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NPTEL ONLINE CERTIFICATION COURSE

Course
on
Laws of Thermodynamics

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Lecture 16: Entropy Change in Closed Systems (Contd.)

Good afternoon I welcome you all to this lecture secession of the course loss of thermodynamics.

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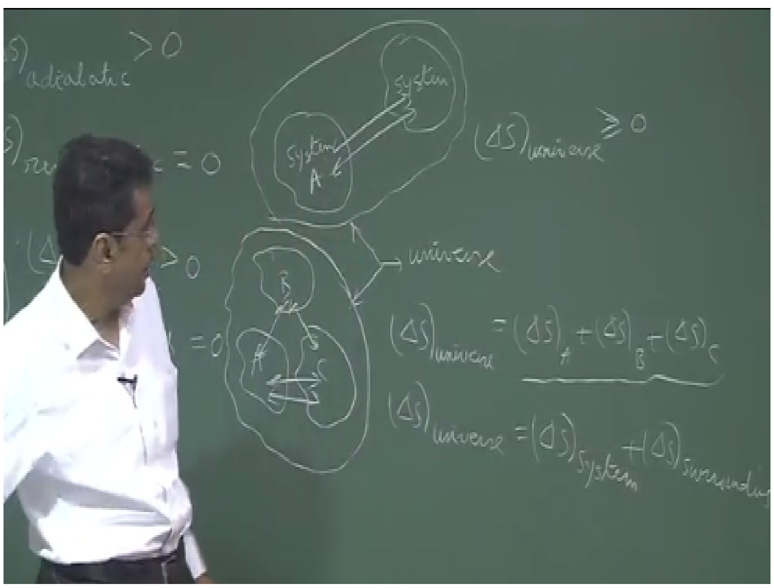

Last class we have seen that the change of interrupted with Δs in a an adiabatic process is > than 0 always because of internal irreversibility if in heat there is no heat transfer if the process is reversible that internal irreversibility is 0 then reversible adiabatic process now question of external irreversibility because the process is adiabatic = 0.

This 2 important things we have come to know at the conclusion of the definition of the entropy through cross inequality now an isolated system and isolated system which does not interact with this surrounding may be considered as an adiabatic system there may be changes that can take place within the system, system may not be at equilibrium state and this changes EPT is irreversible we consider the Δs we can consider as isolated system is > than 0.

If we consider the change inside the isolated system that take place from one part of the system to other part if you consider a single system Δs isolated in case of reversible change = 0 so this two combine we can write Δs of an isolated system of an is ≥ 0 means that the change of entropy of an isolated system is > 0 if the changes with the system is reversible or if the change within the system is revisable then equality sing now in this context is very important thing is that if we have two system, system A and system B interact with each other in terms of energy mass everything.

This two system as a whole and if they do not interact with anything else in this surrounding the two system itself consider constitute and isolate system when this is not for two system if we have number if system A, B, C they are mutually interacting with each other can make an isolated system and this type of isolated system in a very loss term is known as universe that means we consider in our universe there are process take place between system to system between we interact with each other there is number of interaction there are number interaction take place.

But universe is such that it does not interact outside the universal entire thing is within the universe so if that limited sense in classical thermodynamics and isolated system which constitutes interacting systems constitute the interacting systems in the surrounding as universe and therefore and they behave like an isolated system obviously I told that constituting this interacting systems and therefore we can write with this that Δs universe is ≥ 0.

That means if we consider an isolated system consisting of interacting systems either two or more number then Δs of this combined system is >0 when the interactions will be each other when the interactions will be when the interactions will be irreversible when the interactions will be revisable Δs is universe will be equals to 0.

And Δ universe that means of this isolated system is nothing but some Δs of all the interacting system AA + ΔsB+ Δs all the interacting system algebraic sum of all the that means sum may be positive sum may be negative in such way that there algebraic sum is always either 0 for a irreversible process or greater than 0 for nay natural process for example 2 bodies exchange heat

I will show you now if the two bodies exchange heat 1 body which rejects it is entropies decreased but one body which gets CD entropies increased but the algebraic sum is greater than 0.

If the process is irreversible and natural process otherwise it is 0, if it is irreversible process of there are two system one is consider that system another is considered that surrounding to that system sometimes we write these expression so Δs universe = ΔS system + ΔS surrounding that also can be written ΔS is universe ΔS but two system one system another is surrounding.

Now you see this concept how as it work now let us consider in irreversible heat transfer let us now consider an irreversible heat transfer and irreversible heat transfer.

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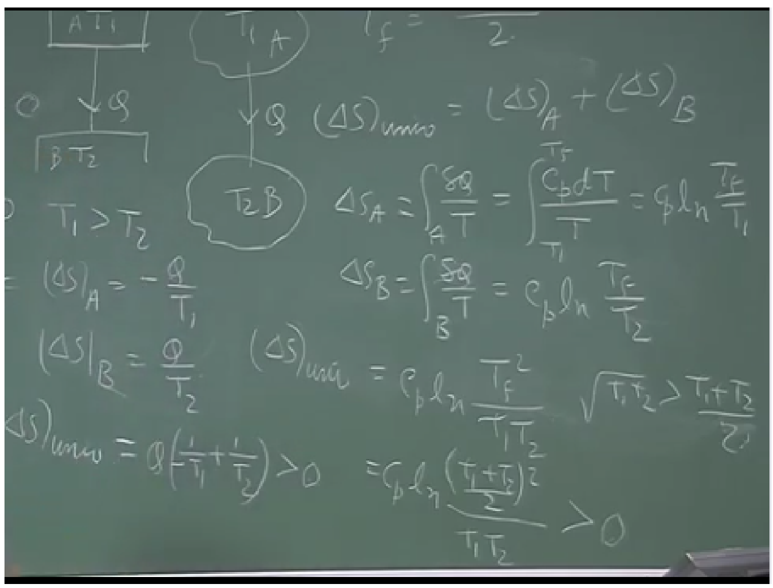

T1 and irreversible and natural heat transfer process will take place if two systems are made into contact through that thermal wall, so that heat can transfer in this case where T_1 is > T_2 heat may occur so now entropy change of this system this is system A this is system B there is A is – Q / T_1 why ΔQ / T is Q / T_1 okay, and this is δSB is Q / T_2 and if you consider the changes internally here irreversible so that we can write the ΔQ / d is δS_A and since T remains constant that T_1, T_1 comes out of the integral this becomes Q and the same Q is transferred hereQ_2.

So ΔS universe will be equal to Q x 1 this is – 1 / Q1 + 1/ T_2 so this is always > this because it is < T_1, T_1 is > T_2 that means this is less that means this is always > 0 another example I give it in the two bodies are finite capacity here you have considered thermal reserve here, whose heat capacity is infinitely high and keeps at constant temperature, but if I may contact of two finite bodies T1 and T2 and heat transfer takes place so that T1 gets decreased temperature get decreased as rejects heat and T2 gets increase that it takes and the heat transfer will go and decreasing the temperature.

Difference goes on decreasing and finally the process will naturally stop oh that will I will tell a mean temperature if we consider the heat capacity is that same then you know the mean temperature is nothing but the arithmetic mean by the energy balance $T_1 + T_2$ / 2 that means heat rejected by this body is equal to like heat gain by this body and if we consider T_f is the final temperature as we know that it be heat capacities are same Tf is there arithmetic mean, but now instead of so this a natural process this is a Tf is $T_1 + T_2$ / 2 now how do we find out the ΔS universe.

So ΔS universe equals to ΔS this is body A then this is body B ΔS A + ΔS now what is ΔS in this case ΔSA if we consider this is internally reversible, is integral δQ / t for the body and heat is equal to CP is the heat capacity total heat capacity mass into specific heat CP x dT is the reversible heat transfer / T and it is from T1 to Tf and this becomes is equal to CP ln Ta / T1 see Tf is < T1 this is negative obviously if ΔS is negative because for A it is reject heat it is cool so therefore we cannot take T out because ΔQ is CPdT and t is changing.

So therefore we have to integrate like this similar way if ΔS becomes around ΔQ / T this is for A this for B and that becomes is equal to at the similar way $C_P l_n T_F/T2$ and this is positive because $T_F > T2$, So Δ is universe is equal to Δ is say plus Δ is B, $C_p l_n T_F{}^2/T1\ T2$ and $T_f{}^2$ is what? $C_p l_n (T1 + T2)^2$ $(T1+ T2/2)^2/T1\ T2$ this is always positive we can prove this is because we know that geometric mean root over T1 T2 is always greater than the arithmetic mean.

This we have proved now this we can prove that $(T1+ T2)^2$ is always greater than T1 and T1 that means it is always greater than 0 that means it is greater than 0, so we can prove since the arithmetic mean is greater than the geometric mean that is T1 + T2/2 is always greater than T1 , T2 root of R, T1 or T2 or this whole square is greater than T1, T2 we can prove simple school level algebra so that entropy change is greater than 0 for a finite word.

Now another very interesting thing comes into picture that if the two finite bodies re attach or connected through a reversible heat engine then what will be its final temperature this is a very interesting problem.

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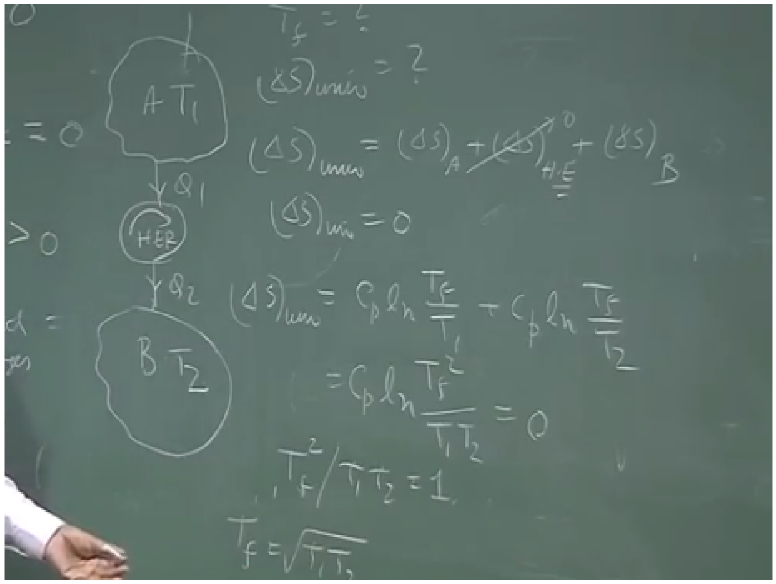

That if two bodies A at temperature T1 another body B at temperature T2 if they are connected through a reversible heat engine sometimes this is a problem that it takes it Q1 which is going on changing because their finite capacity body, so what will be TA and what will be Δx units, TA is not the arithmetic mean so you have to find out TA because they are not in direct thermal contact, now here to find out TA we must know this thing this will act as a clue to find out TA since this is the internally irreversibility taken to is 0 for both these things and since this is connected to a reversible heat engine which takes also heat reversibly from this two reserves.
So the entire process is reversible this system reversible heat engine reversible this that means Δ is universe is Δ is A + Δ is heat engine + Δ is B, now for a heat engine whether it is reversible or irreversible the entropy change is always 0 because entropy is a property and it needs operates on a thermodynamic side 0 and Δ SA and ΔB they are all operates on a reversible process so that ΔSA and ΔSB summation algebraic summation will become 0so ΔS is universe will be 0.

That means ΔSA + ΔSB becomes 0, we take this clue to find out TF what is ΔSA, that means Δ is universe = ΔS it will be the same equation L_n T_f \T1 integral ΔQ/T + C_p L_N T_F/T2 so that this is C_p $L_{N,}$ this expression will remain same earlier one because this comes from the integral dq/ ΔQ/T and in this case this becomes equal to 0, that means TF^2 /T1 T2 is 1 L and $T_F{}^2$ T1, T2 0 that means TF is geometric mean.

So in case of direct thermal conduct of two finite bodies of same capacity is arithmetic mean while it is connected by a reversible heat engine internally reversible it is of the system at 0 then the mean temperature is root over T1, T2 is the geometric mean okay. Now after this I will solve few problem okay I think the concept is clear to you therefore you see before I close this I tell you that it is now concluded that for all natural processes in this universe which is considered as an isolated system takes place in such a way.

That the Δ is of the universe is great than 0 and this is the direction of constant I told at the beginning of this class that there is directional constant for any process, any natural process occurs in such a way that it makes a permanent indentation to the surrounding, that means entropy change of the process plus the entropy change of the interacting systems are surrounding algebraic sum of this two mass be greater than 0.

If the processes are natural, that means if you consider an entropy band of in an universe the entropy is monotonically increasing that means entropy change of the universe always increases for example, I am teaching to you this is a process in this process I increase the entropy of the universe, so there is an increasing the entropy of the universe, entropy is generated in the universe so this is the directional constant of any natural process, okay in general. Now I will solve some problem, let u see this problem.

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Problem 5: A heat pump has a coefficient of performance that is 50% of the theoretical maximum. It maintains a house at 20°C, which leaks energy of 0.6 kW per degree temperature difference to the ambient. For a maximum of 1.0 kW power input, find the minimum outside temperature for which the heat pump is a sufficient heat source.

A heat pump has a coefficient of performance that is 50% of the theoretical maximum, it maintains a house at 20°C which leaks energy of 0.6 kW per degree of temperature difference to the ambient, that means temperature difference from the house and the ambient. For a maximum of 1.0kW power input to the heat pump find the minimum outside temperature for which the heat pump is a sufficient heat source, okay. Now let us come to the board and see what this tells.

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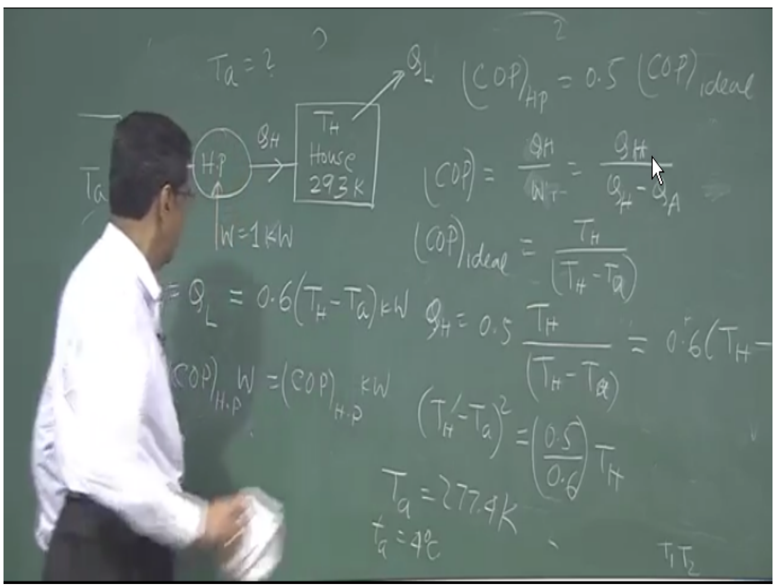

Now there is a house this is the house and there is a heat pump let the temperature of the house is TH which is 20°C it means 293K actually it is 273.15 you have to add because the thermodynamic scale of temperature is define, which has defined, which has been defined as I told but the scale is like that 0°C corresponds to 273.15K but you can neglect this 0.15 293K and heat from gives heat QH to this house and it takes heat from this surroundings, this is the surrounding temperature Ta which we have to find out, so this takes heat from the surrounding let this is QA we have to find out Ta.

And it takes work as 1kW, let us work with the 1kW heat and find out what is the value of TH and that will ne Ta and that will be the minimum value, why I will tell you afterward. This house leaks energy which is QL is the heat at which the heat leaks from the house to the surrounding. Now to maintain the house at 293K Ma will be automatically by common sense this much less than 293K it is the heating the house in knowing tank in Western countries.

Now this QH will be such to maintain the house at 293K must equal Ql that means the heat which it leaks must be giving by Q_h a study state when the house as attend 293K that means Q_h = Q_l and Q_l is it is what 0.6kw Q_w what is this Q_l is 0.6 KW per degree of temperature difference that means 0.6 x T_h – Ta that much KW, because by definition 0.6kw per degree difference T_h- T_a Q_l this is Q_h. Now we have to express Q_h now in terms of this temperature T_a and T_h so that we can find out the T, minimum temperature T.

How you will find out now this Q_h you can be written as the coefficient of performance of the heat pump in to w because coefficient of performance is defined as Q_h / w and w = 1 so therefore it is simply this cop of the heat pump. That much KW why because w is 1kw now we have to express cop in terms of temperature and it is written in the problem the heat pump as a coefficient of performance which is 50% of the ideal one that means cop of heat pump is 0.5 of the cop of the ideal.

Now ideal cop we can write cop is usually can be written w/Q_h or I am sorry extremely Q_h/ w or Q_h/ - Q_a and for a ideal cop this is the basic definition then they are proportional to their temperature, so therefore cop will be 0.5 of this so therefore we can write Q_h = 0.5 of this that means Q_h = cop of heat pump w is one so Q_h = 0.5 T_h /T_h – T_a very simple problem T_a small am I have given small a sorry.

T_h – T_a and that must be equal to 0.6 T_h – T_a okay so therefore it must be equal to 0.5 T_h, T_h – T_a must = 0.6 T_h - T_a because this is Q_h = q_a so therefore we get $(T_h – T_a)^2$ = 0.5 / 0.6 x T_h this is very simple 0.5 / 0.6 T_h is T_h – T_a and if you solving T_h is 293 K you get the value of Ta the negative value you just in ignore which will give a value of T_a higher than T_a so we take the positive value the answer is 277.4 K that means T_a is in the usual centigrade for Celsius scale is 4^o Celsius so this is simply this problem okay I think you have understood this problem well so how I have done this Q_H is equal to Q_L is by definition is Q_H is COP*W is 1 kilo watt so they are simply it is COP kilo watt.

So then right COP of the hit pump is .50% of this is ideal we cannot right in terms of temperature for non ideal hit pump but it is .5 of the ideal hit pump COP so therefore Q_H is equal to COP is equal to this 60% okay.

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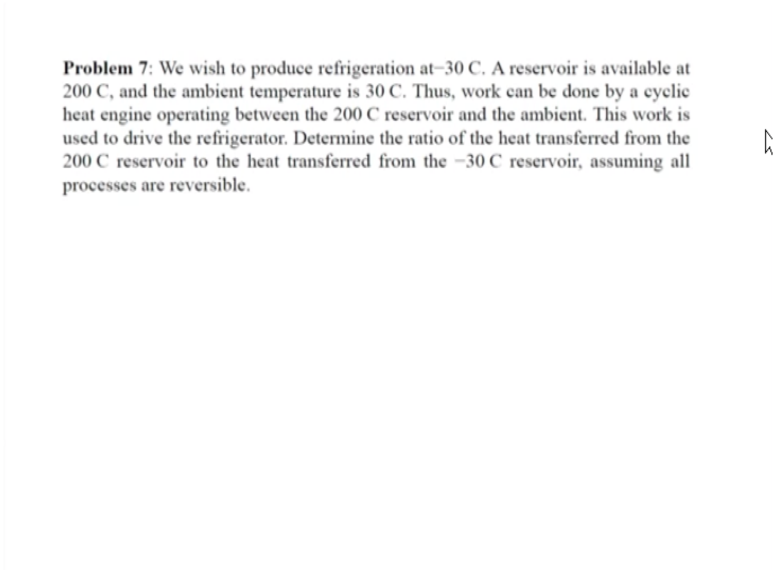

Now come to the next problem, now we come to the next problem now this is the same problem we wish to produce refrigeration at -30°C a reservoir is available at 200° C and the ambient temperature is 30°C a reservoir is a 200°C and the ambient temperature is 30°C thus work can be done by a cyclic heat engine operating between 200°C reservoir and the ambient this work is used to drive the refrigerator determine the ratio of the heat transferred from the 200°C reservoir to the het transferred from -30°C reservoir assuming all processes are reversible.

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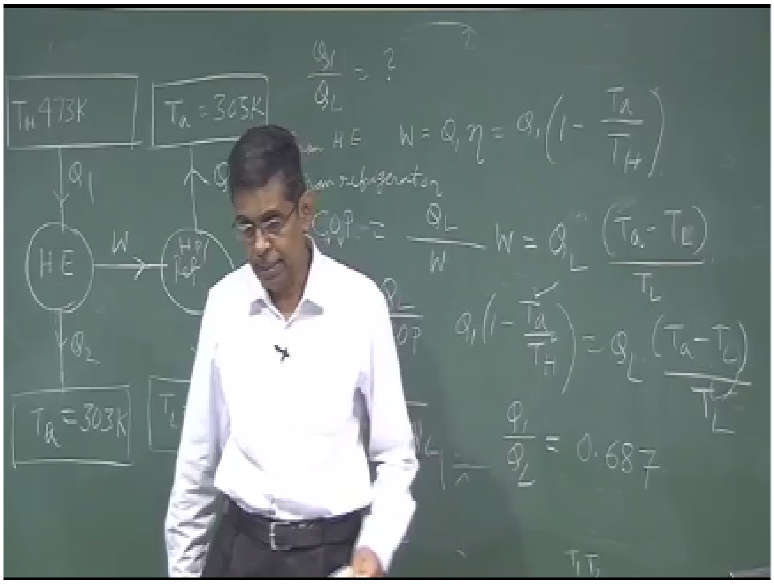

Now this is like this we have ambient we have a hot source at 200^{O}C that means 473k this is T_H hot source then we operate the heat engine with the ambient the heating takes heat Q_1 and rejects it Q_2 to an ambient temperature T_H which is how much T_H and ambient 30^{O}C T_a which is equals to 30^{O} that means 303K 30+273 303K.

Now this heat engine drives a heat pump refrigerator here you write refrigerator, refrigerator which takes a same thing heat pump the same device heat pump or refrigerator takes heat from – cool temperature T_L low temperature which equals to -30^{O}C that means this is what is the -30^{O}C okay.

Let me see the -30^{O}C that means it is 243K it takes Q_L and it gives to the ambient temperature, ambient temperature in this case here see it Cit pumps heat from the low temperature and gives to the ambient temperature which is 303K and this heat you consider as Q_H which it gives here so Q_1 Q_2 are the heat taken by the heat engine giving by heat engine this is by refrigerator given by the refrigerator to this were it access the heat part.

Now our problem is that we have to find out Q_1/ Q_L what is Q_1/ Q_L. So it is very simple W is the connecting it, that means we connect W with Q_1 and then we connect W with Q_L and equate it and then we get the result, because the same W driving the refrigeration, we have temperature this from where the refrigeration has to be made and we have an ambient where the refrigerator will reject.

But do we a source, so that with this as source and the ambient as your seeing a heat engine can operate at that heat engine can drive the refrigerator that means the same W. So from the heat engine, we get W is Q_1 x η and here all process are reversible. It is told in the problem that assumes all process as reversible, so η is what? Q_1 x 1 x – η is $T_A/ T_{H.}$ W is Q_1 x 1 x – η is $T_A/ T_{H,}$ from here W how can I find out? W here COP is defined as from refrigerator, from refrigerator COP is what? COP is Q_L / W.

So Q_L = W = Q_L / COP okay and at the same time COP since this is a reversible heat pump COP is Q_L / Q_h - Q_L that is T_L / T_A - T_L because this is reversible heat pump or refrigerator, so we can express this in terms of the temperatures T_L / T_A - T_L okay. So now W = what from the refrigeration from the refrigerator? We get W = Q_L / COP and COP is that, so W = QL x 1 / COP, that means T_A – $T_{H/}$/ T_A - T_L / T_L that is this temperature.

So these two are equal W, so therefore Q_1 x 1- T_A/ T_H that is the efficiency Q_L x T_A - T_L / T_L here we get everything, so we get Q_1/ Q_L if you take this side divided by this, we know T_A 303 we know T_H 473 and we know T_L is 243. So you know all the temperatures, so therefore we can get the ration Q_1/ Q_L which is = 0.687, okay today up to this thank you.