Concepts of Thermodynamics

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Lecture - 41

Entropy Balance for Reversible and Irreversible Processes

In the previous lecture, we were discussing about the change in entropy in various processes adiabatic reversible adiabatic.

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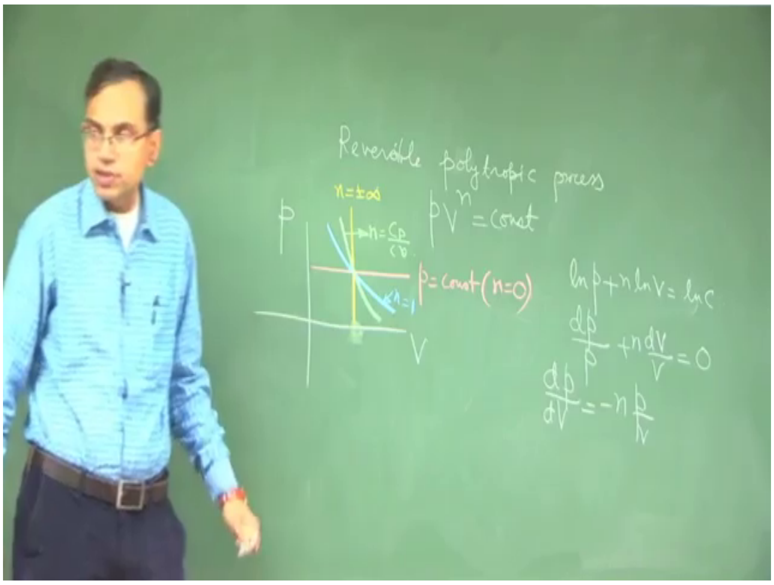

So, we will generalize that a little bit and we will discuss about you know a reversible polytropic process. A reversible polytropic process is defined by a process, governed by the following relationship pV to the power n equal to constant when n; I give you some examples when n is equal to 1, it is reversible isothermal process of an ideal gas that is the so called Boiler's law.

When n is equal to C p by C v that is reversible adiabatic process of an ideal gas, and when n equal to 0 it is a constant pressure or isomeric reversible isomeric process. So, if you now try to draw a p-V diagram describing all this processes. So, when n is equal to, first of all let us take the limit two limits of constant pressure and constant volume there they are easy to draw. So, constant volume is this one, let us change the axis. So, normally and this is very important normally we draw volume in the x axis and pressure in the y axis. The reason is that volume is that independent variable that we can vary in experiments, independently varying pressure is not something which is you know easy to do.

So, if now we draw constant volume process or constant pressure process let us first draw. So, this is p equal to constant. So, this is n equal to 0. Similarly, V equal to constant you can figure out; n is equal to plus minus infinity, V equal to constant then we will consider reversible isothermal and reversible adiabatic process. So, just let us try to get the slope of this diagram. So, just take log of both sides, you have l n p plus n l n V is equal to l n C.

So, now if you differentiate both sides so you have d p by; so you have dp dV is equal to minus n p by V right. Pressure and volume they are both positive, n is positive right. I mean when we are talking n could be actually anything, but when we are talking about comparison between isothermal for an ideal gas and adiabatic for an ideal gas in one case n value is 1 and another case n value is C p by C v both of those are positive those examples will have n equal to positive.

So; that means, in those examples first of all dp dV is negative; that means, it is quite obvious from physical intuition that if you increase volume the pressure will reduce for a given system. So, the slope of this is negative not positive ok; now if n is higher than the magnitude of the slope is more right. So, let us say, let us consider example of air. So, C p by C v for air if you consider calorically perfect gas it is about 1.4 and for reversible isothermal n is equal to 1. So, for reversible adiabatic definitely the value of n should be greater than 1, because C p is always greater than C v. So, if n is greater than one then dp dV magnitude for reversible adiabatic process of an ideal gas is greater than the magnitude of that for reversible isothermal process of an ideal gas.

In other words reversible adiabatic process in this p-V diagram for an ideal gas is steeper than the reversible isothermal process in the same p-V diagram. So, we can draw may be, and in both cases. So, this is n is equal to C p by C v and this is n is equal to 1 ok. So, these are these are just some examples you could construct more examples; I would like to now instead of p-V diagram draw T-s diagram for some of this processes. So, that you know it will give you a nice visualization of the same processes in the T-s diagram.

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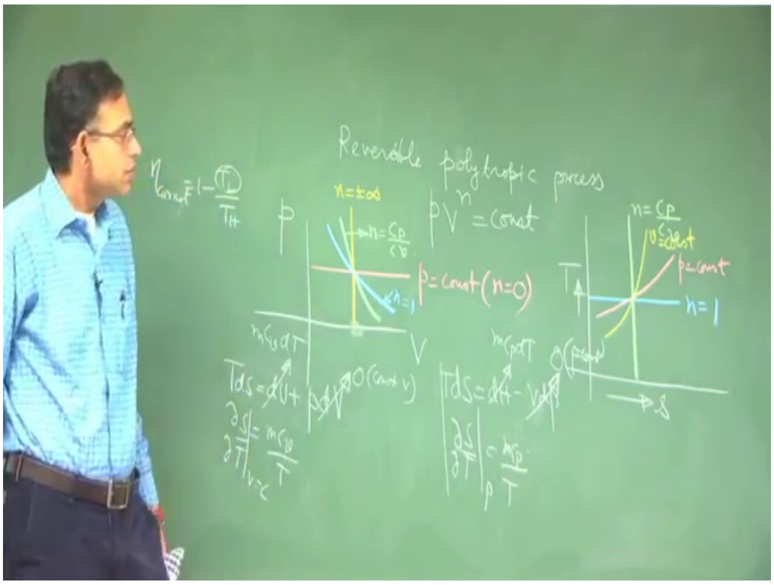

So, first of all isothermal process, reversible isothermal process is temperature equal to constant. So, n equal to 1, is this one.

What will be the vertical line in this? s equal to constant that is reversible adiabatic process n equal to C p by C v, then the two processes that are left are constant pressure and constant volume. So, let us see which one is steeper in the T-s plane. So, remember we are considering reversible polytropic process with specific example of ideal gas. So, Tds is equal to dU plus p d, this is such a useful relationship that you can use for any process diagram to you know explain the diagram. So, for constant volume this is 0 for constant volume and for ideal gas this is C v dT; m C v d T. So, d S is equal to m C v. So, dS dT is equal to m C v by T for constant volume right.

Similarly, for constant pressure we will use the other Tds relationship.

Student: Sir just one thing I (Refer Time: 09:13), while writing equal to m C v d T you told that it is an ideal gas.

It is an ideal gas, yes.

Student: dU is sensibility even if it is not an ideal gas because it is a constant (Refer Time: 09:24).

No, dU is m C v d T it is true only for ideal gas, because the definition of dU is based on so if you if you write. So, the, what is the definition of C v? So, ok; so, what you are saying is for if the volume is constant yes, if the volume is constant then it is true. If the volume is constant that you can then you can write dU equal to m C v d T for any substance, but if the volume is not constant. So, this x, this equation we are writing for any substance you know and then you are applying it for a constant volume process.

So, before applying it to a constant volume process if we write this it is better to commit that we are writing for ideal gas, if we from the beginning commit that it is constant volume process then it can be generalized ok. So, then it is 0 for constant pressure process. So, dS dT for constant actually this should be partial derivates you know, I mean I have written ordinary derivates just for your simplicity in understanding. But because you have kept volume as constant; that means, you know you are differentiating S with respect to T with a constant v equal to constant.

So, let us be technically a bit correct d H is m C p d T; so, m C p by T. In fact, for constant volume and constant pressure processes you can use this for any substance what you know this we are comparing for ideal gases. So, ideal gas has a special case will also work fine.

So, now out of these two first of all these are positive or negative this slopes? The slopes are positive because C p C v are positive and T is absolute temperature which is positive right. So, absolute temperature is positive. So, there are many nice interpretations about it, recall this just I am giving as a side note the efficiency of a Carnot cycle is 1 minus T L by T H right, this we derived in one of our previous lectures.

Now, by second law of thermodynamics the efficiency of Carnot cycle should be less than 100 percent Kelvin plan statement. So, if that would be less than 100 percent T L cannot be less than 0. So, that is why the concept of absolute temperature comes, it cannot have a negative value. So, attaining an absolute 0 is a physical impossibility may be you can go to very close to absolute 0, but you cannot attain absolute 0 here. Because if you run a hypothetical Carnot cycle with T L is absolute 0 then its efficiency will be 10 percent and that will violate the Kelvin plans statement.

So, this is just different approach of looking into the fact that why second law of thermodynamics does not allow you to attain absolute 0 ok. So, the moral of the story which we want to use here is that the temperature is positive. So, both are positive, but you have because C p is greater than C v del S del T at constant pressure is greater than del S del T at constant volume. In this diagram what we require is del T del S, not del S del T because its T-s diagram not s T diagram. So, in terms of del T del S you will have the del T del S at constant volume greater than del T del S at constant pressure; that means, constant volume lying is steeper than the constant pressure lying.

So, constant volume is that yellow line and constant pressure is the pink line. So, this is v equal to constant this is p equal to constant ok. So, these are you know nice physics visualizations of very common processes that we come across in thermodynamics ok. Now we will go to the next agenda item which is change in entropy in an e reversible process.

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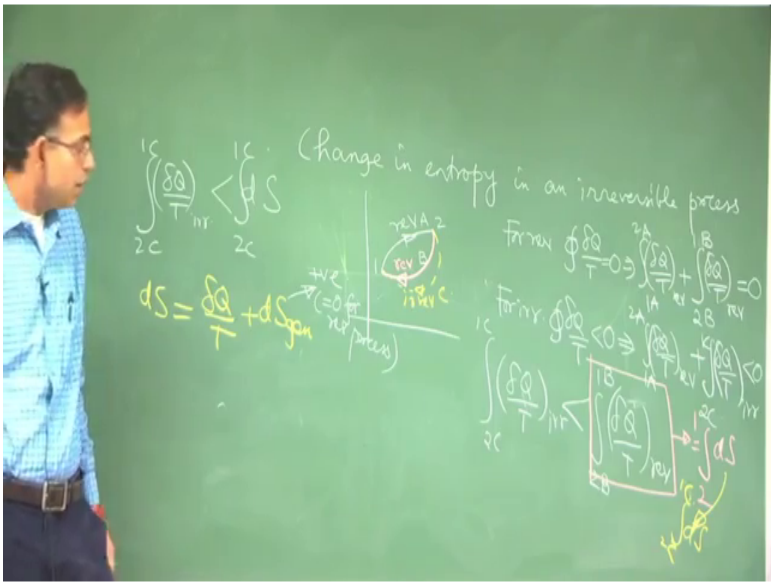

So, when we say change in entropy in an e reversible process what we essentially intent to mean is as follows. So, let us consider say at T-s diagram you have 1 to 2 are reversible path, from 2 to 1 you construct a reversible path. So, this is reversible A, this is reversible B, but you also construct an alternative irreversible path which is path C.

From the Clausius inequality for reversible cycle cyclic integral of del Q by T equal to 0 ; that means, 1 to 2 del Q by T via path A and 2 to 1. So, let us write it reversible by path B this is 0 for irreversible cycle an any if one of the processes in the cycle becomes irreversible it becomes completely irreversible cycle. So, cyclic integral of del Q by T is less than 0 so; that means, del Q by T from 1 A to 2A by reversible path plus irreversible path, this is less than 0 right.

So, now if you combine this two so you can write that from this two combination del Q by T integral along irreversible path 2 C to 1 C must be less than del Q by Tt integral from. So, this is B right, I have mistakenly written as A; 2 B as to 1 B this is reversible because this is reversible we can write this thing as equal to d S between 2 to 1. The formula del Q by T equal to d S we can apply only for reversible process and because it is between 2 to 1 and it does not depend on path the same thing we can say that this is d S from 2 B to 1B right because it is no more path dependent.

So, to summarize that we can write; so, this even if we write in place of C that works, in place of B if you write C that also works. The reason is between point 2 to 1 it does not matter whether its path B or path C, it is the change in property. So, to summarize we have C is any arbitrary path. So, we can replace, see in working with mathematical expressions we are more comfortable with equality rather than inequality. So, we can replace this inequality with an equality by writing that d S for any arbitrary path is equal to del Q by T plus a positive number, this is called as entropy generation. So, this is greater than 0 it is 0 when the equality holds; that means, it is 0 for reversible process.

What is this T? This T is the temperature of the system boundary across which this del Q is interpreted. Now what is interpreted as the system it depends on what is your domain of interest just like in mechanics what is your free body diagram it depends on you are representing forces on what, may be one part or the entire system. So, here also what is your system it depends on whether it is the machine itself or it is only the thermal reservoir or it is a combination of the machine and the thermal reservoir based on that this T has to be appropriately substituted because it is the temperature of that system boundary for which you are writing this equation ok.

Student: Sir, entropy generation is the path function right, it depends on which path you (Refer Time: 22:02).

Entropy generation is the path function yes.

Student: I have written d S.

So, you can write just write because you know this is, I mean it is a not the property. So, it is just you know just make sure that these are these are differences, but this is the path function you can better write this as integral of, I mean that makes the real sense because differentially you do not write it you write this one, right.

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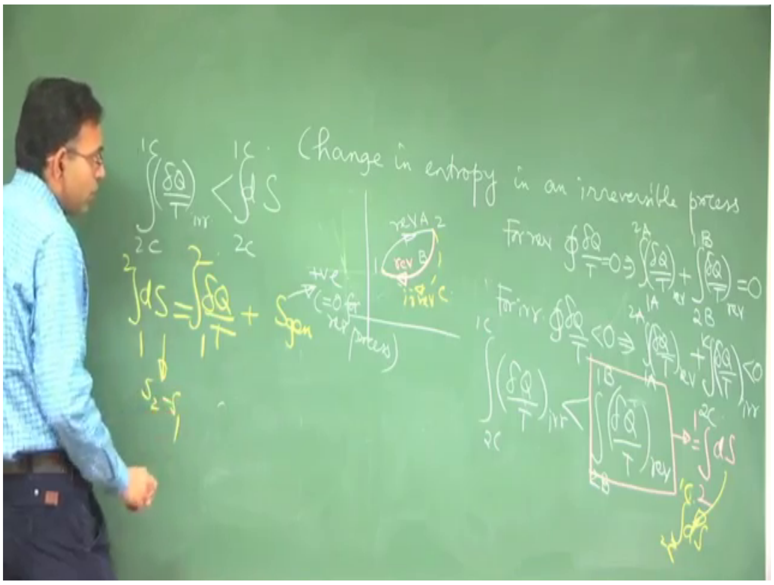

So, this is S 2 minus S 1. So, writing this as d S gen is little bit uncomfortable because you know del Q depends on the path. So, entropy generation depends on the path. In fact, it is very practical because more irreversible the path is more is the entropy generation. So, entropy generation is a physical measure of the extent of reversibility, more irreversibility it is more irreversible the process is more is the entropy generation.

So, here we have introduced entropy generation as or term which is positive just to give the flavor of a mathematical equality instead of a mathematical inequality, but let us try to give a physical interpretation to this. So, we will discuss something which is called as lost work.

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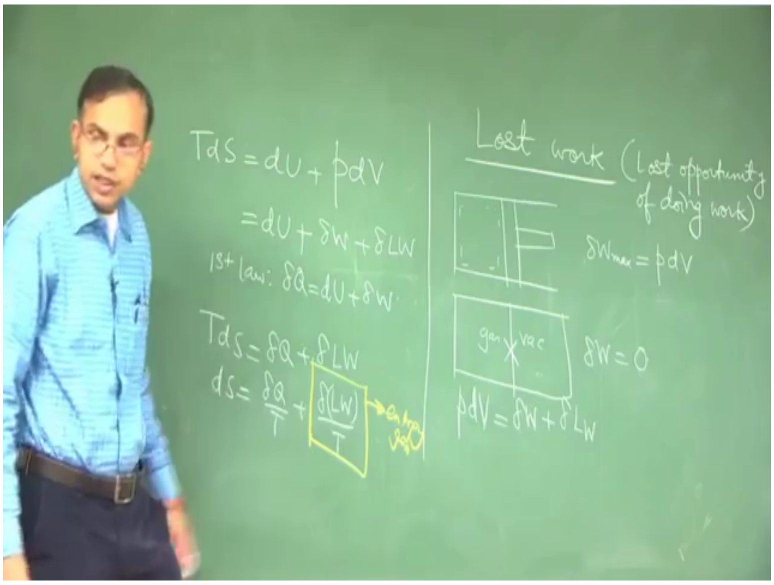

So, lost work is a concept which if expanded in English will be lost opportunity of doing work ok. So, now, when we say lost opportunity of doing work, what we mean? The concept is something like this in a practical process we always have an opportunity of deriving work because of a change in thermodynamics state. Now, if the process is reversible that work derived is maximum, if it is irreversible a part of the potential of deriving work out of the change in thermodynamics state is lost or destroyed we will prove that how it happens.

So, let us assume, let us consider two examples one is you have a piston cylinder where the gas is moving in a quasi equilibrium process. So, if the gas if the gas is expanding in a quasi equilibrium process because of the heat transfer then you have maximum work done which is p d V right. Let us consider another very interesting arrangement same gas, but now partitioned in two places, on one side there is gas and another side there is vacuum right. So, before the process starts both of these hold the same potential of doing work, but if you now puncture this membrane then this gas fills up this entire volume and no work is done.

So, here delta w is equal to 0 because why no work is done, because it is free expansion. So, I mean this is this is even a very philosophical way of looking into life, if we do hard work with resistance then only you know we utilize our potential. If we do not do hard work and do not face any resistance and have a happy go life then we do not utilize our potential. So, in this case the potential full p d V is utilized in this case it is not utilized at all, reality in life is something in between these two. So, reality is that you have p d V is equal to del W plus delta lost work ok. So, this is any case in between the work is between p d V and 0. So, p d V is maximum the actual is less than that and the balance is a lost opportunity of doing work right.

So, now you can write T d s is equal to dU plus del W sorry p d, this you can use for any process right then for p d V you can write del W plus del lost work and from first law you know that del Q is equal to dU plus del W. So, you can write T d s is equal to del Q plus delta lost work. So, d S is equal to del Q by T plus delta lost work by T compare this with d S is equal to delta Q by T plus delta S generation.

So, this is nothing, but entropy generation because entropy generation is positive the lost work is also positive and this term is 0 if it is reversible ; that means, with every irreversible process we have a lost opportunity of doing work, this is a physical interpretation of the entropy generation which is associated with the lost opportunity of doing work. Let us stop here today we will continue with discussions on entropy and possibly some problem solving in the next lecture.

Thank you very much.