IC Engines and Gas Turbines
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Lecture – 25
SI engine injection system, Energy distribution, Engine temperatures, Heat transfer in combustion chambers (Contd.)

We will continue our discussion IC Engine and we will continue our discussion basically the SI engine injection system.

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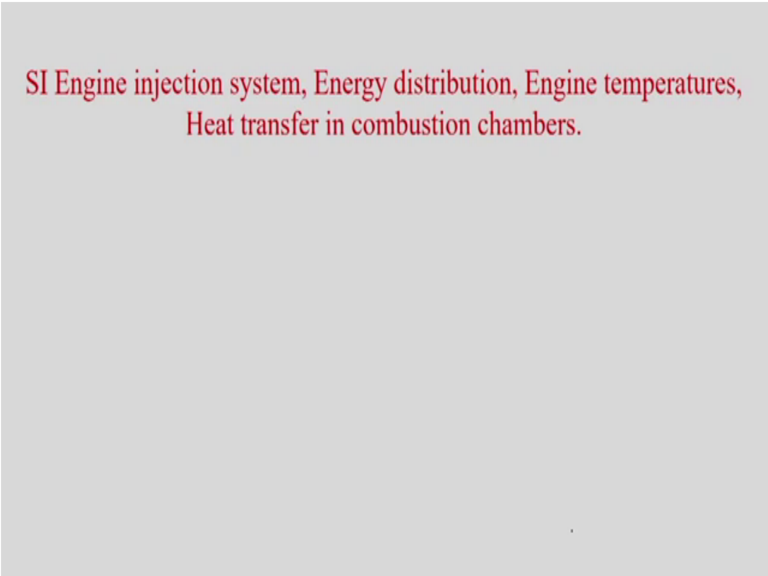

And then we will discuss about the energy distribution rather heat transfer in the engine. So, we have discussed that mechanically operated injection system where; we have seen that using external source like electric field we can excite the solenoid. And when solenoid is excited solenoid coil is excited; the plunger a magnetic plunger was there that is attracted and that lifts by amount 1.5 to 1 sorry 0.15 millimeter and then fuel can go.

I mean if you can try to recall the drawing that whenever solenoid is excited it allows the magnetic plunger to get attracted attacks magnetic plunger. And then the spindle a lifts by an amount 1.5 millimeter and through which fuel is introduced into the intake manifold.

And today at now we will discuss about that; what is electronically control unit; I mean through using an electronically controlled unit because even though we have a mechanically operated you know injection system that is if we excited using the by controlling the pulse of the excitation pulse duration which is around 1.5 to 10 millisecond. injection time critical injection time for automobile engine is which 1.5 to 10 millisecond.

So, by exciting the solenoid valve solenoid coil we can that is by changing the you know; pulse duration we can control the solenoid you know coil excitation time. And then we can control the amount of lift up the spindle and we can control the amount of fuel being discharged into the intake manifold. So, now, we will briefly discuss about what is electronically control unit that is; ECU.

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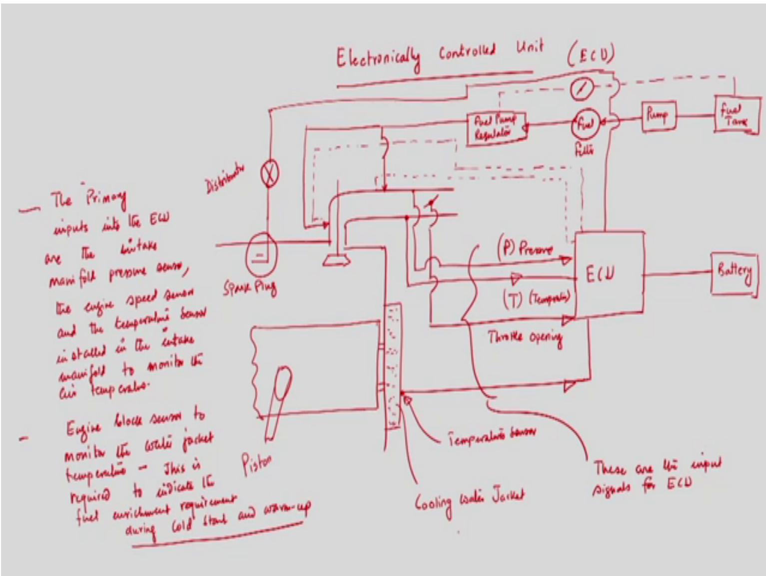

That is electronically control unit that is ECU.

So, what is what are the components of this unit and how it regulates the fuel injection system? I need to draw so I have basically, so that is piston now and this is valve. So, this is electronically controlled unit and of course, this is operated by battery.

Now, this electronically what is the input of the electronically control unit? We have a cooling water jacket so this is cooling water jacket if you have a temperature sensor over here; that information is. So, this is temperature sensor temperature sensor. And that is one input to the issue then if it is intake this is intake port. So, I am writing this is intake port.

So, we need to provide we may have a sensor over here. So, that is again that is temperature T and also we may have a throttle valve we have throttle valve and that throttle valve opening also is given. So, this is you know throttle opening. And finally, we have a pressure; that is pressure P this is temperature T and these are the input signals for issue. So, these four are the so these four. So, these are the input signals for issue electronically control unit.

So, this is spark plug and we have we need to supply fuel so we need to supply fuel here. So, may be this is fuel pump regulator. Then we have you know is a filter fuel filter, this is fuel pump which is taking from fuel tank. Now this regulates so if we have excess supply of fuel then we will be have we will be having formation. So, return back of the fuel into the fuel tank.

Now, this fuel is supplying fuel here and so whenever you are supplying fuel that what is the amount of fuel that will be supplied into the intake manifold through injection system; that information will be provided by the electronically control unit ECU. So, here we will have one input signal and that signal will come from the electronically control unit. So, I will discuss in detail so that will be that is a information. Now if would like to supply fuel over here, if it is a then also here we may have again in that is information will come from the ECU electronically control unit.

So, this is these are actually very important. So, what you have seen that here see that; amount of fuel that will be injected into the engine cylinder that depends upon the load and also the pressure temperature of the air at the intake manifold. So, also we are having one sensor at the you know cooling water jacket. So, we will discuss that; cooling water jacket function is to maintain the temperature of the cylinder valve to a specific value otherwise there will be a thermal cracking.

So, now the input signal to the ECU is pressure temperature and percentage throttle of the intake manifold. That means, what is a pressure and temperature of the air which is being you know introduced into the cylinder also the temperature of the cooling water jacket so this is cooling water jacket. This power plug you know is very important we have drawn spark plug this is distributed. We have seen that we have distributor rotor or distributor cam if it is a multi cylinder engine. And that the timing of the spark plug that also will be connected with the ECU.

Now, sensing the pressure temperature and throttle opening is very important. So, in the speed density system the primary input. So, the primary inputs into the issue are the output from the manifold pressure sensor, engine speed sensor, and the temperature sensor, installed in the intake manifold to monitor the air temperature. So, that means the input to the ECU are; the pressure sensor output are the output from the from the manifold pressure intake manifold pressure.

Engine speed sensor and temperature of the air in the intake manifold right. And essentially to maintain the air temperature engine block sensor we having one engine block sensor to maintain the water jacket temperature. So, the sensor connected with the water jacket we need to maintain the water temperature or the cooling water temperature. Now why we need to that to wanted the water jacket temperature the later being used to indicate the fuel enrichment during cold start up and warm up.

So, we are having I am writing that in the in the issue rather I can write the primary inputs into the ECU. The primary inputs into the ECU are the are the output from the manifold pressure sensor at the intake manifold pressure sensor right. The engine speed sensor and the temperature sensor and the temperature sensor installed in the intake manifold intake manifold.

And the temperature change a manifold to monitor the air temperature. We have another engine block sensor we have another engine block sensor to monitor the to monitor the water jacket temperature water jacket temperature. And this is required this is required to indicate the enrichment requirements the fuel enrichment requirement to indicate the fuel enrichment requirement during cold startup during cold start and warm up during cold start and warm up so it is very important.

So, this is the electronically control unit where providing the input signals which are coming from the intake manifold as well as the engine block sensor. So, intake from intake manifold we are taking throttle opening pressure and temperature. Based on the pressure temperature throttle opening ECU will provide information to the fuel regulator will provide information to the fuel regulator to supply the required amount of fuel.

Now, the spark plug is also connected to the ECU because we have seen that because it is a difficult we need high voltage from a very low voltage battery. So, we have a you know electrics electric circuit. So, the distributor of that spark plug which is again connected to ECU to indicate that; in which if it is a multi cylinder engine then where the spark will be in which cylindered spark is needed.

Now, we also have one you know we can see from the diagram again that if we because we do not know pump is used to supply fuel pump fuel tank. So, we will have a fuel pump regulator of course,, but again depending upon the temperature and pressure of the air if the requirement of fuel is very is less at that condition to get the desired output from the engine. Then the additional fuel being pumped by the fuel pump will be taken back into the fuel tank from the fuel regulator. Now, and that is again sensed by the ECU.

So, in ECU is receiving some signals based on that signals it is providing signals to the you know fuel injector that fine this is the amount of fuel that will be supplied at that condition to essentially to have a better fuel economy and the efficient combustion. Finally, we have one engine block sensor that is connected with the water jacket. And this is required to indicate fuel enrichment requirement that in the cold start and the warm up condition because cold start we require we need to supply more amount of air.

So, what is that temperature inside the cylinder that time that is being sensed by the ECU and that information is provided by ECU to the fuel regular to supply additional amount of fuel. So, with these complete my discussion about the SI engine injection system. Now I will move to discuss about the you know heat transfer in the engine. So, what you have seen that so far we have discussed about the combustion ignition system and also as well as the injection of SI engine.

So, you know that we have seen that we get energy in a in a internal combustion engine from the combustion. So, whatever the amount of energy is you know produced during combustion that has essentially it is an exothermic reaction. So, the heat is being produced 35 percent of heat is converted to the to get the useful you know crankshaft work.

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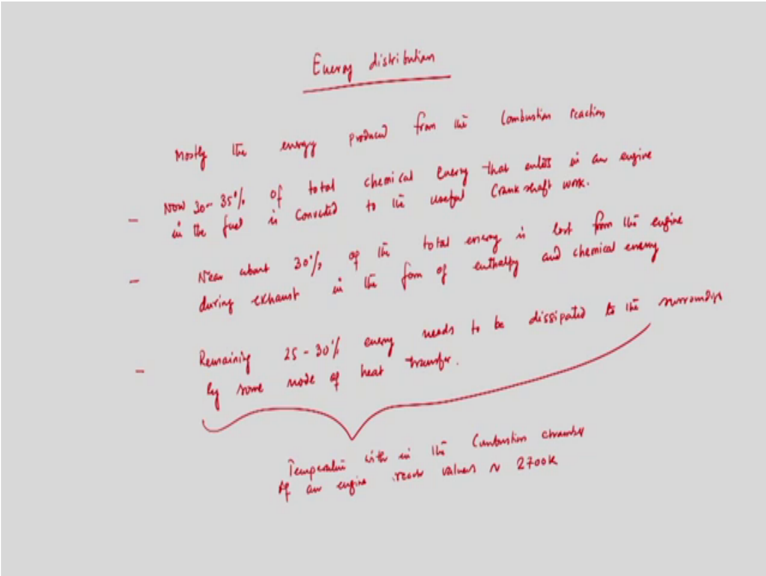

So, I can write that heat energy distribution. So, mostly the energy produced from the combustion reaction. Now 35 percent of the total chemical energy of total chemical energy that; enters an engine in the fuel that enters an engine in the fuel. In the engine in an in an engine in the fuel in an engine is converted to the useful crankshaft work.

So, only 35 percentage of total energy which is which we are getting out of this combustion reaction is converted into the crankshaft work and near about 30 percent of the energy of the total energy is lost is lost from the engine from the engine during exhaust in the form of enthalpy and chemical energy. So, we can see that 35 percentage is converted to get the useful work 30 percent is lost 30 percentage energy is you know 30 percentage energy is carried away from the engine by the exhaust gas in the form of enthalpy.

So, near out 25 to 30 percent energy which we need to transfer from the engine through the to the surroundings. So, remaining 25 percentage to 30 percent energy 30 to 35 percent. So, 25 to 30 percent energy needs to be dissipated to the surroundings to the surrounding by some mode of heat transfer some mode of heat transfer.

So, 30 to 35 percent of the total energy is converted into the use in the form useful crankshaft work remaining 30 percent is lost because of by exhaust board occur exhaust gas in the form of enthalpy while 25 percent to 30 percent that is remaining that must be dissipated to the surroundings by some mode of heat transfer conduction, convection, or radiation.

Now that means, engine cylinder so we can see that 30 percent energy need to transfer. So, material of the engine cylinder that is why you need to have a continuous supply of coolant maybe air cooled or water cooled that is we have discussed a long back. So, material I mean temperature within the combustion chamber opening in a reach values of the order of 2700 Kelvin.

So, that means, we have seen because of this temperature within the combustion chamber within the combustion chamber of an engine temperature within the combustion chamber of chamber of an engine reach values which is of the order of 200 700 Kelvin 2700 Kelvin. because now question is if the material of the cylinder material is not able to send this temperature that cylinder you know that material fails quickly.

Question is whatever it the case maybe you have a good material that can withstand that can you know we can have you know you know that the lifetime of that cylinder is very high. O n the other hand if the material cannot withstand this high temperature that with that you know cylinder you know or the engine chamber fails very quickly.

Now, as I said that 25 to 30 percent engine 25 to 30 percent of the energy of the total energy must be dissipated into the surroundings by some mode of heat transfer. So, either may be convection mostly convection, or conduction, or radiation we will discuss. But there are in general two method there are two methods used to cool the combustion chamber engine.

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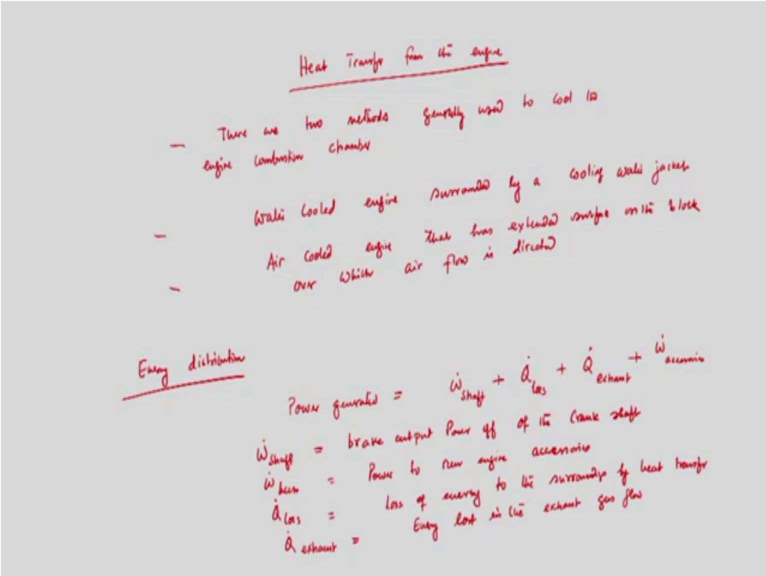

So, there; that means, we need heat transfer from the engine right

So; that means, we need to take away 35 percent of the total heat to the surroundings by some arrangement. So, there are two methods generally used to cool the engine combustion chamber. Either water cooled so there are two so; that means, heat will be transferred from the engine there are by some by some mode of heat transfer there are two methods in generally used to transfer or cool the engine combustion chamber.

One is water cooled water cooled engine surrounded by a water jacket or air cooled engine air cooled engine that has extended surface extended surface on the block on the block which over which of flow of air is directed over which air flow is directed. So, either we have a water cool engine that is what we have seen a few minutes back that if it is ECU.

I mean we need to have we need to know the temperature of the cooling water jacket and sensing the temperature of the cooling water jacket we need to supply more amount of air during cold start and warm up condition. Or if we have a air cooled engine so the outside the cylinder will have a extended surface and we can direct air to flow what there surface so that we can cool the engine.

So, these two are basically the you know cool engine. Now if you talk about energy distribution this is very important. So, what is energy distribution? That is we have seen that total power generated total power generated. So, that will be some amount will be W shaft work plus Q los Q dot los plus Q dot exhaust because some amount of energy is exhaust plus W dot W dot exercise.

So; that means, if the total power generated by the engine is W dot shaft it is; brake power or it is indicated power because brake power we are taking the power which is available in the shaft whereas, indicated power is the power that is produced on the piston phase. So, brake power is lesser than indicated power by an amount or there is overcome the frictional losses whatever it is now the total power generated can be distributed in this four categories.

So, W dot shaft is a brake output of the crankshaft. So, W dot shaft is the break output power rather brake output power that is a power we get break output power of the crankshaft power of the crankshaft. W dot accessories is essentially the amount of work that we take to run accessory like you know pump used to supply coolant and all those things.

that is power to run engine accessories sometimes it drawn air conditioning system we need to run air conditioning system we need to supply coolant we need to pump water. So, those you know accessories are run and the requirement of power to run those accessories is the W dot accessories.

Q dot los is the all other energy lost to surrounding by heat transfer. So, loss of energy to the surroundings by heat transfer. And Q dot exhaust is a energy lost in the exhaust gas flow. So, exhaust gas flow there is a loss of energy. So, these are the total energy distribution. So, may be the amount of work we are getting amount of power we are getting in the engine that partly is use to you know you know 35 percent used to get obtain the shaft work 30 percent is lost to the exhaust gas flow.

There is a loss of energy by heat transfer that is again 30 percent some part of the power is used to run the engine accessories. So, these are the total engine distribution scenario is distribution engine. So, now, we have seen that we need to supply we need to transfer some amount of heat by some mode of heat transfer from the engine cylinder engine block to the surroundings. So, what will be the what are the modes? Now very important you know either it may be conduction or convection.

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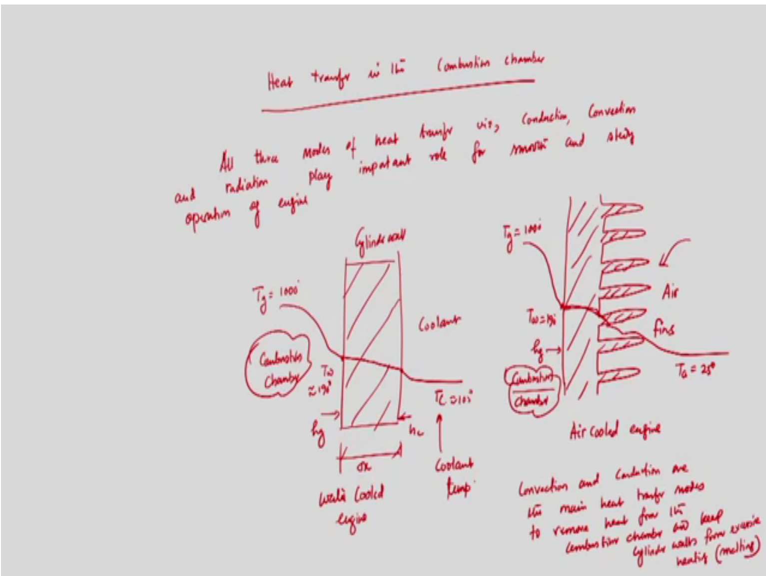

So, there is heat transfer in the combustion chamber. So, heat transfer in the in the combustion chamber. So, once the air fuel mixture is in the cylinder of an engine there are three modes of heat transfer; conduction, convection, and radiation that is what we know. So, all this three modes of heat transfer play important role for the steady state operation. sometimes we have some phase change, but normally conduction convection radiation.

Therefore, all three modes all three modes of heat transfer these conduction, convection, and radiation play important role for smooth and study operation for smooth and steady operation of engine so these three are important. there are other you know other modes, but these three these three important. If I now try to draw that if it is a water cooled engine or if it is an air cooled engine fine.

So, if it is a you know liquid cooled engine or air cooled engine water cooled engines. So, maybe if I drawn other temperature so this is the temperature of the cylinder wall right. So, now temperature of the combustion product or temperature of the gas is very high may be of the 1000 degree then that wall it is T w and that is again very less. And now there is a conduction from the in the wall.

Then finally, we will have a again loss to the surroundings and this is T c so this is T c so this is h c this is h g and if it is delta x. So, if the thickness of the cylinder wall so this is cylinder wall cylinder wall thickness is delta x combustion temperature 1000 degree Celsius from that we get temperature at the wall it is near about 190 degree Celsius. Then it is h g and then finally, we are having you know temperature at the whenever we are getting outside it is near about 105 degree so this is coolant.

So, now, we need to supply coolant at the outer wall and coolant water we will take away the heat from the wall and then it will try to maintain the wall temperature specific limit. But question is inner surface of the surface is always needs to withstand or to face the highest temperature of the combustion product and that is why that material will be able to withstand that. On the other hand if it is a air cooled engine if it is an air cooled engine suppose we have you know air cooled engines. So, maybe we have fin surface.

So, we have so all these are fins. So, this is air flow right. These are fins or extended surface the same thing is happening maybe T z is 1000 degree. And then it is coming at the wall maybe it is T w is equal to 190degree. And then this is h g enthalpy and this is this is the combustion chamber this is the combustion chamber. Now, this is combustion chamber this is combustion chamber and this is fin.

Now from here there will be conduction up to the fin surface then from fin surface there will be again convection and ultimately you will get a constant temperature T a, that is to 25 degree Celsius. So, this is T coolant this is coolant temperature. So, this is air cooled engine and this is water cooled engine. So, we have seen air cooled engine and water cooled engine.

So, temperature of the gas and combustion start these already a convection heat transferred to the cylinder walls. So, there will be a convection heat transfer. So, gas is there inside the combustion chamber there is a convective heat transfer from the combustion product to the cylinder wall. This is a conduction within the cylinder wall and from outer surface of the cylinder wall again there is a convection either to the coolant or if it is air into the air.

So, we have seen there is a conduction convection and sometimes also radiation plays because if the temperature is so high inside the combustion chamber. Then there will be some amount of heat is will transferred because of the radiation. So, some of these you know so convection and conduction at the main part of heat transfer may be energy from the combustion chamber and keep the cinder walls from the melting now from these we can see that convection if the temperature is.

So, high then sometimes there is a radiation, but convection and conduction. So, the similar the similarity is there in case of a air cooled engine so from within the combustion chamber. So, there is a convective heat transfer to the cylinder walls from the gas. So, from the inside the combustion chamber there is a convection up to the wall heat transfer to the cylinder walls.

And then within the wall we are having conduction again from conduction or extended surface we are having continuous supply of air that is air cooled engines. So, from there again we will have a convection and a heat will be dissipated. So, in case of a water cooled engine or air cooled engine we have seen that convection and conduction these two modes. These two are the main heat transfer mode modes to remove heat from the combustion chamber.

And keep cylinder walls from out of excessive from out of from excessive heating from excessive heating which in turns may leads to melting. That means if you do not have proper coolant supply of coolant proper heat transfer from the cylinder walls there might be a situation that there will be excessive heating within the combustion cylinder walls which in turn will try to you know melts the engine cylinder.

Now during the combustion as I said that the gas temperature might goes of the order of 2700 degree Kelvin. And therefore, we need an effective heat transfer to reduce the temperature to reduce the cylinder walls from overheating. So, continuous you know continuous supply of continuous supply of coolant and so that continuous heat removal will be there because peak temperature might go of the order of 2700 Kelvin.

If you do not have proper or continuous heat transfer from the engine cylinder or walls of the engine cylinder then it may you know leads to overheating of the engine walls and which in turn with made help turn you know melting of the cylinder I mean. So, this is what is the heat transfer in the combustion chamber. So, normally convection and conduction of the main heat transfer mode.

But we cannot ignore even the radiation because sometimes radiation is there because of the high temperature that is 2700 Kelvin. So, now, as I said that heat we need to we have continual removal of heat from the engine cylinder. Now, what are the effect of engine operating variables on heat transfer?

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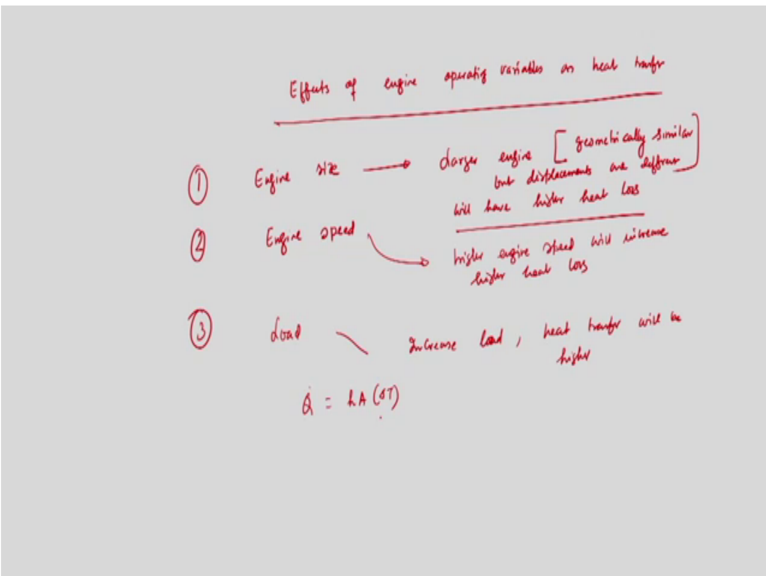

So, I mean size speed so I mean what are the effects of engine operating. So, effects of engine operating variables on heat transfer on heat transfer. So, basically engine size first one is engine size is very important engine size. So, it everything is remaining same to geometrically similar engine of different size different displacement.

So, geometrically similar engine that is cylindrical in shape, but to define displacement are operated at the same speed and all are the variables are remaining same everything is remaining same except their displacement their displacements are different. The larger engine we will have a greater absolute heat loss, but will be more efficient if the temperature metal of the both engines.

So, as I said that if we have two geometrically similar engines, but their displacement are different. And if the speed and other conditions are remaining same the larger engine will have a greater heat loss to the surrounding, but will be more efficient. Similarly we have engine speed so engine size larger engine larger engine those are geometrically similar, but displacements are different.

Larger engine will larger engine will very important we will have higher heat loss is important engine speed. So, if the engine speed is increased gas flow velocity in and out of the engine goes off with a resulting rise in turbulence and convective heat transfer coefficient. So, if we increase the engine speed.

So, if we increase the engine speed this is very important that the gas flow in and out of the cylinder will increase and which will turn will results a turbulent and convective heat transfer mode. So, this increases the heat transfer occurring during intake and exhaust strokes so this is important. So, higher the speed higher will be the convective heat transfer because higher will be the turbulence it is very important.

And if we go back perhaps I have not seen that coolant here this heat loss is basically Q dot is equal to area into k sorry enthalpy area into enthalpy into T w minus T coolant. So, this is the heat loss to the surroundings where h is the convective heat transfer coefficient. So, we have seen higher. So, higher engine speed higher engine speed will have will increase higher heat loss that is 2.

Number three is also important that you know load and as the load of the engine is increased they like half fill and you know pulling a trailer throttle must be opened further to keep engine speed constant. So; that means, when an engine is the half filling or it is you know pulling a trailer we need to open the throttle area so this is load. So, number three is load that if we have an engine and if the engine is half filling or engine is pulling a trailer; that means, load is increased.

So, we need to open throttle valve essentially to is maintain the speed constant. This causes less pressure drop across the throttle and higher pressure density of the intake system. So, mass flow rate of the air will increase therefore, mass throttle air fuel therefore, goes up with the load at given speed and heat transfer also will goes off. That means, if increase load so increase load heat transfer will be higher.

That means, if we increase load that is what I was telling that if engine half filling or if it is pulling a trailer then we need to open the throttle valve wide open throttle valve to maintain the speed constant pressure drop will decrease there will be a you know increment in the mass flow rate of the air and fuel goes up which in turn will increase the heat transfer of the engine because; Q dot so Q dot since Q dot is equal to h into a into delta t so this is very important.

And there are so many other factors like spark timing fuel equivalent ratio and evaporative cooling or injection. So, these are the I mean if we supply more amount of coolant of course, heat transfer will increase like this. And you know if we have we have seen that the equivalence ratio; that means, if the if it is a lean or richer.

So, there will be a greatest heat loss heat losses occur when this is also heat loss occur engine runs either leaner or richer. That means, for equivalence ratio 1 that is maximum powerful heat transfer if we somehow increase the you know leaner or richer mixture then lower losses when greatest heat loss will occur when mixture becomes richer and leaner.

So, we have discussed about today; the injection system in a spark ignition engine. Then we have discuss about the why how what is the heat distribution? And what is the amount of heat we need to transfer from the engine essentially to set the cylinder out of excessive heating or to mayor the melting phenomenon of the engine cylinder? Then we have identified there are two different mode I mean there are three different modes of heat transfer like; convection, conduction, radiation.

While convection convections are important and we have seen by how we can remove heat from the engine cylinder either by using a water supplying water or air as a coolant. So, that is water cooled engine and air cooled engine. Also we have discuss about the effect of engines operating variable how they influence the heat transfer from the engine cylinder.

So, with these I stop here today and I will continue my discussion in the next class with the topic of you know injection system on you know CI engine and then some other aspects or related to internal combustion engine ok.

Thank you.