Engineering Thermodynamics

Dr. Jayant Kumar Singh
Department of Chemical Engineering
Indian Institute of Technology Kanpur

Week-01
Lecture-7
Energy Efficiency

Welcome to the fourth lecture on Energy Transfer. In this last lecture, we will discuss energy transfer. We will discuss energy efficiency, the devices in plants and in general the devices that we use in our homes. We will discuss the definition and how to use it in general. Overall efficiency in a system where there are many devices. We will discuss how to use it. We will start with a simple water heater. Do you analyze efficiency, or do you calculate it? So, how do you do it? What is the meaning of efficiency? What is the basic definition? In simple words, the energy you have entered on that device, whether it is a water heater, and finally, the output it is giving, whatever form the desired output is, we see its ratio, we divide it. by required input. Now, this required and desired value will change according to different devices. We will talk about that in detail. But now, if we talk about the water heater, then you can see that the heating element that is heated by the water heater comes in different ways. Like, it is gas based. the heating and electric base. If you look at its efficiency, the conventional gas is 55% and the higher efficiency gas is 62%. The electrical is 92-94%. So why is the gas efficiency less? It depends on your heating value. Because combustion is heat and burn So it depends on how much fuel and energy it contains So if you look at the efficiency of combustion It will be defined as the heating value of the fuel burned as much as possible heat that comes out of the chemistry Heating value Okay and Finally, the amount of heat released during combustion is the ratio of both. So, Q is divided by heating value. For example, here we see that gasoline is burning at 25 degrees. So, the room temperature is 25 degrees Celsius. And this is a combustion chamber. And later, the combustion gas is also at the same temperature. In the case of CO_2, H_2, N_2, these gases are firm. So, this is your low heating value. This is a simple example of gasoline. There is also a high heating value. This happens when you condense the water, i.e. liquefied it. And if you recover the heat vaporization, the total heating value will increase. delta amount will be added. which will come in the latent hilt so this will be the latent hilt of the polarization LV. So, this is the higher heating value, so this effectively describes your combustion efficiency. But if you talk about plants, there are many units in it. There will be combustion, there will be thermal efficiency, in which your work output and heat will be related to it. And finally, there will be a generator. Because the generator will convert your mechanical energy into electrical energy. So, the efficiency of the generator is the ratio of the electrical power output to the mechanical power input. And the thermal efficiency of a power plant will be the ratio of the net shaft work output to the heat input to the working fluid, which is normally water in the plant. So, what will be the overall efficiency? That means you are trying to get mechanical work from the same heat. And then you are converting the mechanical energy through the generator. So, there are 3 units. So that's why the overall efficiency will be the multiplication of all 3. But what do we need for overall efficiency? We need the total electric work. And what is the input? The fuel that we used in combustion. that is your higher hitting value multiplied by the total mass we used for fuel. So, this is your ratio of overall efficiency. So, I am talking in simple terms. You can understand this in detail through examples. And you will have some questions in the assignment. So, you can understand it by using it. So, if there are many devices in the system, like a plant has many devices, and you are making a process by combining those devices, then the overall system and overall process efficiency will be less than the efficiency of every device because they are being multiplied. To increase the overall efficiency of the process, you need to multiply the unit operations of the devices.

Energy conversion efficiency is very important because if you use more efficient appliances, the energy loss will be less. If you use energy efficiently, then the coal that is burning will extract carbon dioxide and other gases. And naturally, as you can see, the temperature of the surface is increasing. And this is a big role of carbon dioxide. So, it is important that as an engineer... you should understand that efficient things should be used only there. Like the environmental impact should be minimal. Because it is very important for society that there should be efficient vehicles, efficient energy resources, and renewable forms. Efficiency is between 50-60%. Maximum appliances are, as shown in the example given in table 2.2, which is the textbook used in the textbook. You can see the cost of energy in dollar terms in 1996.

Now, in India, it will be different, but it can be in a similar form. Because our cost of energy is not much different. But you can note in rupees how much you are spending. And if this efficiency increases, then your appliance cost will be one time more, but overall daily and annual cost will be less. So, this is the use of this particular table. To find out what is the benefit of buying an efficient appliance. If we talk about a simple cooking appliance, then we can simply define its efficiency as Energy Utilized divided by Energy Supplied to Appliance. In this case, the energy supplied is simply electrical energy, which is 5 kW. And the total amount of energy that you are using is only 3 kW. The rest is wasted in the environment. So, approximately 0.6 is your efficiency. You can do more examples like this. In this lecture, I am trying to explain the basic definition. We will not do more examples because there are many examples in the textbook. Now, this slide summarizes the efficiency of mechanical and electrical devices. Where there is mechanical energy, it is always connected to a shaft. mainly in rotation form and that's why the mechanical energy connected to the device is called shaft work and normally what happens is that the pump or fan will receive shaft work from where? from the electrical motor and it will transfer the fluid as mechanical energy to as it is written here, the pump and fan. The electric motor will receive the energy from the shaft and then transfer it to the fluid. In this case, the fluid is the air from the fan or the pump. The shaft receives the energy from the electric motor and then transfers it to the mechanical energy. This turbine uses mechanical energy that is connected to the fluid and converts it to shaft work. So, we assume that there are no frictional losses and usually this conversion will not be 100% efficient. There are always some losses. But if there is no loss, then any mechanical energy can be theoretically converted into 100% mechanical energy. So normally it is not achieved, but it can be completely converted into 100% mechanical energy. But if it is less than 100% then some form is converted to thermal energy. That is losses. So usually, ETA is less than 1. So, you have losses. So, what is the definition of this?

$$\eta_{mech} = \frac{mechanical\ energy\ output}{mechanical\ energy\ input} = \frac{E_{mech,out}}{E_{mech,in}} = 1 - \frac{E_{mech,loss}}{E_{mech,in}}$$

you will get this expression So here, in any system, particularly if you have a fluid The basic interest of the fluid is that When we use it in the form of devices The interest is that if you increase its pressure, velocity or height So in these three forms we change the fluid's properties and in general the energy system. And these are devices like pumps which change your pressure. Fans or compressors, these are all forms of you These devices basically supply mechanical energy to the fluid. So, it is commonly used everywhere. Pump, fan, compressor. So, if you talk about the pump, then the efficiency of the pump will be the mechanical energy increase of the fluid which you have applied to increase the mechanical energy of the fluid divided by mechanical energy input because you have used shaft in your pump so the energy of the shaft is inputted and the mechanical energy of the fluid is outputted so we have to take a change in it because there can be some mechanical energy in the fluid and we consider the change so this is the change and this is the input and we have put a dot because it will be rate because it will be in flowing term, so it will be rate and usually this This form is also written in some cases that it is useful work related. We will ignore this now because we will not talk about it in detail. We will focus on this particular part. So, delta E fluid is equal to delta E Mach out minus delta E Mach in. Similarly, if you want to extract mechanical energy from the fluid, then you have to use a turbine. So, what you do is convert mechanical energy from your fluid to power. Power in the form of which goes into your rotating shaft. So, you used the fluid in the turbine. Suppose the fluid is coming from high pressure and it is going into the turbine. In the turbine, it is converted into the rotating shaft into mechanical power. And the same mechanical power which rotates drives the generator and becomes electric power. So, this Eta, the efficiency of the turbine, will be the mechanical energy output. The shaft work is divided by the change in mechanical energy. The change in the mechanical energy of the fluid. And since it is negative if we do 2-1, the final minus initial, that's why we take absolute. So, this change in the mechanical energy of the fluid. and this is the final output, desired output, required input that is the definition of eta desired output divided by required input so desired output is shaft work which is doing the turbine work and input is change in mechanical energy again, you can write it in this form, but we ignore it, we only talk about this ok Delta E mech is equal to E mech in minus E mech out. For example, this is a fan that you normally use. And this is the stationary side, which is air. So, this is 1 and this is 2. This is 50-watt power. Initial velocity is V1 on this side and 12 on this side. and also, the pressure, which is P1 P2 So if we want to get mechanical efficiency, then how will we do it? Suppose we want to get mechanical efficiency of fan So the main thing is what is the required desired output and what is the desired required input So first of all, this is a simple mechanical fan and finally the right side is changing in the mechanical energy fluid so we will see delta E mechanical energy fluid divided by shaft work so what is delta E mechanical energy fluid? simple because there is no change in potential energy and there is no change in flow work because your P1 is equal to P2 so this is your It is simple kinetic energy, initially zero, so it is final kinetic energy divided by work shaft. So, shaft is your work, simple 50 watt. And you know what m dot is because it has the problem of 0.5 kg per second. And you know the velocity, so you enter it and finally the heat is at 0.7. So, it was straight forward in which you used a simple definition.

Motor efficiency

$$\eta_{motor} = \frac{mechanical\ power\ output}{mechanical\ power\ input} = \frac{W_{shaft,out}}{W_{elect,in}}$$

Generator Efficiency

$$\eta_{generator} = \frac{electric\ power\ output}{electric\ power\ input} = \frac{W_{elect,out}}{W_{shaft,in}}$$

Pump-motor overall efficiency

$$\eta_{pump-motor} = \eta_{pump} * \eta_{motor} = \frac{W_{pump,u}}{W_{elect,in}} = \frac{\Delta E_{mech,fluid}}{W_{elect,in}}$$

Turbine-Generator overall efficiency

$$\eta_{turbine-gen} = \eta_{turbine} * \eta_{generator} = \frac{W_{elect,out}}{W_{turbine,e}} = \frac{W_{elect,out}}{|\Delta E_{mech,fluid}|}$$

Now if you take both combination of pump and motor you have to multiply eta so basically this part if we pump eta and eta motor so here is your delta E mech I am writing it in short form and this is the shaft. And this is your W shaft by W dot E electrical part. This is your motor, so it is cancelled. So, this is your delta E mech divided by W electric in. This is the combined efficiency of your pump and motor in definition. In the same way, you can do turbine and generator in the same way. Eta turbine multiplied by eta generator. So, this is your final form. You can ignore this. This is a useful and general concept that has been explained in this textbook. But you can simply consider this. It will be easier for you. Ok, so this thing you have understood hopefully. Now if we see the example of this generator and turbine combination. What turbine did is, turbine took a high-pressure fluid and converted mechanical energy into shaft energy. Power 0.97 multiply by 0.73 this represents total mechanical energy 73% of the total energy converted to electricity. You can understand this this way. Effectively, it represents so much that it converted to electrical energy. 73% of the total energy is converted to electricity. Because it converts to electrical energy. So, this is the overall efficiency of the system. We have discussed how to use it. Finally, we will do it as an example and try to understand it. Finally, we will close this lecture. This is turbine generator efficiency. It is given in this form. Earlier we gave an example that is already given. Efficiency is given. Here, by not giving efficiency, you have given these terms. And you have to calculate how much efficiency there is. So, it is not directly efficient. So, it is given that the electrical power is basically generated by this combination which is 70 meters below the surface of the riverbed. This is a large reservoir or dam; you can understand it as such. And here the water comes here and here the mechanical energy is with it. is converting it to shaft work and this shaft work is finally converting it to electrical energy now the question is that the water flowing finally coming out of here is your 1500 kg per second that means this water is coming out of this rate this is a steady state at a steady rate 1500 kg per second free surface of reservoir. And the mechanical power output of a turbine with turbine is 800 kW. And the electrical power generator is 750 kW. Now we have to calculate the efficiency of turbine. It is said that all the losses in the piping should be ignored. There is no loss associated with it. Because when it comes from here, its mechanical energy can also be lost in thermal and other things. So, it is said to be ignored in this flow. So, the first thing is that there will be some assumptions in it. First, suppose if we consider it as a reference, so this is zero and here the potential energy is per unit mass is G times Z. So, this is called Z1. So, this is G times Z. So, the potential energy is G times Z. And here the atmospheric pressure will be because this reservoir is... The air is above the pressure and the distance is 70 meters. So that we can assume that P1, P2 and P atmosphere are present here. So, it means that the contribution of the fluid in the energy, has become potential energy, kinetic energy, and of course, there is also internal energy. But there is also a flow energy, which depends on the pressure. The pressure and density are the same, so the difference in flow energy will also be zero. So, its contribution is also zero. Now the kinetic energy here is stationary, so the velocity is zero. And this velocity is also almost zero, it is a very slow process. So, we have ignored the kinetic energy difference, that is, we considered it zero. So, Delta E Mechanical, what will happen? In Mechanical, what will happen? There is potential energy, kinetic energy and flow energy. We have ignored flow energy and kinetic energy. We have ignored the difference between both. So, Delta E Mech is only E mech in minus E Mech out which is your PE1 minus 0 So this is your delta, E Mech So we have removed delta E Mech first Why are we removing delta E Mech? Because your turbine What does it do? What is your required input? Change in delta E Mech Output is your shaft So you have to remove the efficiency of the turbine So you have to give delta E Mech and your w shaft will be out. Here your w shaft is already given, so basically, we have to take this out. And to take this out, you have to write E Mech in minus E Mech out. E Mech out is zero because we are considering it as reference. So we have entered the potential energy, we have found out the P, E, G and Z1. Z1 is 70 meters. So, this is 9.8 multiplied by 70 and mass is 1500 kg per second. So, this is your delta E Mech 1031 kilowatt. So, this is with you. 800 kW shaft output is 800 divided by 1031 kW this is 77.6% efficiency ETA turbine multiplied by ETA generator This is finally What is desired output? Desired output is WE electrical And input is the one which is coming out of the fluid Because these two are combined So it has one or two blocks So finally, what is coming from here We will consider it as this What is coming from here is your input Desired input And what is coming out is your This is your required and this is your desired output so what is the desired output? electrical output and required input is delta E because you will convert the mechanical energy of the fluid through these two devices finally into electrical energy so this is already given as 750 kW this you have calculated So, the reservoir supplied so much mechanical energy, finally we converted 800 kilowatt shaft work and finally we generated 750 kilowatt electrical power from the generator. So, this is a very ideal scenario. Of course, if there are some thermal losses, then efficiency will be a little less. So, this was the topic of this video. We discussed it in four parts. One is about energy. We discussed two forms of energy. One is about microscopy, which is applied to the whole body, kinetic and potential. And the other is about molecular nature, how molecules are with each other, how they hit each other, how their internal energy changes. Or if they work together, their internal energy can be less. We discussed about the forms of internal energy like sensible, lightened, chemical and nuclear We discussed about the system's energy transfer or heat or works or boundary interaction and mechanical forms of works We tried to understand these in some examples Finally, we discussed about the first law of thermodynamics We have discussed about energy balance and some examples. And in this lecture, we have discussed conversion efficiency. I hope you enjoyed this series of lectures. And I will see you in the next lecture where we will discuss new topics.