**Course Name: Engine System and Performance**
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**Week - 04**
**Lecture – 10**

## Lec 10: Description of Energy Transfer Mechanism

I welcome you all to this session on engine systems and performance. Today, we shall discuss an important topic of this course, which is the energy transfer mechanism. We all know that in an engine, essentially what we need to do—or rather what we do—is supply fuel, and fuel has chemical energy stored within it. That chemical energy is converted into useful work, which is available at the shaft. Now, this conversion of chemical energy, which remains stored in the fuel, has to be converted into another form—that is, work, another form of energy.

But this conversion is not directly possible. That is what we have learned. So, what we do is supply a fuel-air mixture if it is an SI engine. If the engine is of the compression ignition type, then we need to supply fuel and air separately.

Whatever may be the case, in both cases, this fuel and air mixture—rather, they mix together—and then combustion occurs. Because of this combustion, we get some heat energy. And then, that heat energy is converted into work energy. That conversion is not very efficient, as we know that heat is low-grade energy and work is high-grade energy, which we have studied in our basic thermodynamics course. So, what we need to discuss today is the mechanism by which that chemical energy, which remains stored in the fuel, is converted into work.

And that work should be available at the shaft. And then only we can propel the vehicle. So, fuel which has chemical energy, that fuel should be converted into work should be available at the shaft. This conversion is not directly possible, which means what is done essentially is, this fuel is mixed with air, and then there will be combustion, and out of this combustion, we will get heat—another form of energy.

And then that heat is essentially converted to work through certain mechanism. So, this is essentially the energy conversion or energy transport mechanism. Now, the question is, the energy that we are supplying to the engine—if we assume that is 100%, 30% of that energy is lost through enthalpy or, rather, in terms of enthalpy and chemical energy.

So, this is very important to know, if I write here, 30% of the stored energy. So, this is chemical energy—'stored'. Now, this 30% of stored energy leaves the engine in the form of enthalpy and chemical energy. So, this is something not on the positive side because if the stored energy is 100%, then 30% of that stored energy is leaving or will leave the engine in the form of enthalpy and chemical energy.

That means this energy is not available, and if it is not available, then certainly efficiency would be less than 100%. There is no doubt about it. But is it that only 30% of the energy will remain in the form of enthalpy and available energy? Is this 30% the only energy that will remain in the form of enthalpy and chemical energy from the engine?

The question is: this is not the only energy that will leave the engine in the form of enthalpy and chemical energy. Typically, the rise in temperature in the combustion chamber because of combustion is of the order of 3000 K. Try to understand: if there is no mechanism, no avenue to transfer this much amount of heat, if there is no way to reduce the temperature of the combustion chamber, certainly it is very unlikely to have any material that would be able to withstand this high temperature.

So, there must be some mechanism to transport or remove heat or to reduce the temperature of the combustion chamber to prevent the combustion chamber cylinder from melting and other problematic issues. Many other detrimental effects. So, the temperature has to be reduced—the temperature of the combustion chamber. So, certain heat removal management, thermal management of heat, must be there in an engine.

Now, question is, we have to remove heat, that is available in the combustion chamber. We can remove heat through certain surfaces rather what are those surfaces through which we can really remove certain amount of heat. Otherwise the temperature which is available inside the combustion chamber will lead to several mechanical failures, which is very important to know at this time, that places which are exposed to high temperature are spark plug. Exhaust valve, which is very important to know. Intake piston face and also to some extent intake manifold.

Now, these are also the places wherein temperature will be high because of this temperature rise. So, can you really remove heat through the surfaces? No, we really cannot because these surfaces are so very complex arrangement.

So, these surfaces are integrated to an engine block through some complex position, we really cannot have any supply of coolant so that we can remove heat from the surfaces.

So that means these surfaces are having very high temperature and removing heat through the surfaces is not so easy because of lack of integration of cooling system. So then let us, briefly discuss about the energy transport or rough estimate of energy transport. What is the total amount of energy and then the possible surfaces through which we can have thermal transport of heat so as to prevent engine from their engine cylinder and several other components like spark plug exhaust valve and piston phase which is very important rather very critical part of the engine exposed to a very high temperature.

So now we shall discuss a rough estimate of the energy available inside the engine. So, we shall discuss energy distribution. So, to know that, let us discuss the amount of energy available with the fuel, how much of that energy is available at the shaft, and where the remaining energy is transferred from the engine cylinder or combustion chamber into the ambience through certain surfaces. Mind it, the spark plug, exhaust valve, piston phase, and to some extent the intake manifold are the surfaces where temperature is hot surfaces rather, temperature is maximum.

But unfortunately, it is not so easy to remove heat through those surfaces. So, we have to know what those surfaces are through which heat removal is possible effectively. So, if we write here just available energy.

That is in the engine, is the mass flow rate of fuel, the heating value of fuel. So, this is the heating value of fuel, and this is the mass flow rate of fuel. This is the total amount of energy available. So, if we supply this much fuel to the engine, we are supposed to get this much energy, which is in the form of chemical energy or stored energy in the fuel. Now the question is, what is the amount of energy?

So, out of this total energy, useful work or useful energy which is in the form of work certainly available at the shaft is how much? This is essentially what we can write as brake thermal efficiency into mass rate of fuel. Heating value of fuel into combustion efficiency.

So, this is the amount of energy we are going to supply. Now, if we try to recall, we have already discussed that this is the amount of energy we are supplying with the fuel. And this conversion is not directly possible.

So, we have seen, or rather studied in our undergraduate course, that combustion will be there. Now, combustion—any mechanical process—cannot have 100% efficiency. So, this combustion efficiency will be there. So, that is why you have multiplied with this. So, this is combustion efficiency.

So, though we are supplying this much amount of energy because of the combustion, we will be getting this much amount of energy available in the inside the cylinder rather. So, this is inside the cylinder. This is with the fuel and finally we will be getting this is what is available at the shaft.

So, this is brake thermal efficiency. So, this is the amount of energy which you are getting at the shaft. So, that means if we write one step further, we can tell that

$$\dot{m}_f Q_{hv} - \eta_b \eta_c \dot{m}_f Q_{hv}.$$

So, this is the energy which is not available. So this much energy is not available, this figure includes.

That means this much energy will be lost through heat losses, parasitic load right and energy that lost through exhaust gases. So, this is the figure. Now so that means these are the losses.

Not available. If we now write this expression in a slightly different way. Total power generated equals $\dot{W}_{shaft}$, which is available, plus which is not available that is $\dot{W}_{not\ aviailable}$.

So, this not available includes. What?

$$\dot{Q}_{loss} + \dot{Q}_{loss,exhaust\ gases} + \dot{W}_{parasitic}$$

Now, so this is the loss of energy that we shall discuss now. This is the loss of energy through exhaust gases, though, conduction, convection, and radiation from the engine cylinder into the ambience. This is the loss of energy, which is in the form of enthalpy and chemical energy through the exhaust gases.

Rather, yes, exhaust gases will leave the engine cylinder, and there will be some loss of energy in the form of enthalpy and chemical energy. And certainly, some part of this energy would be utilized to, run several units of, an engine. If it is a luxury car or any other system, there will be several parasitic loads to run a small pump, to run several, lights, to run an air conditioning unit, so many things. So, parasitic load is there.

Let me tell you one thing—just one part I would like to highlight. This loss of energy through exhaust gases is sometimes even higher than the brake power or the shaft power. So, this is the shaft work which is available. That, you should remember.

Now, as I told you, this loss is mainly through conduction, convection, and radiation because this amount has to be lost. Otherwise, we would not be able to save the engine cylinder, piston, or phases for a longer period because several mechanical or problematic issues will arise. So, if we now look at this quantity $\dot{Q}_{loss}$, equal to—so this is basically the energy lost through cylinder walls into the ambience. Now, this is

$$\dot{Q}_{loss} = \dot{Q}_{coolant} + \dot{Q}_{oil} + \dot{Q}_{ambient}.$$

So, as I said, this energy is lost through cylinder walls into the ambience through the cooling system and through oil circulation. We shall discuss all these things. Now, what about this?

So, $\dot{Q}_{coolant}$ is basically 10 to 30%. $\dot{Q}_{oil}$ is very small, 5 to 15%. And $\dot{Q}_{ambient}$. is 2 to 10%. So, this is the classification. So now we have come to a point that there are certain places, surfaces through which this loss of energy should occur or should take place.

I mean it has to be. We must design in such a way that this much amount of energy should be lost, should be transferred, so as to keep the cylinder or several other components of engine block from melting and other possible failures. So, this is what is important to know.

Now question is, we know cooling system if it is air cooled engine then extended surface would be there through which we can have continuous supply of air. As such forward movement of the vehicle will allow to suck certain amount of air to be directed into that place that surface extended surfaces rather. If it is a water-cooled engine, certainly we need to supply coolant water with some antifreezing reagent. And that circulation of coolant mass flow rate would be designed accordingly so as to remove certain amount of heat from the cylinder outer wall. And also, it is not a case that all part of the engine cylinder would be surrounded by the cooling water jacket.

So, some other exposed surfaces of the engine cylinder through which a certain amount can be transferred to the ambience directly. So, this is basically the quantification. Now, if we look at that, this shaft work is available work. This, which is not available, has three components: $\dot{Q}_{loss}$, $\dot{Q}_{loss,exhaust\ gases}$, and $\dot{W}_{parasitic}$.

As such, we really have no requirement to remove this because this is needed to run several units. This is automatic because we need to remove exhaust gases from the combustion chamber. So, when combustion gases are leaving the engine cylinder, combustion gases will carry certain enthalpy and also chemical energy with them. So, this loss is also inevitable.

Now, this loss is very important—that is what we have focused on—and we have to keep in mind that some arrangement should be there to have this much amount of energy loss from the combustion chamber through cylinder walls. So, possible mechanical failure of several engine components can be prevented. So, one such—and then Q-dot loss has three components—that is what we have now discussed: coolant in the cooling system will be there. Oil circulation is done because, we have discussed—if you can recall correctly—when we discussed the engine block.

So, an oil pan is there from that oil pan, there would be some oil splashing system so that oil can be splashed over the piston face. While oil is splashing over the piston face, it should carry a certain amount of energy or heat from the piston face. We have discussed today that the piston face is one of the heated surfaces. And as I told you, it is not the case that the entire engine block or engine cylinder would have a standard surface outside, or that the cooling water jacket would occupy the entire outer periphery of the engine block or engine cylinder.

So, some part would be there through which a certain amount of energy would be transferred from the combustion chamber through the cylinder wall into the ambience, and that is 2 to 10 percent. So, let us briefly discuss heat transfer or energy transfer in the form of heat from an engine. We have understood that we have discussed how a certain amount of energy has to be transferred from the combustion chamber or engine cylinder into the ambience. And the possible modes of energy transfer are conduction, convection, and radiation.

In principle, these are three modes. The most important modes are conduction and convection. Conduction will occur because heat transfer through the engine cylinder wall will be there. And then, inside the combustion chamber, some convective transport of heat would occur from the gases into the inner wall. And from the outer wall into the ambience, convective heat transfer will occur again.

So, these modes are there. Important now as I told you that though spark plug exhaust valve or exhaust port and also the piston face to some extent intake manifold these places are having maximum temperature or the heated surfaces. It is not so easy to remove heat through those surfaces. So even then we need to know what are the surfaces rather through which energy transfer or heat transfer takes place. One is heat transfer in intake system or manifold right. Number 2) is heat transfer in the combustion chamber.

Number 3) is heat transfer through exhaust gases. I should not write exhaust gases rather I should write because exhaust gases is also having some part in exhaust system or port. So, these are the three important surfaces through which we can have heat removal from the combustion chamber into the ambience. So as to keep several components intact or to prevent several components from their possible mechanical failure and to enable the engine to run smoothly. Now question is heat transfer in the intake system, heat transfer in the exhaust system. We have discussed that intake system is to some extent but exhaust system is rather exhaust is not so easy to remove or to transport heat through the exhaust system because it is not possible to have any cooling system.

Mostly you have to rely on the conduction and certainly some convection from the outer surface of the exhaust manifold into the ambience. In intake system also, but we shall discuss about several other possibilities by which it is really possible to transport certain amount of heat from the combustion chamber. Certainly, you can understand that heat transfer in the combustion chamber is only the way because we can have cooling water system. So as to remove certain amount of heat even if the entire outer surface of the engine cylinder is not surrounded by the cooling system, from those parts also some amount of heat will be transported into the ambience. We shall discuss all these cases in detail, together we shall try to solve a few numerical problems, and we shall take up this part in the next class. With this, I stop here today. Thank you.