**Indian Institute of Technology Madras**

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**National Programme on Technology Enhanced Learning**

# Chemical Engineering Thermodynamics
**by**

**Prof. M.S. Ananth**
**Department of Chemical Engineering, IIT Madras**

## Lecture 10

## Heat – Work
## Interconversion Devices

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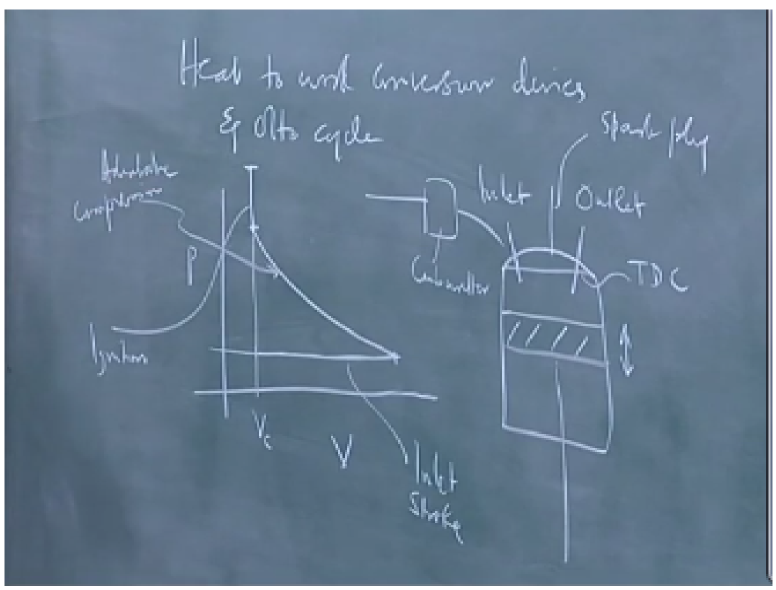


Heat to work conversion places, this is the you will taken any one example take the auto cycles so called auto cycle this is one on which your gasoline car still operate so I have p vs v, what I have is a piston cylinder assembly piston moves up and down in normal procedure is for you have to have two valves you have now 16 valves or even 32 valves one is called is an inlet valve this is the outlet valve these are the details that Corno refuse to get it in to, I told him what sheer engine he said I do not care, first aided people back in you know you are talking of though experiment and abstract thinking and then you now take it for granted I means every others you are go and tells you do a thought experiment but you must realize that when Carno did it first nobody ever thought that you could discuss the heat engine meaningfully without an actual engine.

But anyway this is just for concreteness there is a piston cylinder assembly this moves up and down these strokes are like this first you have at atmosphere repressor you have an intake stroke let us draw some figures this is clearance volume that is the when the cylinder is when this cylinder reaches the top dead center this place is called top dead center dtc, the cylinder shaped in such a manner that you have actually a small dead volume there it is called clearance volume for example one of the achievements of Japanese manufacture is just reduce the clearance for you and show you the efficiency increases tremendously.

So there is a clearance volume this is a design specification you when make it as small as your capable r it can be made 0 but sub date to that then from here you have you open the inlet valve keep the outlet valve close then the gas is taken and the air is taken and typically in the cylinder moves out toward so the volume increases it moves to some point here, so this is the inlet stroke. Stroke is simply movement is a piston stroke during which the air is taken and then the valve is closed here the inlet valve is open the outlet valve is closed at this point you are close both the valves and you have an adiabatic compression, at this point in gasoline engine was spark plug.

This spark is created across the spark I do not know how many of you have seen as spark plug spacing is we used do it in about one tenth of a mm spacing or actually it can be up to have a limit verse less much less your scale. A spark is actually you have a induction coil that generates very high voltage and a spark cross this and that spark ignites the fuel at this stage this air is actually a fuel air mixture nowadays what you have is an injection devise that injects the fuel as well was it measures the fuel exactly.

Normally in a normal in the classical engine we still have a few of them, those the air that comes in air comes in through a corroborator the word may go out to the dictionary soon, so humanity when need to know it. The corroborator what it does is measures the if you put your peddle to the metal then a lot of fuel will be taken a, if you relax on the axial rater only a few drops of fuel we taken and that actually control where a beautiful mechanism if you have seen many of the I think I am talking to you in a language if before you are born practically this.

Actually till last ten years ago there where corroborated engines even now you have corroborated engines the corroborated usually as a needle valve it is very nice mechanism.

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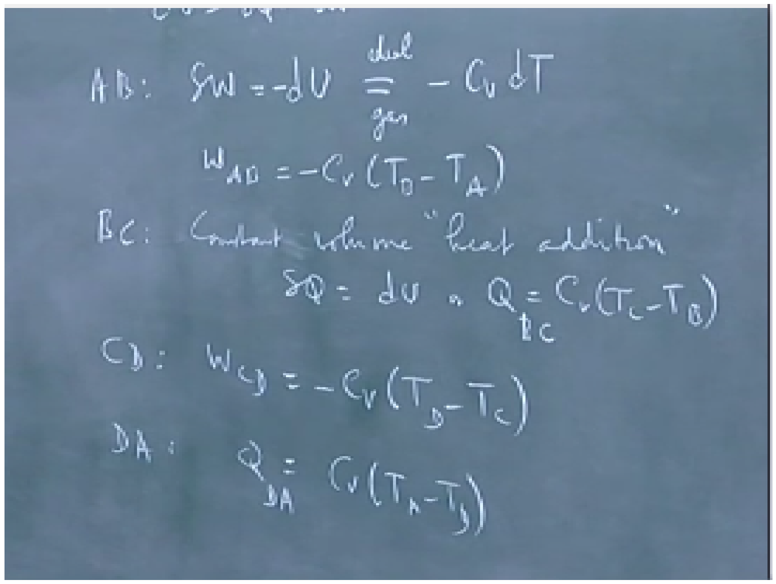


You have valve that looks like this, this is the tank that contains the liquid and as this valves goes up and down the air flows over the sorry air flows over the this thing as this goes up and down you have exposure of the liquid the exposure the liquid will vary I should make this narrow air then the amount of fuel picked up by the air will depend on the surface area of the fuel

So it will vary I am drawing on upset picture I have to actually see the corroborator properly I will get picture for that anyway that this controlled so at this stage this is the fuel air mixture very small amount of fuel and air enough air to cumbers the fuel and normally you have excess air because you want to pressure the fuel is to pressure so you want complete compression, so if you suddenly press the exalter you often do not have enough air that is why you get a smell in the exose.

But anyway at this stage the sparking is done when sparking is done the in the auto engine the ignition is this is the ignition stage so this is adiabatic compression then this is ignition, the ignition is so rapid at the cylinder that comes up to the top does not move back during the time of ignition if the time of ignition is really small so effectively it is constant volume ignition that is the characteristic the auto cycle.

That is what the thermo dynamics is concern this is where the reaction occurs reaction products have much lower internal energy than the product sham ion so the difference appears as heat because no work is done $\Delta q = du$ in this process. So the change in internal energy is what is supplied as heat, normally you call it constant volume heat addition in the case our diesel engine this actually pressure is much higher and the ignition is suppose we had constant pressure because as you inject the diesel it burns by spontaneous compression and that takes longer than spark ignition.

So actually the piston moves back ion the pressure is maintained instantly this is what they will do and they tuned a corroborator they can tune a corroborator for you to get better axial ration I man they can tune engine what they do is to say that this fuel intake I am sorry this ignition a spark ignition this spark will be ignited a little before the piston reaches the top dead center. So that the ignition occurs exactly when the pressure is maximum it is measure in degrees because you have a dial on top which is turned they will say $5^0$ if you talk to this mechanics a pretty clever guys they do know exactly what is going on inside.

But he will tell you how much advanced keep in, it is particularly effective in your motor cycles keeps a little more advance and it will go there is a big difference if you make it too if the ignition is too far in advance then before the piston reaches the top demister it will be sent back, so you will lose some power in that process. Okay anyway you get to this you get ignition then you have adiabatic expansion this is adiabatic meaning it occurs in such a short time that there is no time for exchange of heat to this surroundings.
And then this is simply cooling this is you radiator fluid if you have an old forks when beetle and does air cooling very effectively simply with more fins, and then there is a exhaust stroke the inlet stroke and the exhaust stroke the exhaust stroke pushes out all the material inside this piston and actually nitrogen is a same part of the oxygen will be consumed replace by carbon - di – oxide.

Since a fuel also has a bit of hydrogen you will have some water in the exhaust, but if you ignore the inlet and the outlet strokes and simply look at this cycle it is a close cycle. If you pretend instead of change in composition does not really change the specific heats significantly, so it is air plus whatever or just call it here with the certain specific heat that goes through a cycle and here you have heat addition at it instead of the reaction that produces a change in internal energy that gives you the heat, we just call it heat addition and this heat addition here it is keep removal.

So effectively you have an adiabatic compression followed by heat addition at constant volume and then you have an expansion, so this expansion will give you work on this diagram you calculate work as PDV so the area under this curve is the work done by the system the area under this curve is the work done on the system because you have to compress it which is why we always have an electric motor to get the whole thing started you crank the motor it compress it first once this heat addition occurs then there is enough energy then it goes out here then it can keep.

So the net to work done is this area under the curve is the net work done in the cycle, so this volume here we will call this areas points by name all this a we start here a, b, c and d is your cycle. This volume is called the stroke volume simply measured by the π d 2 / 4 in to the length of this; this is the volume swift by the piston and an movement.

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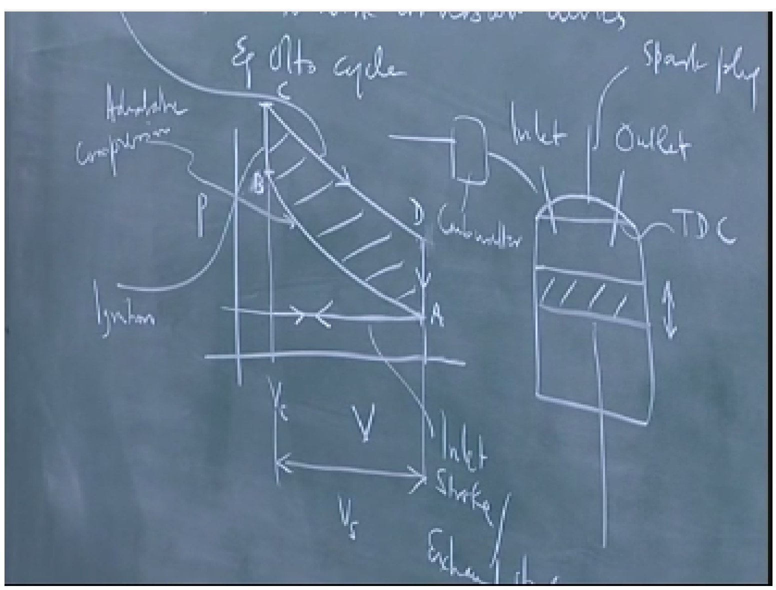

The quantity of interest is how much heat do you add here we write this in terms of q in actual fact it is a reaction occurring where as I told you internal energy as a product is less than the internal energy of reactance and therefore you get net heat added to the system but we calculated in terms of heat added and work done the heat added divided by the a calorific value of the fuel will give you the amount of fuel consumed.

So effectively for fuel consumption what is the amount of work you can do what is the mileage you get in to work so this is the one that I want analyze this is the original cycle propose by auto, so what you do is in order to the analysis write a b all the equations are given on this is the close system $\delta q - \delta w$ that is it, so the stroke a b I am going to ignore the inlet and the outlet stroke as cancelling one another I do not have to consider them at all I pretend that here I started at a, a pretend instead of fuel ignition I pretended heat addition.

And I pretend here that there is heat removal which is actually is truth it move it very quickly, a b is an adiabatic systems so $\delta q$ is 0 so $\delta w = du$ for assume ideal gas I do not have to this is actually thermo dynamic charts for this which you can use but if I assume ideal gas you are taking of cv dt, then I have bc or I will write w itself w ab so I can integrate this w ab I simply cv x t2 tb – ta see if cv is constant you use an average value of cv otherwise you have to strictly a function of temperature work for all practical purposes in engineering we use average values of c.

Then I have bc sorry here, bc is simply constant volume heat addition it is actually not heart addition as I told you it is simply a reaction occurring the coronal go to carbon dy oxide the heat is in fuel is go to water in the change in the internal energy is equal to the heat addition. So again if you like $\delta q$ is actually = du or heat addition is simply integral of again cv c tc – tv, the conditions that a are known the pressure at the intake is known it is usually atmospheric this can be when you have as upper charge engine or you do is have a compressor and increase the raise this level and insure you that gives you better more power for cycle but at the cost of partial it is does not make it more efficient.

So initial that kick you can get by the super charging your engine putting compressor in the outlet compressing in the inlet gas inside it a inlet air and sending at air then cd is again adiabatic process you have wcd there is a –sing here because du is $-\delta w$, this is – this is – okay. Then wcd is exactly like here I can simply write it down this is cb x td – tc because $td < tc$ this wil turn out to be positive that will turn out to be negative.  And last one is da so again q this is q bc this is q da da is exactly like this cv x ta – td.

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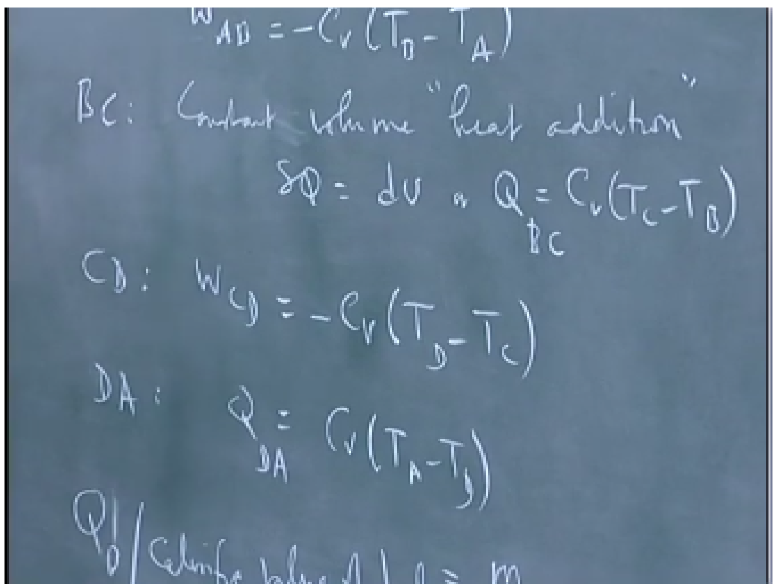


So what I am looking at is what I am interested in is w net / q bc because q da is simply heat loss to the environment I get nothing from it q bc is what is supply that is my fuel so remember q bc / calorific value of fuel will give me mass of fuel so if I want work done for unit fuel consumption now essentially have to calculate w net w net is essentially wcd – wab / qbc, so you get tc – td – I have w ab – tb – ta now taken the – sign out by switching / qbc is tc – tb so this is 1- td – ta / tc – tb so this is your efficiency.

All we need to do this calculate the temperature and you can calculate these temperature very easily first ta is known ta and pa are known this is adiabatic you have your formula pv per γ is constant, so from here to here you know this volume so can calculate the final pressure here. So once you calculate the pressure your t is again pv = rt then here again this temperature is known this temperature is not directly known unless you know the heat addition at depends on hwo much fuel you add so I will give the fuel consumed you can multiplied by it calorific value and pout in q here.

So you can get this temperature actually backwards from this equation, that is I know tb now I can calculate tc = tb + qb c / cb okay. so I can calculate that temperature so I can calculate these conditions and then these conditions again this is an adiabatic expansion one say these two I can calculate here because everywhere the volume is fixed it is fixed by the geometry of the, so in this say 1.3 liter engine they usually mean this is 1.3 liters vs, so if you have a bm w 6 5.3. 0 5 is the series then 3.o liters 3 liter engine because it is very big engine.

And the compression ratio also determines the pressure from here to here depending on this ratio you get higher or lower pressures and if you look at this clearance volume it has physically a bad influence because at the end of the process when you are compress it you have clear is you have gases at the end of this process at this pressure and this volume, so when you expand it out this gas remains when you finally expand it out that gas remains in the system and so it occupies pace much more atmosphere pressure it occupying more space then it would before.

So essentially it represents a loss because you have this spent fuel air mixture that still occupying the space inside the cylinder, so clearance volume represents loss what we can di is work this out in terms of geometric specification as for as possible you get all the variables in terms of geometric specification we will do that. So we will calculate each of these temperatures then I can get these ratios.

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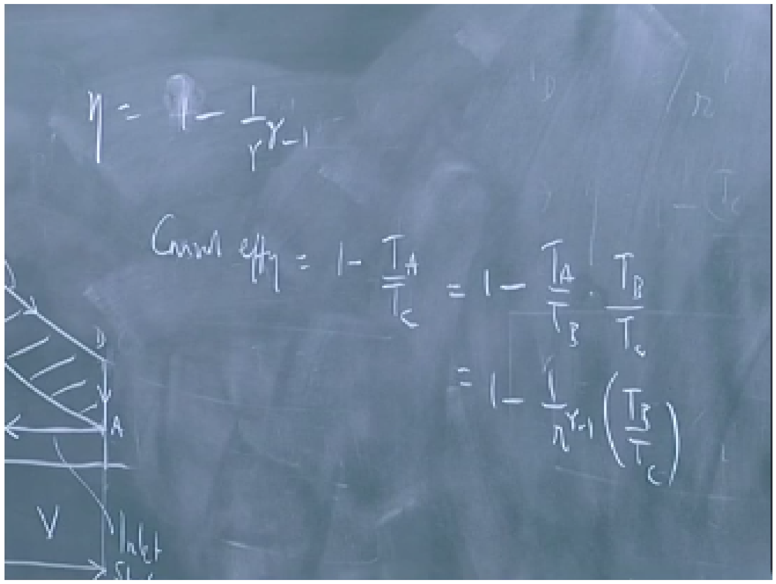


Ta is known I should have done it in terms of it is okay, and leave to a as it is tb what is the formula it is pv per γ = constant pv = rt n is constant here the number of moles is constant so I want vt relationship that is well so instead of p arrived by v γ – 1 so tv per γ – 1 = constant right. So tb if I am writing in terms of ta, tb is simply ta (va / vb)γ-1. Va vb are geometric specifications. If I give you the cylinder dimensions then I have given you alkl the data per va and vb.

Then similarly this was I should have kept pc comes out in terms of heat addition okay I will try and use this equation rather than this, so I have got tb in terms of ta similarly td = tc in to the same ratio vc vd are the same ratio as va and vb so tc vc is (vb / va) γ – 1. You want va / vb so I will write everything in terms of pc here or this is td that is efficiency is equal to if I pull out a td this will become tc / td which is va / vb we will call va / vb as r, it is a geometric specification so I have td x tc is r $^{\gamma-1}$-1 – ta (tb/ta) I want vb / va so – tb I will pull out this tb in to 1- a is the smaller one it is vb/Va now va / vb is r so this is correct what I wrote is right, ta ( r $^{\gamma-1}$-1) / tc – tb you want to plate in this equation or this one? This one okay what you want?

Okay ta in terms of tb that is already written right here, but you can take va and vb to the other side, and then you write, you want ta? I have written that tat b x r $^{\gamma-1,}$ I have written that, ta is tb x vb / va so 1/r $^{\gamma-1}$ right, this equation I have written ta then, 1/ r γ-1 comes out you will now doing this equation? Yes, okay td – ta yeah so you got yeah thanks, so ε = 1- td and ta is tb – tc – tb x r γ-1 / tc – tb yeah thanks. Do you have efficiency equal to 1 – 1/ rγ-1 r is what you have control over, because you are building this.

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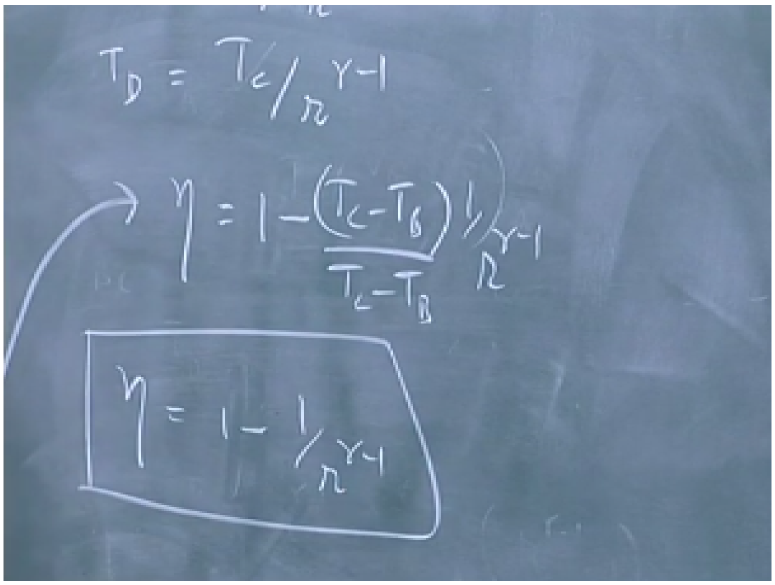


So your r is actually vs + vc this is stroke volume this is clearance volume if you want I will call this vcl to make it clear okay we have another vc by v clearance, clearance volume is the date volume if you like when the piston is at the top.

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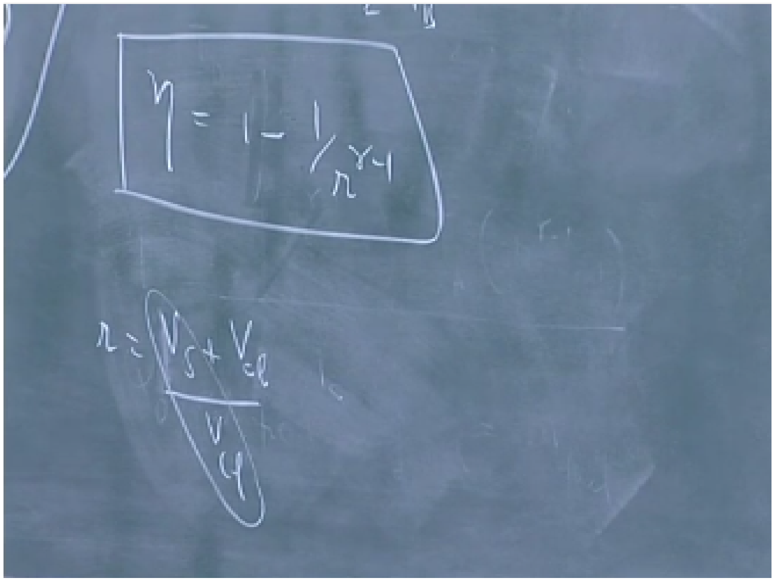


So this ratio is in your control, actual practice what happens is that these things are rounded off it does not happen exactly like this was the actual stroke the valve has to close it takes some finite time soon but if you look at the whole process in sort of controlled if you have talking of 300o rpm you got one explosion about for every rotation of the crank shaft of the wheel not the wheel the crank shaft because then the wheel is geared, but for every rotation of the crank shaft you have two explosions and you are talking of 1000 rpm you are talking of 2000 controlled explosions per minute.

So that is who your vehicle runs your vehicle runs through a series of controlled explosions every time you have a fuel burning you have small explosion it is all contained the other cycle that one can describes incidentally the Carno efficiency the efficiency here is $1 – 1/ r^{\gamma - 1}$ of course the other way of changing this has to use a fluid that has a different $\gamma$ but rather than her anything else you going to pay heavily so there is no point unfortunately air and oxygen have the same $\gamma$ otherwise you can try purifying suing oxygen.

But many case does it make sense so this is only thing the Carno efficiency is you have to take the higher temperature as the source and the lower temperature as the sink equivalent Carno efficiency, it will be 1- the lowest would be $t_a / t_c$ so they have an expression for $t_a / t_c$ $1 – t_a / t_c$ would be written in terms of $t_a/ t_b \times t_b/ t_c$ you do not like $t_b / t_c$ that is why I do not have a choice this is $1- t_a / t_b$ is $1/ r^{\gamma – 1}$ again $\times t_b / t_c$ so $t_b / t_c < 1$ and therefore your Carno efficiency is greater than the efficiency that you get crumbly auto cycle analysis right.

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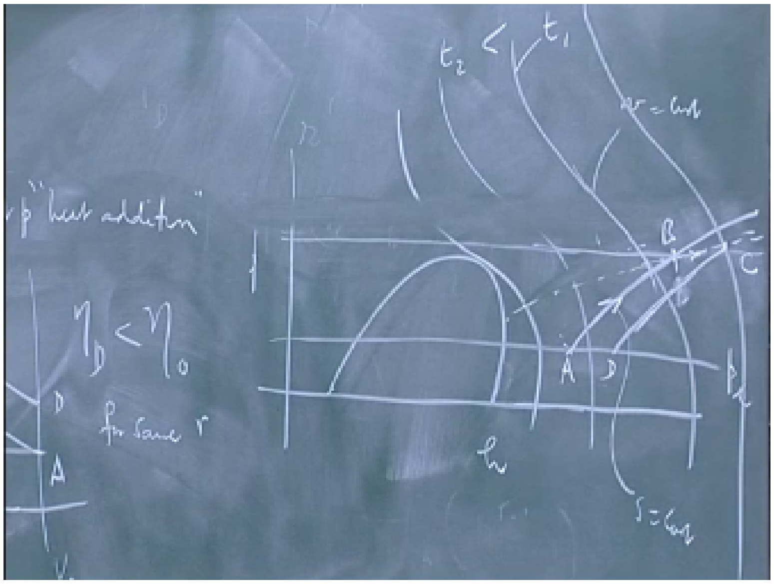


The diesel cycles are actually similar except that you have two parameters for control you have a vs and vc again it is a same contraction you have the exhauster can the inlet stroke what you have is a compression adiabatic compression and this stage the fuel is now added by injection and you cut off the fuel injection at some point then it goes like this so here it is constant pressure heat addition.

The word heat addition is used to denote the change in internal energies are occurs during compression, so here the same a b c d usually these pressures are much higher so the diesel engine has to block has to be much heavier not at extended pressure, and there is a cur of ratio here this ratio of the volume here c this is clearance vc / vs + vcl is defined as a cut of ratio rc it is the time at which you cut off your diesel.

That depends on how much you press your peddle and you can show there is a just lot of algebra you can show that it is always less than this for rc when the rc = this when this is equal to 1/ what did we call this v clearance by vs is that what we called r yeah, so when it is equal to r you will find that the efficiency is same as an auto engine. So in general the efficiency of a diesel engine is less than the efficiency of an auto engine for the same r.

Actually there is a near standard cycle table from which take thermodynamic properties, so you can actually calculate the you can take the non idealities intercom because you are doing this ideal gas analysis here at this point it can be an ideal gas but it the higher pressure if it would not be an ideal gas some departures from ideal gas but these have been computed and you can read it from your standard cycle.

The other thing I want to say was in the terms of the ph diagram here you do not actually have a ph diagram for a case like this because in your pure substance but if you treat it as air or if you treated as single substance again here is a mixture we should treat the single substance you have to always starting above the critical point, so you really looking at this region all you have is you are starting at some you working between two pressures, there is p1 or p high and a p low and you are working within two adiabatic processes.

So you can start at p low at some temperature and you have an isentropic process it goes up to p high and then you have heat addition at constant volume so how will you represented on this diagram, only you are do is go along a constant volume line and this is isentropic this is v is equal to constant along the constant volume line you have a heat addition that means temperature how I will draw this diagram I have these lines.

This is t1 this is t2 < t1 I have compression from low pressure some this is where I start let us say this is a from here I have I go to the higher pressure, I think I should draw this a little lower because it getting outside the board otherwise. I go to this pressure this is b from there I have a constant volume line which is different slop this is the constant entropy line then you see that the constant volume lines are the different slop low slop, so I have some heat addition so I will go up to this point c and then come back along an adiabatic.
This is d so a then b b to c this is b this is c here then d this heat addition is what you have to know you have to know how much heart is added during this process so you will have to add the internal energy there and amore along that line with the new point. Essentially I would not it to you ion tot form of you in the form of chat I mean the form of a graph it will given to you I the form a table. And then there are variations of these that have been discovered whole history but really the auto and the diesel are the one set of remain the simplest in these easiest to operate what I will do is I will for the sake of completeness I will discuss refrigeration very briefly on the well you have done this.

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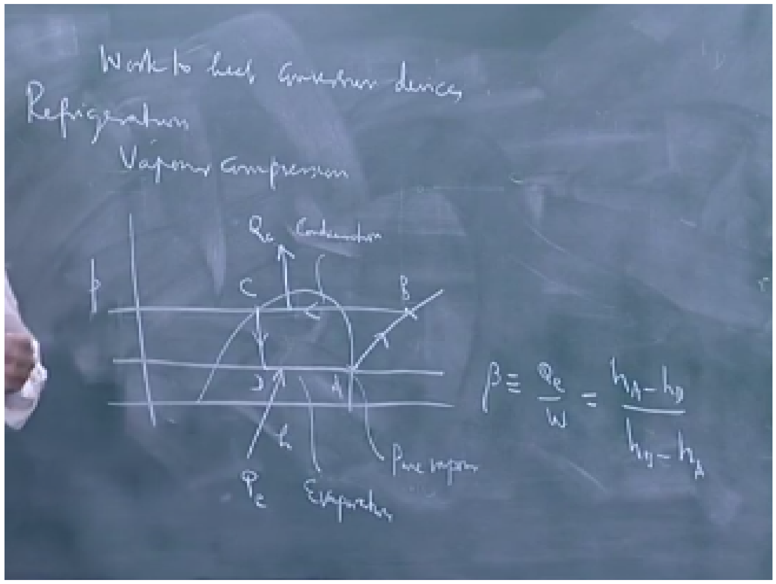


Because this is called vapor compression refrigeration which is what you would have done on the ph diagram and then I want o discuss later absorption refrigeration which is used in large scale this is work to heat conversion devices, here you are talking of two phases what you do is take let us say pure vapor could be free on now you have non florohydrocarbons for this thing but you have pure vapor which you compress a long an adiabatic.

I work between two pressures again I have a b this is adiabatic compression from a to b from b I cool it to saturated liquid, then I carry through an isenthalpic process this is call through line so you bring it down to a point d where you get a mixture of liquid in vapor then whatever liquid there is you have evaporate here this is actually I will call this condensation I will call this evaporation, evaporation requires that you take heat from the surroundings qe here you add heat you give up heat when you condense a fluid latent heat is given up to this surroundings.

That is happens that you give up heat at a higher temperature and you absorb heat at a lower temperature, since you are interested in the extent of cooling the coefficient of performance for such a cycle is the amount of cooling that you produce which is qe which is ha – write this one qe / w this is where the workers this process for the sesobaric process the total heat that is removed is ha – hd the amount of work done for an adiabatic system for flow systems for unit mass flowing through the system, it is a difference in enthalpy.

So by hb – ha it is call the coefficient of performance, so if I give you the chat for the fluid it is absolutely trivial for you to calculate this you must have done this calculation, this is vapor compression what we will look at is mixtures where you do absorption refrigeration find that for large scale absorption refrigeration is much better, here you have a compressor with moving paths you do not have the same what you do is absorb at the gas in a liquid and you take away the gasoline liquid in to different temperature you find that this you can use this difference in solubility's and the enthalpy of resolution to extract some refrigeration out how to heat.


This Lecture Series Edited by
Kannan Krishnamurthy

Online recording &
Post Production Team
Subhash
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Producers

K R. Ravindranath
Kannan Krishnamurthy
Recorded at NPTEL Video Studios
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