MARINE ENGINEERING

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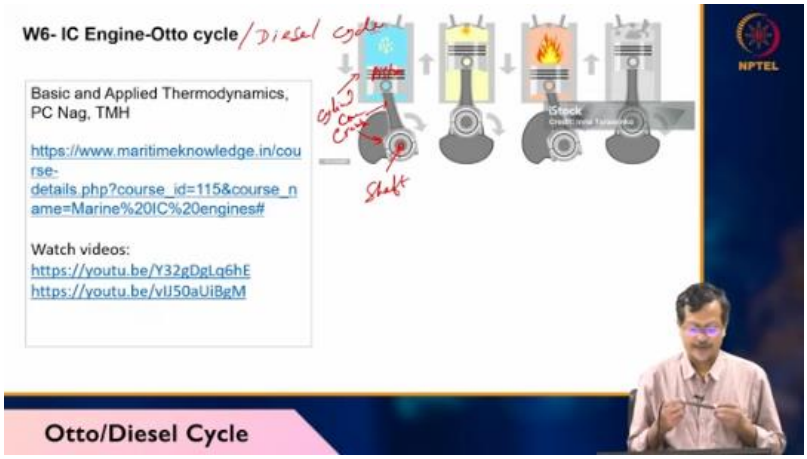
Lecture37

Otto/Diesel Cycle

Today I am going to start IC engine second part, next part means that is including Auto cycle, Diesel cycle and DI Diesel cycle ok. So, in previous lecture you have seen the IC engine is having one piston, one cylinder basically and one crank, crank is here. connecting rod. So, when piston is moving up and down combustion will be occurring. So, because of combustion your crank shaft will be rotating shaft will be perpendicular to this one.

So, shaft is here So, in shaft you are getting torque. Now, what are the different cycles are there what two stroke engine four stroke engine I will discuss. And this topics I have taken basically from basic and applied thermodynamics book. and some internet sources plus you can watch several videos are there available in youtube so just you can google i have given two links but there are many videos available so you can watch so before you dis we discuss about auto cycle diesel cycle or different types of cycles we have to know about two stroke engine four stroke engine okay so two stroke engine four stroke engine so first you see the pv diagram



in previous day we have discussed one compression cycle will be the compression stroke one expansion stroke arrow direction will be opposite one combustion will be happening so one two three four okay so one two two compression compression means you have one cylinder okay and you have one piston piston will be moving forward backwards this is TDC and this is BDC so the piston will be moving within TDC to BDC it will not move further there and you can see this piston certain specific gap is there that is called clearance volume and clear volume is given for mechanical reasons there is no other specific reason ok when piston is moving towards TDC you are compressing so 1 to 2 is compression stroke ok and this is happening we are assuming this is adiabatic condition ok so this is isentropic PV PV power gamma equals constant adiabatic or isentropic similarly expansion stroke 3 to 4 it is also PV power gamma equals constant now what is two stroke what is four stroke now if you see this crank drawing we have done already crank case connecting rod crank and this will be rotating like in circular fashion right so this one I said crank case okay this is your crank crank is rotating so piston will be moving up and down now you can see when crank rotating and piston moving up let's say initially you filled your cylinder with air and fuel you are compressing after certain temperature you are giving spark and fuel will be burning and piston will be moving down continuously right so when piston is moving down because of high pressure gas you created so you are getting power or torque ok now

at 4 when you reach at 4 at BDC piston will be reaching at BDC this is not BDC so there instantaneously you have to remove all the air burnt whatever burnt gas is there you have to remove so but practically it is not possible because crank is rotating continuously piston moving BDC bottom dead center and instantaneously everything will be going out of the cylinder is not possible so you need certain time again it will be your combustion or burnt gases should be going out from cylinder again you have to take air and fuel mixture also at the same time so how is it possible so it's not possible difficult right so you are getting power stroke then all gas will be going out of the cylinder and you are getting air and fuel mixture again you are compressing so instantaneously is not possible okay so if it is happening so so that's why this concept came up two stroke and four stroke engine Two-stroke engine will have like this 1, 2, 3, 4, but if you have four-stroke engine, four-stroke engine will have like this, P, V. So, one is here, one is here, as it is I am drawing 1, 2, 3, 4. So, from 4 to 1, exhaust, we are assuming exhaust happening, but practically it is not possible. So, what will happen?

Piston BDC TDC so when piston reached at bottom drain center you open exhaust port okay exhaust port open and you push the piston towards TDC when you are pushing piston towards TDC you are not talking taking any air fuel mixture inside cylinder so whatever burn gas is there you are just removing from the cylinder okay so that means piston be moving again towards TDC so this is one this is four five four uh one maybe we can say five four to five it will come again then again when piston reached tdc again piston will try to move towards bdc okay because continuous rotation will be occurring so that time you remove this you stop or close the exhaust port open intake port Intake valve you open and you take air and fuel mixture.

So, piston moving you are injecting air and fuel mixture. You fill piston cylinder with air and fuel mixture. So, that time you are not creating any pressure or you are not taking any pressure. So, atmosphere pressure is there. So, small low pressure you are creating.

So, mixture will be entering into the cylinder. So, 5 to 6 again 1 and 6 will be superimposed actually same point. so 5 to 6 actually so 1 to 5 exhaust gas going out of cylinder okay 1 to 5 when piston moving BDC to DDC but no power it is producing neither it is taking too much power okay it is just moving so just removing burn gas from cylinder to outside so that is called exhaust stroke okay so you are not getting any power now five to one five to one or five to six one and six was the same point actually so five to one remove stop or close the exhaust port open intake port you take air and fuel mixture okay so five two six or one taking air air plus fuel ok now what will happen BDC after power stroke remove all the gas burnt gas there is no fuel available because already combustion happened again move towards BDC take fresh air and oxygen fresh air plus fuel now close both valves exhaust and intake start compressing

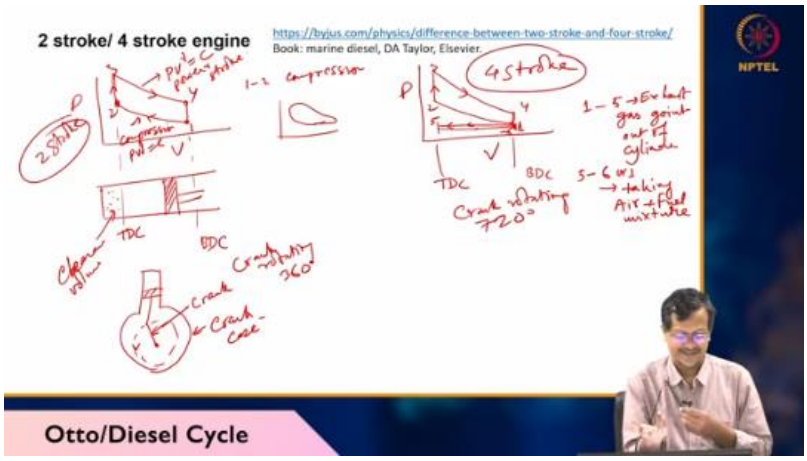
When you are compressing, temperature will be increasing, volume reduced, pressure increased, temperature increased. After a certain time, it will be burning instantaneously. When burning happening, so here again we are assuming at point 2, combustion is happening instantaneously. So, 2 to 3 combustion happening, but 2 to 3 you see this volume is 0, sorry volume is constant. so in practically it does not happen volume will be constant so practical cycle will be like this if I draw practical cycle ok there will be no sharp corner but for our calculation purpose we are giving some sharp corner so that we can calculate and see what is happening ok so 2 to 3 combustion happening that means you are getting lots of heat ok then 3 to 4 exhaust 3 to 4 power stroke is called power stroke ok

now you can see this four stroke engine this is four stroke this is two stroke okay so in two stroke what is happening crank rotating 360 degree and one time compression one time expansion happening okay but you see four stroke engine actually 70 degree rotation will be happening then one compression one power stroke you are getting so crank rotating 720 degree here crank okay you can see when piston moving up to down 180 down to up 180 for two stroke engine for four stroke engine up to down 90 degree then exhaust intake So, 90, 90, again compression. So, 90, 90, 90, 90, sorry, 180, 180. 180 expansion or power stroke, then exhaust 180, intake 180, compression 180.

So, 180 into 4, okay, 720 degree. So, 2 stroke, 4 stroke is that. 2 stroke will take only 360 rotation of crank, but 4 stroke is taking 720 degree. Then what is the difference? Why should I use 2 stroke or 4 stroke engine?

Now 2 stroke engine you can see when air is exiting near 4, we are not giving enough time for the air. Again intake also will happen at 1. So there is possibility of mixing of exhaust gas and intake fluid, intake fuel air mixture. So, what is happening? So, intake fuel air mixture you are giving, but exhaust gas also same port will be open at the same time.

So, your energy loss will be there. Complete combustion may not be possible. So, it may not be good for your environment. So, in India also, India government instructed to remove two-stroke engines actually. Chennai autos also government instructed to remove two-stroke engine, use four-stroke engine.



This four-stroke engine is having separate intake stroke. exhaust stroke so inlet fuel fuel air mixture and exhaust gas burn gas will not be will not be mixing okay so then complete combustion possible no fuel loss no environmental hazard okay but two stroke engine it will have mix up possible mixing of exhaust gas and fuel so environmental issue will be

there your fuel economy will lower fine so propeller speed for two stroke cycle 80 to 100 rpm propeller speed will be there for four stroke cycle 250 to 750 rpm okay so it is around 200 rpm propeller speed will be there but ic engine speed normally it will be higher okay then you have to use gearing later we'll discuss about gearing mechanism clutch mechanism other mechanisms okay okay formula i'll discuss later so what is the next flywheel okay I think I took this picture from your sarang you may have remembered okay so this is IC engine actually whatever in this engine I am teaching so IC engineering will have engine crankcase will be here inside there will be crankcase cancass will have lots of lubricating oil okay and engine is hot gas engine so it must be cooled so that's why they these there is having one fan uh the fan will be reducing engine temperature okay and there is one flywheel this heavy mass is there okay this is called flywheel so what is flywheel flywheel conserves angular momentum see

let's say shaft is rotating and if I have heavy mass so this heavy mass will absorb energy okay now because my engine when it is rotating 360 degree or 720 degree I am getting one time power let's say four stroke engine you can remember one time moving backward forward compression expansion so so many time moved but you are getting power only one time okay so then how the smooth power will go you will get for your specific application maybe your car bike truck train anywhere so you need continuous smooth power right so your car should not move like move then stop then move it will not do like this so you need a smooth power the smooth riding experience so smooth power supply is required for electrical production for any moving vehicle shipping applications okay so for that actually you should have flywheel so flight what what will you do Let us say during idle stroke, piston should be moving forward backward. You need certain amount of energy. So the flywheel will be storing energy, heavy mass.

When you are rotating, it will be absorbing energy. And during idle stroke and compressor stroke, it will be supplying energy. When you are getting power stroke, power stroke will have pressure pulses. I can draw one timing diagram, turning moment diagram. moment okay turning moment diagram is like this suction will be like this

then compression then power stroke then again like this so this is this will be about suction stroke suction stroke means one two three four five so 5, 6. 5, 6 you can say. 5 to 6 suction stroke. And then you are having compression stroke. Compression stroke means 1 to 2. Then you have working pulse.

That is power stroke. 3 to 4. And 4 to 1 or 1 to 5. 1 to 5 exhaust. This is power stroke.

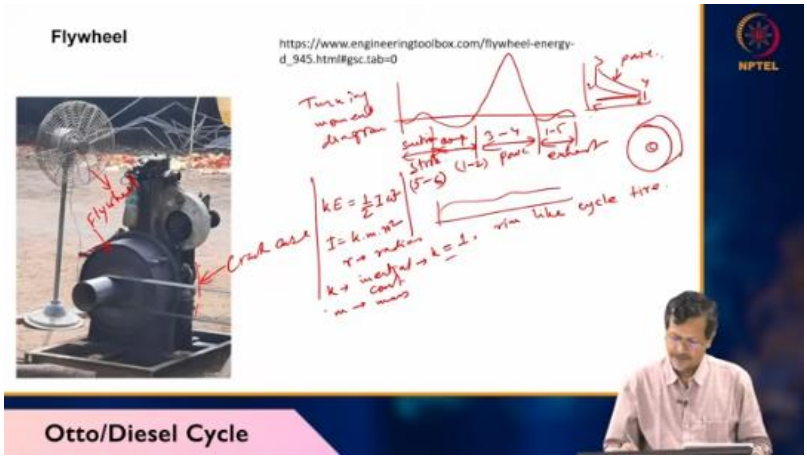
you can see your crank rotated 720 degree or maybe 360 degree but you are getting one time power and very high pressure or high power okay so that power may not be useful for your car application motorcycle anywhere right so you have to smooth it so if i get a turning moment like this it will be very good okay but practically it's not possible so engineers or scientists thought let's put some flywheel so flywheel will be smoothing the power It will be storing energy during peak, high power stroke, it will be absorbing energy. Then other strokes, it will be supplying energy. And how much smoothing you need, based on that, your flywheel size will be decided.

If you make very smooth power, then your flywheel size will be very high, very large size flywheel you should fix there. But if you think some pulsation is okay, then a small flywheel will be okay. So, flywheel used to smooth energy fluctuations and make the energy for intermittent operating machine more uniform. Flywheels are used to most combustion piston engines or CI or IC engines, ok. So, kinetic energy is stored, kinetic energy stored half I omega square.

I think it is coming from your plus 2 books, right. So, half into I means momentum inertia, omega means rotational speed. So, what is I? I will be coming as KMR square. What is R?

R means radius. Radius of the flywheel. So, flywheel will be like circular in shape. Central hole may be there. K is inertial constant.

K inertial constant. depending on the shape of the flywheel m is the mass mass of the flywheel r is the radius okay so k value k will be one for rim like cycle tire tube that assembly okay so the value will be one for cycle rim type rim like bicycle tire or rim Its value will be 0.606 for solid disk with uniform thickness. 0.3 for flat disk with central hole.



so if i know the k value m value i value i can get kinetic energy how much energy it is storing then if we make average it then you can say okay this much of size may be required for smoothing the power okay just wait what is this one multi-cylinder engine multiple cylinder engine. So, you may have seen the V-type engine, other type of engine. Maybe it is used in many cars and even high-end motorcycles also they are using V-type engine.

Very heavy vehicles like cargo ships or your heavy machinery, especially trucks, they will be using V-type engine or multi-cylinder engine. So, one cylinder you are getting pulse like this, right? One-time pulse, no pulse, like this. Now multiple cylinder will reduce this peaks and it will make more smooth power. How does it look like?

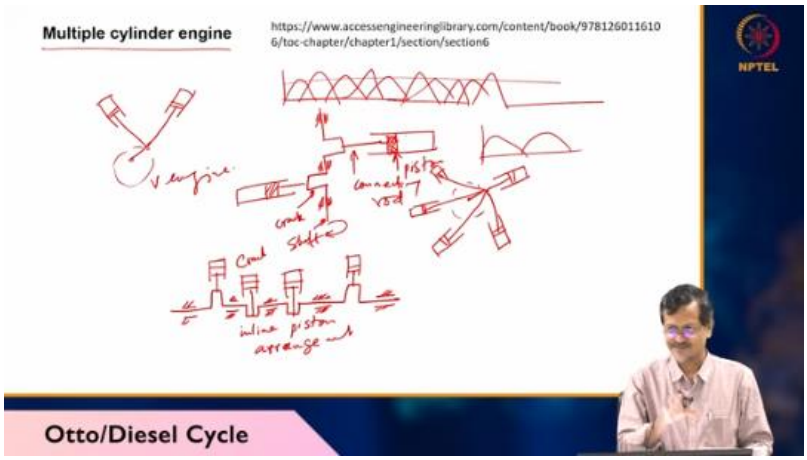
Like say if I have cylinder 1 here, another cylinder here, it is connected to common crank. So it is rotating. So what will happen? You see one piston is going up while other piston may be going down. i may have many other pistons also okay so for example i may have piston here also if i have many pistons then i will have many pulses all right 10 20 many i can make right so actually you see average pulse almost smooth okay that's why they'll have multiple cylinder engines

And different arrangement also there. For example, one arrangement, this is V. If I have like this, this is V engine. It is looking like a V shaped. Opposite cylinder piston will be there, engine. Opposite cylinder engine will be like this.

Crank shaft is coming. Crank is there. okay these are my bearings that's why i'm writing like this this is my shaft crank shaft okay this is called crank shaft and this is crank so crank is connected to connecting rod then my piston is here okay this is my piston piston i'm just making shaded okay there also another piston okay this is piston this is connecting rod now you see if I rotate the shaft one piston will be moving towards TDC another will be moving towards BDC so I am getting like two pulses actually instead of one pulse I am getting now another pulse also okay so little bit smoothed now if I have if I want to smooth further then I can make piston arrangement like this

piston one here another piston may be here another piston may be here okay and i will have bearing every time everywhere there will be bearing other did not rotate these are bearings okay so this is inline piston arrangement okay uh some other like radial piston arrangement radial piston arrangement will be like this uh one piston may be here another piston may be here another will be here another will be here so connected this one this one will be connected this one will be connected this will be connected this will be connected okay so one common crank and different connecting rod and piston will be rotating i mean

moving forward backward but in sequence so you are smoothing the power actually so flywheel is working but for smaller application like for your like sarang application small engine flywheel is okay but when even you need big power for you know cargo ship moving or train or truck



so in that case you need multiple cylinders so that will be smoothing the power and your flywheel requirement will be lower so flywheel means heavy mass you are carrying unnecessarily right heavy machine truck is there so instead of carrying the heavy mass you make multiple cylinder you get total power higher okay this is done. What is next topic? Terminology. Okay, so different terminology we will be using when we will be solving problems for IC engines.

Okay, you have seen PV diagram. 1, 2, 3, 4 I am not showing idle stroke every time because idle stroke is not contributing in power or it is not taking power also we are assuming although there will be certain friction and other losses but we are approximating so we are assuming there is no power loss or no gain from this idle stroke so that is why maximum time I do not show actually ok so this is compression stroke you know compression This is expansion stroke. This is combustion.

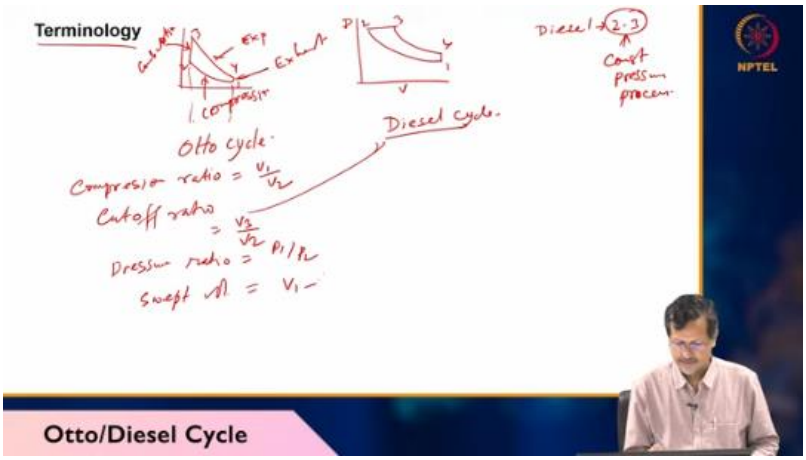
Okay. And this is exhaust. This is exhaust. Now, if I have many types of cycle, this is called Otto cycle. This is not like Chennai Otto.

This is OTTO. another cycle is like this it's called diesel cycle there are many other type cycle cycles are there but basically two cycles are very common auto cycle basically for two stroke engine diesel cycle will be basically for four stroke engines four stroke engines already say i said like 720 degree crank rotation one power stroke but complete compression is possible the good for environment and environment and it is good for your

economy also so 1, 2, 3, 4 so you see the change in diesel cycle 2, 3 you become horizontal so diesel cycle 2, 2, 3 this is constant pressure process so compression ratio These terms you have to remember.

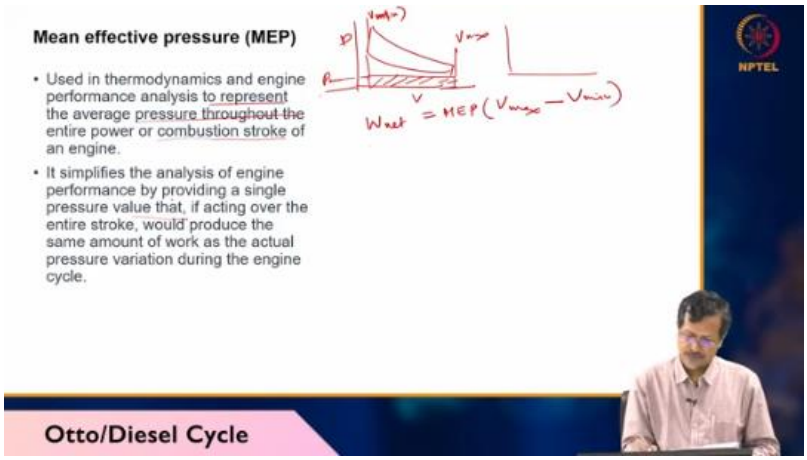
Compression ratio equals V1 by V2. Vmax by Vmin. Vmax by Vmin. Cutoff ratio. Cutoff ratio for diesel cycle actually.

For this one 1. Diesel cycle cutoff ratio V3 equals by V2. a pressure ratio V P1 P1 by P2 ok so whenever you are solving problem these terms will be coming so you should remember clear and swept volume swept volume is V1 minus v2 so piston is moving one to two so that's wave volume will be v1 minus v2 okay mean okay writing some more terms will be coming later this I am changing slide.



Mean effective pressure, it is using thermodynamics and engine performance analysis for to represent the average pressure throughout the entire power. So, you can see the pressure and volume diagram whatever I have drawn. So, it is pressure is changing actually, but if I make like this. So if I take this one, if I assume this average pressure is here, this is P max, P min may be 0. So average pressure throughout the entire power combustion stroke is same and it simplifies the analysis of engine performance by providing a single pressure value that if acting over the entire stroke would produce the same amount of work as the actual pressure variation during the engine cycle.

So this is the formula for this one. So, W net output power M E P V max, V max, this is V max, this is V min, minus V min, M I N. So, MEP equals W net divided by V max minus V min. This formula will be using later. So, auto cycle.



Auto cycle will have, I already told, PV and you are compressing completely, then combustion happening, then expansion happening, then exhaust happening. so already you are familiar with these terms intake stroke here intake stroke is not there separate no separate intake stroke but if you want to represent then you have to draw like this okay basically this is spark ignition engine and you know spark in bike there will be these days battery operated bikes are there right car also if just rotate it rotate the key it will be starting so there will be battery so battery will be creating small spark You compress it then you give small spark. I got one spark plug actually I can show you how does it work. if you put positive electrode here and negative here so because of small gap and you apply very high voltage because of that in small spark will be created.

Spark means very high amount of energy it will be releasing. So, because of high amount of energy it is releasing and combustible fuel and air mixture is nearby. So, that some particle will be burnt. So, some particle will be burning they will be producing again exothermic reaction I mean lots of heat will be producing. So, that heat will be transmitted to another particles.

So, in that way the whole cylinder inside cylinder whatever fuel is there fuel and air mixture it will be burnt ok. So, this is one spark plug, I think it is bike spark plug, I got, so I got, maybe you can see later. This is called indicated diagram also. So, we will try to formulate some equation, efficiency equation, how to calculate pressure, temperature, different points based on your simple Boyle's law, Charles' law equations. So, this is PV diagram and TS diagram will be like this 1, 2, 3, 4 TS.

Let us M is the mass flow rate mass flow rate Q1 is heat addition Q1 equals Q2 to 3 MCV T3 minus T2. Simple formula, Q2 heat rejection, heat rejection 4 to 1, Q4 to 1 equals mCV, again constant volume process, so mCV T4 minus T1. So, what is eta? Eta will be 1 minus

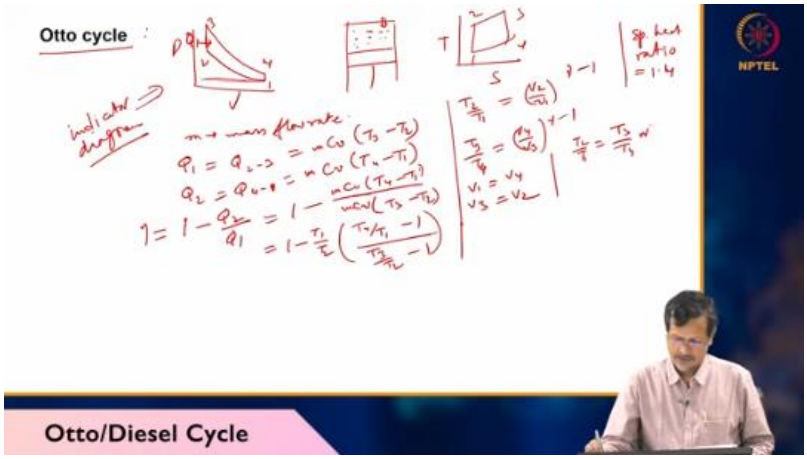
Q2 heat rejection divided by heat intake. So, 1 minus MCV T3 minus T2 MCV T4 minus T1.

Now, MCV will be vanishing the same value equals 1 minus T1 by T2 T3 minus wait some mistake again. T4 minus T1. Some mistake. What mistake? What mistake?

This one. This one, right? Q2. T4 minus T1. and mcv T3 minus T2.

Now, T1 by T2, so T4 by T1 minus 1, T3 by T2 minus 1. Now, T2 by T1, T2 by T1 equals V2 by V1 gamma minus 1, gamma specific heat ratio, specific heat ratio Normally if I do not give any value for your example purpose, so you take 1.4. So, T3 by T4 equals V4 by V3 gamma minus 1, then V1 equals V4, V3 equals V2. So, then we are getting T2 by T1 equals T3 by T4.

or t1 by t2 equals t4 by t3 okay or t4 by t1 equals t3 by t2 okay so if you replace all these values 1 minus t1 by t2 equals 1 minus 1 by r gamma minus 1 r equals compression ratio v 1 by V2. Diesel cycle we discussed PV and your heat addition process horizontal means constant pressure process. 1, 2, 3, 4 and whenever you are drawing please put proper arrow direction also. If you put wrong arrow direction, then meaning will be different.



So, in that case you may not get marks. PV per gamma equals constant, this one also PV per gamma equals constant. TS diagram also will be same as motorcycle 1, 2, 3, 4. So, here Q1 heat addition process. and heat rejection process here q2 so you are approximating heat we are assuming that heat is getting rejected at 4 to 1 but in actual process there will be separate stroke exhaust gas will take all the heat actually okay

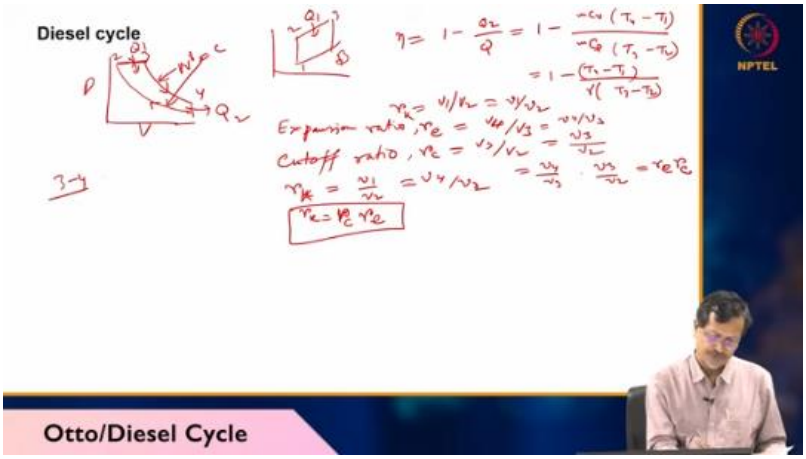
when you are removing exhaust gas that exhaust gas heated gas that will be the heat rejection process but here because of approximation we are assuming 4 to 1 heat rejection

is happening okay so eta equals 1 minus q2 by q1 this is the formula Heat rejection divided by heat addition. So, 1 minus MCV T4 minus T1 MCP. You can see here. Q2 by Q1.

Q1 is CP actually constant pressure process. But heat exhaust is constant volume process. T3 minus T2. Now, we will be solving this one, we will try to formulate the efficiency equation T4 minus T1 gamma T3 minus T2. So, compression ratio R equals V1 by V2 equals specific volume I can write

V1, V2. So, many time we specify specific volume per kg, volume per kg then small v we write. But now if we have mass value also then you can write capital V. So, that is normally people will be assuming this is the notation. Expansion ratio, here another term you are getting Re equals V4 by V3 i can write this in rk v4 by v3 equals v4 by expansion ratio v4 by v3 okay so it is not no need to write cutoff ratio cutoff ratio r c equals v3 by v2 equals v3 v4 by v3 of a specific term it is written

So, RK equals V1 by V2 equals V4 by V2 equals V4 by V3, V3 by V2 equals RERC. RK is related to like this, RK equals VRCRE. So, now process 3 to 4, 3 to 4 process means it is expansion process. So, T4 by T3, T4 by T3 equals V3 by V4, V3 by V4 gamma minus 1 equals 1 by Re gamma minus 1. Therefore, T4 equals T3 Rc gamma minus 1 Rk gamma minus 1.



Now, 2 to 3, process 2 to 3 is heat addition process, constant pressure and heat addition. So, T2 by T3 equals P2 V2 P3 V3 equals V2 V3 equals 1 by Rc. So, T2 equals T3 divided by Rc. and one two one two two process t one my by t two equals v two by v one gamma minus one because one by r k gamma minus one okay some uh so substituting eta equals one minus t three r c gamma minus 1 r k gamma minus 1 t 3 r 3 t 3 by r c r c 1 by r k gamma minus 1 divided by gamma t 3 minus t 3 1 by r c

So, this is giving 1 minus 1 by gamma, 1 by rk gamma minus 1, rc gamma minus 1, rc minus 1. As rc greater than 1 implies 1 by gamma r c gamma minus 1 r c minus 1 greater than 1 so eta diesel less than eta auto same compression ratio okay Thank you very much and next day we will start the calculation part. Thank you.