Engineering Thermodynamics
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Lecture – 28
Properties of a Pure Substance: Ideal gas processes

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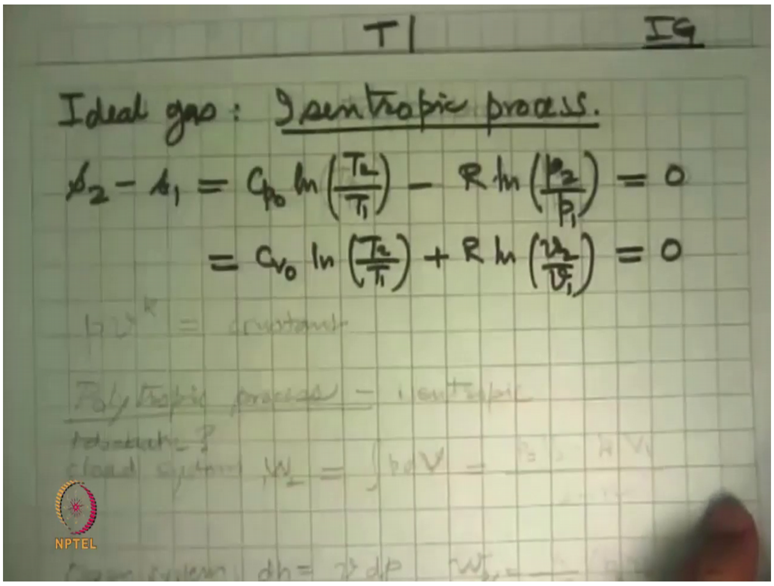

Ideal gas : Isentropic process.

$$s_2 - s_1 = c_{p0} \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{p_2}{p_1}\right) = 0$$

$$= c_{v0} \ln\left(\frac{T_2}{T_1}\right) + R \ln\left(\frac{v_2}{v_1}\right) = 0$$

Now, we will look at something that you would like to know is that what is an Ideal Gas Undergoes an Isentropic Process.

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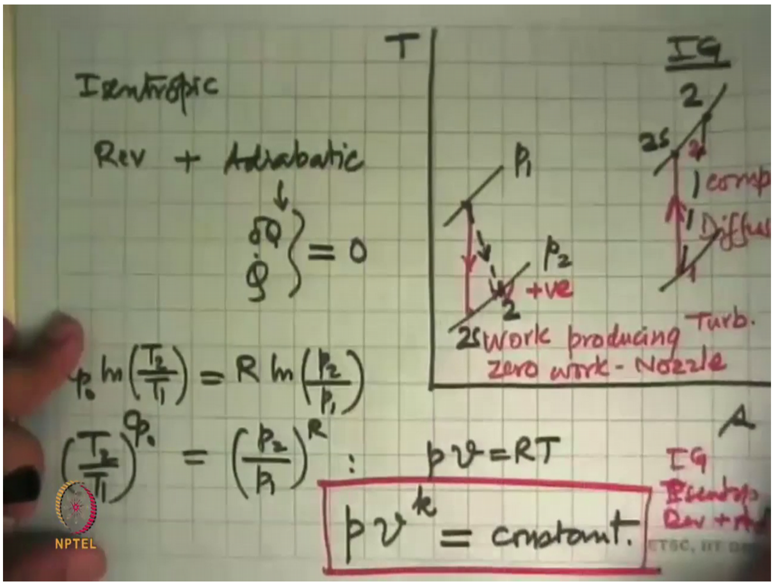

Isentropic

Rev + Adiabatic

$$\left.\begin{matrix}\delta Q \\ \dot{Q}\end{matrix}\right\} = 0$$

$$c_{p0} \ln\left(\frac{T_2}{T_1}\right) = R \ln\left(\frac{p_2}{p_1}\right)$$

$$\left(\frac{T_2}{T_1}\right)^{c_{p0}} = \left(\frac{p_2}{p_1}\right)^{R} \quad : \quad pv = RT$$

$$\boxed{pv^k = \text{constant}}$$

IG
Isentropic
Rev + Ad

So, before we go to the mathematics let us just look at property diagram. And say, well I will plot here s and this side is T, we are looking at ideal gas so there is no need to draw the dome. And now say well what is the isentropic process look like and it will be a vertical line. So, I could have a vertical line that goes like this from state 1 to state 2 or a line that goes from here to there, this is state 1, this is state 2

So, you can you are very quick application of the equations of the laws that we learnt and you will find that for this process to happen W is positive; that means the system does work it is a work producing device. This could be a expansion in a turbine, or expansion in cylinder piston arrangement, or even that we saw one more case zero work, but a nozzle. And this could be the opposite work consuming like compression. So, this is like a turbine or expansion in a cylinder piston arrangement the power stroke of an engine. So, this is a compressor or the compression stroke of an engine say a diesel engine or a electric engine (Refer Time: 02:19) vessel and the opposite process this is called diffusion.

So, what a nozzle does is that it takes in material at a higher pressure and temperature and it puts it through a contraction area in cause one class of flows in that high velocity on the other hand. But it will does exactly in opposite that you put high velocity fluid and you put it through an expanding area its pressure goes up.

So, these are the isentropic processes that we are looking at and say what else can I know about this for an ideal gas. So, what we do is we start with this equation that, we just derived that for this process s 2 minus s 1 can be written as C p0 ln T 2 by T 1 minus R ln p 2 by p 1. We could have as well use the other equation there is no problem with that, we could even say that this is C V0 ln p 2 by p 1 plus R ln v 2 by v 1 in the end the answer will be the same.

And we see this is an isentropic process which means that this has to be set to 0. And remember isentropic process means that, this is a reversible process and adiabatic. Adiabatic means it does not exchange heat during that process. So, delta Q or Q dot whichever way you look at it, it is a closed and open system this is 0, and reversible means it is the most ideal process that is possible. So, what we do is we take this equation now put equal to 0. So, it tells us that C p ln T 2 by T 1 is equal to R ln p 2 by p 1 or T 2 by T 1 to the power C p C p 0 is equal to p 2 by p 1 to the power R. And we can now exploit an apply the equation of state p v is equal to RT and when you do that and simplify this we get a very familiar type of an equation p v to the power k is equal to a constant.

So, that something we do. But now we know very well that this is applicable under what condition and only under those condition. This is for only an ideal gas for an isentropic process that is reversible and an adiabatic. So, this has to the applied to any of these types of processes, a turbine or an expansion in a cylinder or a nozzle. And this has to the apply to compression stroke or a compressor or a diffuser.

There can be no heat transfer in the process that is the case this equation is not applicable. So, this is one nice important thing that has come out from everything that we have done. And we started off if you look at the origins of where it came from it came from this equation; where did this come from we got the definition of specific enthalpy which come from the first law of thermodynamics, then we exploited the second law of thermodynamics and then we get this one special case. So, p v to the power k equal to constant.

And now we say that what if the process is not like this; what if it is some irreversibilities are there in this process or what if there is heat transfer during this. Can I use this equation? The answer is no. So, what the next best simple thing that one can do; we can make an approximation.

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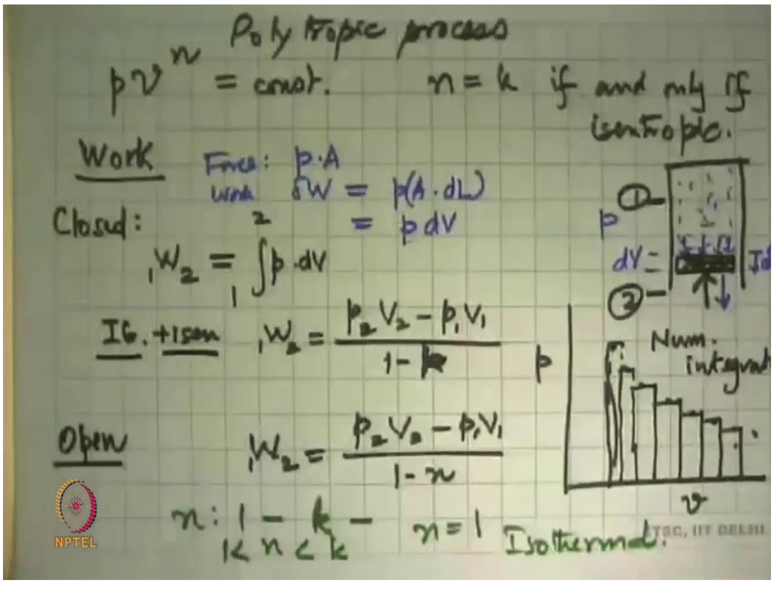

Polytropic process

$p v^n = \text{const.}$ $n = k$ if and only if isentropic.

Work Force: $p \cdot A$

Work $\delta W = p(A \cdot dL)$

$= p\,dV$

Closed: ${}_1W_2 = \int_1^2 p \cdot dV$

IG. + Isen ${}_1W_2 = \frac{p_2V_2 - p_1V_1}{1-k}$

Open ${}_1W_2 = \frac{p_2V_2 - p_1V_1}{1-n}$

$n: 1 - k -$ $n = 1$ Isothermal.

$1 < n < k$

And we say that instead of calling p v to the power k is equal to constant I will call it p v to the power n equal to constant and used it with the fair degree of (Refer Time: 07:29).

This could be a closed system under going this process or it could be a slow going through a passage or through a turbine or through a compressor and doing this. As long as we know that at any point during the process the states are known and those states follow this equation, then we are to use this equation. And when we do that we can then do lot of other calculations from here, but then remember that n equal to k if and only if it is isentropic process; under no condition it can be used back.

The treatment of both follows very similar to one another. So, we will look at some more examples of how we use this, especially in computing work, and for work we look at two conditions on. One side we will look at a close system, and then we look at an open system; open means its a slow process. So, let us see what happens in the close system. So, that is a device in which there is a cylinder and a piston and we apply this force to say compress this system; the substance inside it or alternately we allow this to expand and do work against the resisting force. So, we get work from there.

And for a very small change of volume say from there to there dv; we assume that the pressure acting on this (Refer Time: 09:30) change in volume is constant at p. Then the work done by this will be that is this was the displacement delta l or dl then the force being applied then we p into the area of this device this area, and the work it will do and (Refer Time: 09:59) work for that say delta W this will be p a into dl and that is why we say this is p times dv these two terms.

So, we say that for a very short period of time the pressure did not change and for that little part the work done is this much. One actually does this thing these days with numerical simulations and let us look at a graph which say that if I know and this is my specific volume and this is pressure. And they were say expanding and coming through these states and I want to calculate the work when somebody would try to fit a curve to this get the value of n and then do something.

But there is a second we have to do it, that we say that this pressure was there for a small period of volume, this pressure prevailed for this volume change, this pressure prevailed for this volume change, this pressure prevailed for this volume change. And so we do something which you learnt in mathematics which is they do numerical integration. And that is what one does in the laboratory many of getting the efficiency of air compressor or an engine by looking at what happens in the compression stroke. The instrument give you this type of a discrete data it is not a continuous data, and one then does this type of a calculation to calculate the work done or the work done by the system or work done on this. So, this p dv.

And now we say that initial position was 1 over here final position is 2; how much was the work done by this process. And all we do is we integrate this an say W 1 to 2 because this is now closed system this is equal to integral 1 to 2 p dv. We are only exploiting the definition of work in a nothing to do with the first law or the second law, simple straightforward definition of what is work. And work as I defined in the thermodynamics. So, when you do this integration and assume that this is an ideal gas undergoing isentropic, when you put all of these together then this W 1 to 2 comes out to be p 2 V 2 minus p 1 V 1 upon 1 minus n.

So, that something you saw in school, when we kept using it now we know the what all things that we have gone through it to get to this point. And that is the important thing to remember that this is an idealization of this particular case sorry; 1 minus k. And if it was following n and that is what is the poly tropic process then this work becomes p 2 V 2 minus p 1 V 1 upon 1 minus.

Now, what it tells us in that when k is always greater than 1, negative work means work done on the system or positive value means work done by the system with the surroundings. Out here this n can take any value there is no restriction on this in relation to k it could be between say 1 and k or more than k; all you have do is ask know what is that would be necessary to pull that type of a k. If n is between 1 and k this would mean that irreversible process or there is heat transfer out of the system. If in that work expansion process you also heat it up you may get n more than k. And if n is equal to 1 you can except what is an isothermal process.

In which case this definition gets into a problem your denominator become 0, we have to go back here and say that now p v is equal to R T and from there we start into getting it and we get slightly different form of this which is the logarithmic function. There we will tribute to do that derivation. So, that is the interpretation value n. Usually in real cases when there is some irreversibility and also in all practical cases we there is some heat loss to the walls of the cylinder or we are deliberately cooling it like in an internal combustion engine n will be less than k. And then you can see from here the work done is different from what we had earlier will be slightly less.

And if you want to plot those cases on this property diagram then we say that if at all operating between the same pressure which are these two pressure: this is p 1 this is p 2 isobars the real process in this case will go like that; you always have increase of entropy. And in this case where these are the two cosmic pressure lines the real process will go like this. So, this is 2 isentropic, this is 2 this is 2 isentropic this is the real value. We will see increase in entropy during this real process.

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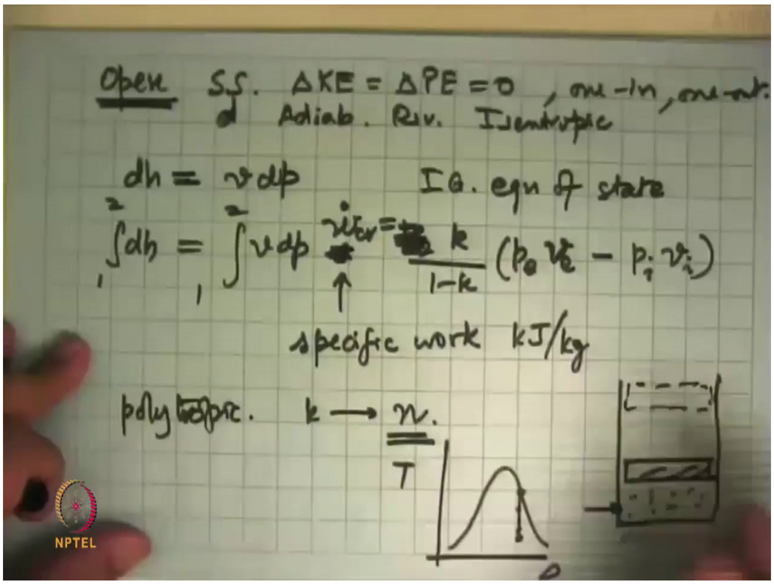

Next, that is one thing to be remember right. In this open system we write that for all this assumption that we made steady state delta KE delta PE both being 0 1 inlet, 1 outlet and for the time being we also assume that it is adiabatic and reversible which is what we are looking at in isentropic process. Then we can derive this equation and say that dh is equal to v dp. As we check you can check yourself is this v dp or minus v dp.

And now we integrate this assuming ideal gas equation of state dh is this and we use the ideal gas equation of state do the integration 1 to 2. And this is now integral v dp 1 to 2 and we get a very different types of a function which is n or k upon 1 minus k p e v e small volume minus p i v I; this is not there.

This is a very different looking relation and what we had putting it back. For a closed system the work done was p 2 V 2 minus p 1 V 1 upon 1 minus k or p 2 p V can be written as R p, so this can also be R T 2 minus T 1. In the case of a slow process this is k upon 1 minus k p e v e minus p i v i. Again we can put this as a equation of state and get R T p e minus p i, but now it is k over 1 minus k instead of 1 minus k.

So, this is something we need to be careful about that open systems the relation is this and what is this this is W dot C v. That is specific work sorry; yeah (Refer Time: 18:40) kilo Joules per kg of the working substance. So, this is the actual work W, this is specific work, and which tells us that if you want double the work you can double the mass flow rate then work done is. If you triple it, triple the mass flow rate work done is. And that is we actually scale up and design machines.

Same thing one can do and see what happens right this is the poly tropic process and instead of k if you just get substance required. Now let us look at something where there is little bit of doubt as to what is actually going on. And what I have in mind is a cylinder piston arrangement into which we introduce which is filled with dry saturated steam, and now this was allowed to expand. We know that on the T-s diagram now I have to show that same because I talking saturated, so the dome has to come. This was a inlet state.

And if we saw isentropic which is the work producing device the final state will go like that it becomes wet. But then as a first approximation if you know these values here we can approximate this process with some value of n and still consider this process as p v to the power n equal to constant. Even though, this was not an ideal gas. But one has to the clear that which cannot exactly tell during this equation what was the intermediate states; it is only an approximation of what the real thing is.

So, that was an a very commonly encountered relation for ideal gases, where we do adiabatic expansion or compression. If you do heating or cooling you already got those relations changed internal energy was C v 0 p 2 minus p 1 and changing in enthalpy for slow process was C p 0 h 2 minus h 1.