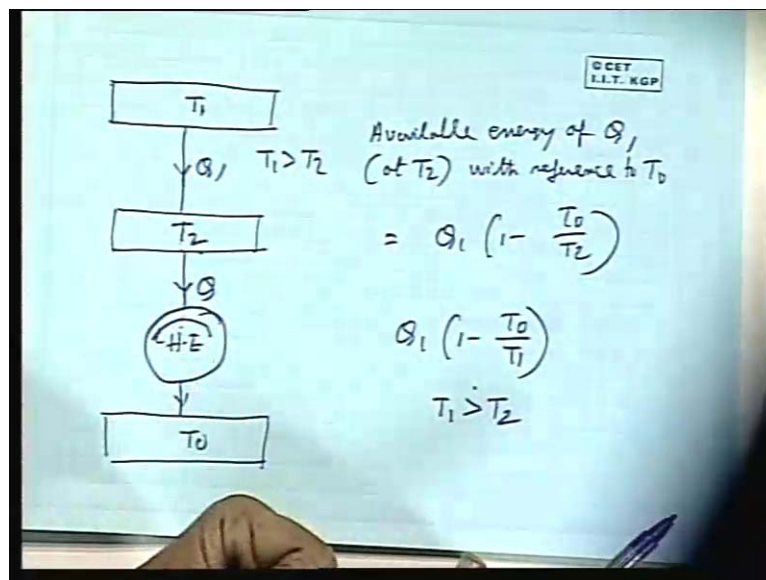
What is available energy of Q_1 at T_2 with reference to T_0? This available energy is Q_1 into 1 minus T_0 by T_2, this available energy is lower than the earlier one. Earlier one, it was taken from T_1, it was Q_1 into 1 minus T_0 by T_1. Now, T_1 is greater than T_2, therefore this available energy is lower than this (Refer Slide Time: 42:00 min).

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When same heat is taken from a lower temperature, its available energy or work potential is reduced. Therefore, it is always advisable to accept heat as high as possible, thermal reservoir. If the temperature is reduced, its available energy or work potential is reduced that means it is not only the amount of heat which is important, but it is the temperature of the pot or thermal reservoir where from heat is coming in is important, provided the surrounding is fixed. Therefore, always it is advisable that heat should be taken from the temperature which is as high as possible. So, this is the basic concept of available energy or availability of heat, the energy in transit.

Okay! Today up to this, thank you next class again I will continue this.
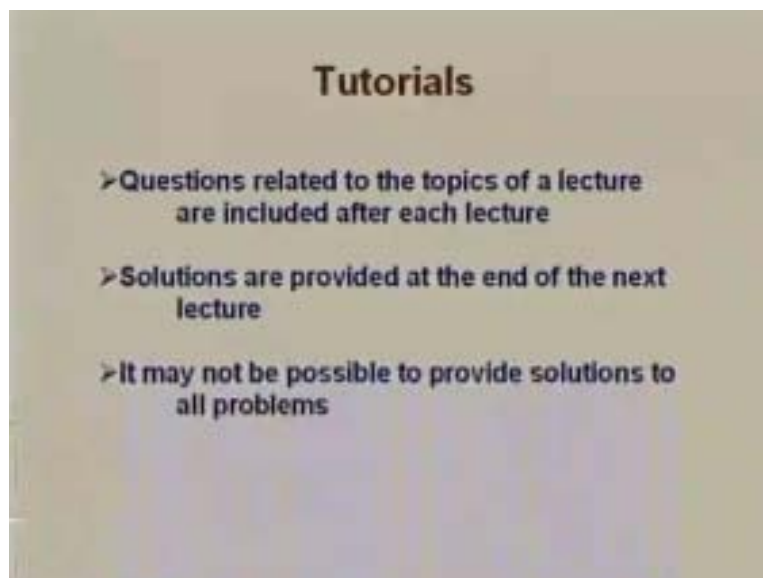
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Review Questions

1. Define high grade and low grade energy.

2. Which of the following energy quantities are high grade energy and which ones are low grade energy
    (i)   Intermolecular energy
    (ii)   Kinetic energy
    (iii) Work
    (v)   Heat
    (vi)   Potential energy

(Refer Slide Time: 57:31)

3. What is meant by available energy ?

4. What is the available energy of a quantity of heat Q obtainable from a reservoir at a temperature of T_1 ?

5. What is the available energy of a work transfer W ?

(Refer Slide Time: 57:04)

6. A quantity of heat of 1kJ is being transferred from a temperature of 1000K to a temperature of 500K. What is the loss in available energy ?

7. Which of the following energy quantities does have the higher availability

 (i) A heat flow of 1kJ from a source temperature of 600K.

 (ii) A work transfer of 400J.

(Take the ambient temperature as 300K)

Answer to the above questions are given at the end of Lec No. 14

(Refer Slide Time: 58:38)

Answers of the Review Questions given at the end of Lec. No. 9

(Answers to objective / short Questions are only given. Answers to routine descriptive Questions are omitted)

1. All natural processes are irreversible.

4. Temperature of source and temperature of sink.

6. $\eta_{Carnot} = 1 - \dfrac{T_2}{T_1}$

7. By decreasing the temperature of heat addition.

(Refer Slide Time: 59:12)

9. Extensive.

10. $\oint \frac{\delta Q}{T} \leq 0$ (the equality sign holds good for a reversible cycle)

11. (iii).

12. (iii).

15. Yes. Example : A diabatic process with irreversible work transfer.

17. For only reversible processes: (i) and (iii) For both reversible and irreversible processes : (ii) and (iv)

(Refer Slide Time: 59:12)