Engineering Thermodynamics

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Exergy

Welcome to a new lecture on Exergy. In this lecture, we will discuss what Exergy is, and how it is related to useful work, and what is the definition of Exergy. Let's start the lecture. If you take any system that has energy, the first question you will have been how to use that energy. Like we talked about heat engine, that heat engine gives energy and how to convert it to heat we designed this heat engine. Similarly, a question arises that if you have a substance which has some energy then how much portion of that energy can you convert into useful work? So, this answer and this parameter are given by this term exergy which we used to call availability. In many literatures, you can see that in some books, the old books use the word availability. Availability energy or available energy. This means that the energy available to us, the portion that we can convert, that is the available energy. That is the only thing that is accessible to us, that is the only thing that we can convert and that is also called Exergy. So, Exergy is a useful work potential. How much is its potential? which can be converted into work. And this will always be a system definition, a specified state, a state that is defined in it.

So, to understand this, let's take a little example. Like, if you are considering this system, which has a temperature of 25 degrees Celsius, 100 Kilo Pascal, and the environment outside is also the same. So, in such a system, since there is no change in the surrounding, it means that there is no change in the energy state. And in such a system, you cannot extract anything in any form or useful work. So, such a state which is equilibrium with the surrounding and with the environment, we call it equilibrium state. So, equilibrium state is your dead state. We can't do anything about it. We can't convert energy from it to any useful work. But let's take an example. For example, if this is a hot potato, as it is given as an example, if it is at 70 degrees and the environment is at 25 degrees, then the temperature change will end by some distance from the boundary of the system. And let's assume that this is the immediate surrounding. There is a region right next to it, which we call immediate surrounding. If you take both of these, then the changes between the two are with you. You can get some useful work out of it. But after this process, the environment here will be at 25 degrees. So, this system will finally come to the boundary and it will be dead work. What I mean to say is that if you think about it carefully, the whole system is transferring heat from its system to the surrounding. The change is in the path, in the process, from the system to the immediate boundary of the surrounding. After that comes the dead state. The definition is that if any system has energy, if we use it reversibly, so that the system will finally come to a dead state, the environment will come to a dead state, then the work that we can do through the whole process, we call it the maximum possible work, if we do it in a reversible way. The same maximum work is exerted. So, in any system, in general, the temperature is higher than the environment, there is an exertion, there is an available energy, we can extract the work from the reversible process in some form or the other. In many books, you will find the available energy formula. But in this lecture, we will talk about exergy. So, we defined immediate surrounding as the portion of surrounding where temperature changes, but it is more than the temperature of the environment. And the environment is where temperature changes, means it is a dead state, equilibrium state. If it happens in the environment, it will be in the finite temperature difference, meaning it will be in the immediate surrounding region. Irreversibility ends as it reaches equilibrium. So, the discussion we were discussing was that... The process we mentioned earlier, the useful work potential of the system, we will call it exergy first, so exergy is important, this is available energy, availability, and we will call it useful work potential, that is, how much capacity of the system is there which can convert its energy into work. So that was exergy. We can't do it 100% but we can do it with the energy we have. We call it useful work potential. So, in a way, it is said that Exergy is an upper limit. Because to do this, we will have to do a reversible process. Because we are talking about maximum, not possible work. Maximum possible work. only then we can reverse the process without any violation of the thermodynamic law so this is the upper limit if someone asks what the exergy of the system is then you can say that we will do it with a reversible process and will not violate the thermodynamic law so the value of the exergy of the system will be It depends on the state. If you change the temperature, for example, then the acceleration will change because its internal energy will change, and its energy will change. So, the specified state is also important. It will be there if you are talking about a specified state. So useful work is defined for a system. If we read the statement again, then it is done. A system delivers the maximum possible work as it undergoes a reversible process from the specified initial state to the state of the environment.

So, another important thing is that when we are processing to get the excision of a system, first is the reversible process, second is the path or final state we are taking. Paths can be taken but it is an irreversible process. The final state is specified in the initial state. And the final state is the dead state. It should be the environment state. If there is 70 degrees in hot potato, then the energy of 70 degrees Celsius, we have taken potatoes, but anything can be taken. If we do the reversible process by changing the system by 25 degrees, then the maximum work we can do will be defined as useful work potential. And we will call it Exergy. Now let's talk about kinetic energy. So, if there is complete conversion, then Exergy is total. Whatever kinetic energy is Exergy. Whatever potential energy is Exergy of any system. But we cannot do the same thing with internal energy or enthalpy. So, this is why I have told you through Venn diagram that if you have total energy, then we can convert some portion of it into useful work. So, some portion of it will be Exergy. And if we talk about potential energy, then it can completely convert you into some form, into work. So that's why mechanical energy can be entirely converted into 100% and its potential, its useful work is 100%. This means complete Exergy, as X is called, it represents Exergy in KE. And XPE means Exergy or potential energy. So, V square by 2.

Let's try to understand this by using the example. The question is if you have a wind turbine, and it is said that the wind is blowing steadily from 10 mps. And the diameter of this turbine is 12 mts. And the question is that your maximum power What can it generate? We have to find out how much it can generate. So, first of all, we will assume that the air is in the standard condition. The air that is flowing is in 1 atmosphere and is at 25 degrees Celsius. So, let's assume this. So, since it is kinetic energy, we try to get the kinetic energy out of it. So, according to the per unit mass, V2 will come. So, this is approximately 0.5 kJ per kg. If we add value to it, 10 mps, then we can convert it into per unit joules per kg. So, this comes out. Because this will come out in mps, m square per second square. So, if we call it 1 kJ per kg. divided by 1000 m2 per second square so this is your kinetic energy now the question arises that what will be the maximum power in this? because we can convert this total kinetic energy into power according to the discussion, we had just done so your maximum power will come out For this, you will need to find the m dot. Because you need a rate, the mass is flowing from this mass, multiplied by K. And to find the m dot, you will have to find the row, its density, area and velocity. So, the area is 12 meters in diameter. And you have to find the density. We can remove the air from the table. The air density will be 1.1. 8 kg per meter cube and area is pi d square by 4 d is given by 12 meter and velocity is given by 10 meter per second so if you put 12 meter then it will come out as 1 3 5 kg per second so you can put this in m dot so maximum power will come uh Actually 0.005 kilo joules per kg In general, the maximum power is given by default, but it has an efficiency. Its efficiency can be extracted in general 20-30% only. So, if you have 66.8 kW based on the kinetic energy given. But the turbine that will be available for it. The design is effective, and it comes out in 2030 but the work potential is 100% In reality, you can get 20-30 kW from this But the potential is equal to kinetic energy which is 0.05 kJ per kg It is also known that design will matter a lot, but here are some laws that state that with a wind machine. So, we are out of this discussion. So, we will not discuss it. Now let's move this discussion forward. And in this, we especially take Exergy transfer from a furnace. What is the Exergy transfer from a furnace? Here you have a large furnace. Which is transferring heat to this rate at 1100 degree Celsius and we have to extract its exergy flow which is associated with heat transfer. So now we will try to extract it. You can understand this as a heat reservoir that can continuously give you heat at a particular constant temperature.

The exergy that we have to extract, the flow that we have to extract, is basically a useful work potential. Which is the maximum potential, maximum possible amount of work that we can extract. And that will only come out when we use this reservoir, this furnace, the heat is being given to it, it should operate with a reversible heat engine which will operate at the temperature of the furnace and the sink will be in the environment so you can understand that this is your furnace we have put a heat engine on it and this is your sink which is surrounding at 25 degrees which is at the environment temperature and this is your and the work reversible will give you the effectively Exergy. This is called exergy flow To remove this you have to see the efficiency of the liquid TH which is 1 minus 273 plus 1100 divided by 25 plus 1100 so it is approximately 0.76 now it tells that 76% Q which is coming from here which is 3000 kJ per second is coming from this rate you can convert 76% of this rate this means W because eta is W by Q so it is Q dot and W dot is there so in reversible case you can use this because we are considering reversible so W is max so this is max and this is your eta which we have Calculate it, multiplied by Q dot, and it becomes 0.76 multiplied by Q dot, which is 3000 kJ per second. so you notice that we cannot use 24% of the heat. So, 24% of the heat is unavailable. Meaning you cannot use it. So, this is one thing that we understand. You can't do anything about it. You can only get a maximum of 76% of it. And they will only get it when you have a system which has irreversibility. When irreversibility is zero, then you will get 76%. But in reality, it will be less than this. so this is what we are telling you. Out of the total energy, almost 24% was wasted and you are 76%. This is what we call Exergy, which is the maximum work. Exergy is a useful property that is used in the system. It becomes very valuable for the engineering system to find out what condition you can use it at the maximum if there is energy. But only that does not work. We have to see that because we have taken the reference of Exergy, and normally in engineering processes, you do not always bring the final state in the dead state. So, we will go ahead and study that Exergy will matter more in difference. Difference of X and Z. But for now, we are talking about reversible work and irreversibility. And especially, we are discussing closed system. When we are using closed system, and for example, piston cylinder, in which the bond is moving, so if you take a system in which the system is expanding, it is working against the external pressure of the piston, the air outside will also work against it because some volume will also displace it so from the example we understood so this is your initial system in which P0 is V1 and finally volume is V2 and to achieve this state it will have to do some work on the surrounding how much work has come? it has worked with W surrounding which P0 The volume that was displaced on the multiplier, you can see the difference here. So, this is V2 minus V1. So, we had to do this much extra work. It was wasted. Where this bond is moving. So, what was the useful work? The actual work that was done, which is W and minus the surrounding work that has been done to push the air. So normally, the W surrounding is a loss in this case. But suppose, for example, compression is happening. The piston is coming down and compressing the system. So, if that volume is shown, it will be negative in a way. So, it can be a gain too. So, if the volume is compressed and the volume is reduced, then sometimes we can consider it as a gain too. If there is any change in the constant, then the useful work will be W. So, we will define W reversible and then we will define I irreversibility. So reversible work is defined as the maximum amount of useful work that we can produce when system undergoes process between initial and final state.

We will bring it to B and from initial to final. If it is reversible, we call it W reversible. Like we did here. So, this green line is doing it with a reversible process. And the work that is happening this way, we call it W reversible. This is the maximum amount of useful work to produce. Or if this work is supplied, then it will be minimum work. Now, the actual work that will be done is W. which is of course less than W reversible if it is a work producing condition and if it is a work consuming condition then it will be more but it is Wu if it is a final state if this final state is an environment state and it is called a dead state then this W reversible is your exergy if we take the definition, this is what we said earlier But the actual process is Wu, so the difference between the two is like if you have w reversible out minus Wu then i is irreversibility so irreversibility is the one we have lost we have destroyed it, we cannot use it and i will be greater than zero. If the work producing device has W reversible out minus W useful out and where we have to take energy like in a pump so here it is W in minus W reversible in and Win is more because in this process your irreversibility is connected so you have to work more and what is the difference between them which we are losing, which we are destroying So, you can understand this by the definition And we should try to minimize this I in some way Mainly, to reduce irreversibility in the system we have to think about friction, slow process etc.

Let's take the example of the top. Here you have a heat engine which is receiving at source 1200 Kelvin Qin is given which is the heat engine that is receiving at this temperature at this rate. And the waste heat is finally going to sink to 300 Kelvin. We have to get it out. Its power is also given at 180 kilowatts. Now we have to get the reversible power and irreversibility rate of this. if there is a reversal process, which is assumed that this heat engine is given. So, this reversible power and the irreversibility rate of this process. So reversible power condition will be there only when you assume that this is Carnot cycle, this is the ideal condition, then you will get maximum power. Since you have been given source and sync, you can remove it. And W of course is given on current condition. So, to remove it, we need W reversible out. reversible into q dot in And this is your 1 minus because we will assume that it is reversible 1 minus t Sink here is the sink so let's take the sink divided by t source Q dot is given to you 500 kilo joules so if you insert these values 1 minus 300 divided by 1200 into 500 kg per second so it comes out to be 375 kilowatt so W dot reversible out that is your reversible power comes out to be 375 and we said that what is irreversibility? So, this is your reversible output, 375. And Useful Work, which you have taken out, is around 180. Which you have taken out. So, in general, your irreversibility in this process. In this process, if you have 375, which can take out maximum power, minus the one you have given, 180, then this is your kind of irreversible. 195 KW. Which is result of irreversibility, So this is your total irreversibility. But you can see in this also how much amount is going into your sink. so, 500. If you see, you can only extract 3.75 from it. So, approximately, your amount that will come out, 125 kW, is rejected in the sink. Which is not available anywhere. So, this is not available. You wasted 195 kW due to irreversibility. And this is not available.

So, this is also included in a way. So, in a way, 500 kW, 500 kJ per second watt, if you see, so out of this, 125, you had to waste it in the sink, throw it, 195, you lost because of irreversibility, and you could only use 180. So, this is your loss. In a way But this is not because of irreversibility of 125kW It is only 195kW which is the reason for the energy loss Let's understand this in different ways We have just given the heat engine Let's take an example according to the system This is the iron block which is at 200 degrees Celsius 500 kg And here and cool it down to 25 degrees Celsius and heat transfer will occur in the surrounding We are also being asked that how much reversible work can we do and how much irreversibility is there in this process So this question is a bit unique Now you should understand how to do reversible work with iron So the meaning of this is that you will basically do it when you Imagine that you have used this energy, whatever energy is being transferred, you can use a reversible heat engine to make a source for it. And also, you can throw the remaining energy into the sink, which is the surrounding, which is at 27 degrees Celsius. So, we have to find out how much W is reversible. So, this is your Qin which will come out and we will have to find out Qin also. So, to do this process, we first see in the definition what we can do. This is your source which is 200 degrees Celsius. So, if you do it in differential amount because your T will also change. If it is in reversible form, we can say that it is differentially eta. We call it in reversible form. If we multiply it with delta Qin, then it will come out as delta W reversible. We can write this as 1 minus T sink. and this is called T0 so T0 by T delta Q in so W reversible will be your integral 1 minus T0 by T this form will come.

Now we can represent del Q its change in iron block is the change in internal energy. So how will we do that? To do this we have to apply energy balance that is also differential energy balance, and we can say that delta E in minus delta E out is equal to dE system. And this as you know, this is net energy transfer from heat, work and mass and here only heat transfer is there and that is also only coming out and this is your d of u so we can ignore other things and only the internal energy is changing and we can call this mc average dt and c average is t0 average you have said that heat capacity is average now this thing the dq is coming out is qin In is your del Q out and this will come out minus Cv average dt Now we will plug in this here So W reversible will come out 1 minus T0 by T And in this comes your minus mc average dt. T will go from 200 to 27 T1 to T0 T1 will go from 200 to 27 So when we integrate this, what will come out? We will multiply this first, then multiply this T0 by T But the integrated will come out as mCvAvg T1 minus T0 This is from the first term and from the second term, it will come out as T0 is constant T1 by T0 So this is the result So this is your W reversible. Now in this you will plug in the data You have to get the Cv average from the table Cv average is your A3 W reversible 8191 kJ Cv average T1 minus T0 38925 kJ Proto Q is the same but W reversible 8191 is there This means only 21% of Q is converted to W reversible This is your maximum reversible. This is the exergy of your maximum reversible. This is the maximum useful energy that you can convert in your work. This is 8195, which is 25% and this is the exergy of your maximum reversible.

Now the question is, what is your irreversibility? W minus U So this is an interesting question because as you can see Wreverse minus Wuseful 8191 but how much is the useful work First of all, what you have done is in this process you have given the whole heat and the energy in the surrounding so Irreversibility is complete in this case because your possible reversible work is 8191 that is your exercise if you can get it out but since the energy is transferred in the dead space after that state you don't have a useful work so it is completely wasted this is your energy 8191 W useful actually is zero So because of this, the potential of reversible work, you destroyed the waste. So, as you can see, the irreversibility is completely irreversible. Because the total 8191, will come out, the kilojoules, which you have lost. Because you have wasted all your energy in this process. Whereas the actual capacity of the battery is 8191. But due to the irreversibility of the process, because we have wasted it, that's why your battery is 8191 kJ.

Let's move ahead. Let's try to understand this more. Thermal efficiency and COP, this is sometimes called as the law of efficiency. Is it the right parameter to be considered right? Let's understand the performance of any device by using this example. As you can see, this is a kind of a heat engine. We have used two heat engines, A and B. We have used both of them at 30%. The maximum capacity of one of them is 50% Carnot Reversible. which we can extract, you have done reversible A, do Tl by Th, then you will get 50% Second is that 70% will come out. Now the question arises that now tell me, its thermal efficiency is first according to the law, 30% is of both, but actually according to the capacity, B is not working properly. Because actually its maximum capacity of efficiency is 70%, but it is working on 30%. So effectively, this thing is understood from this example that on the basis of the first law, the thermal efficiency or COP is not the right parameter to judge whether the device is working properly or not. Is it working smoothly or not? And sometimes, with very small differences, it’s not clear by words which equipment is better. But if you pay attention to the engineering form, you will understand. Sometimes the devices mean that they are efficient. But the question is whether the performance is good or not. We will understand it through an example. But to do this, from this example, we understand that first class is not sufficient. And B is inferior, that is, it is performing badly. So, you can understand this by looking at it as a reference. device is performing a parameter which is working in the maximum reference for example, if you are 30% then 30% means 70% if you are 100% then how much is 30% if you consider that reference then you will get a second law of efficiency, so the second law of efficiency depends on how much your device is performing relative to the reversible condition. That is, the maximum possible is how close to that maximum. And to do this, we are considering a ratio. For example, if we talk about eta, the heat engine, then the efficiency divided by the efficiency in reversible condition. If you see this example, in this case eta will be equal to 0.3 by 0.7 and this will be equal to 0.3 by 0.5 so naturally its efficiency will be more than this second law efficiency. So, we can say that the performance of A is better. So, you can take this thing out. As I have just said, it is 0.6A and 0.43A So the second law of efficiency is a good measure It is a right measure in a right way It is a practical measure, an engineering measure For performance That how close is the maximum possible of this So you can measure which engine is better.

Let's generalize this because you will not be able to use ETA. The way to generalize this is that you will generally say that useful work is divided by the work which is reversible condition. That is, the work which you are taking out normally divided by the work which is reversible condition. So, this is generally for the work producing device. But there will be many devices in which work will not be produced or consumed. Like your nozzle. So, what we will do for that? For work consuming device, you will do the reverse work divided by Wu which will be in your normal process and in this case, since it will be more So, the ETA will be less than 1. You can use the same for the refrigerant and heat pump. But as I said, it's okay that these are work consuming or producing devices. So, it's okay for that. But we need a general definition because you have other devices in which the work is not related. As we said, the nozzle was made. So, to do this, we use a generic term or definition which depends on exergy or work potential. So, in this definition, eta is exergy recovered. How much we recovered exergy divided by the exergy we spent. Expanded means the expense we spent. So, in a way, the ratio is the amount we recovered divided by the exergy we spent. You can understand what the heat engine is. What does expanded mean in heat engine? It means the amount of heat transfer you have done in the engine. That will be the amount of heat you have spent. The difference is the heating supply minus the amount of heat you have rejected. And the amount of network you have done, that will be recovered. Similarly, if we look at the refrigerator and heat pump, the exergy that you have expanded is the work input that you have put on the refrigerator. So, in the heat engine, this is what it looks like. T0, TH, TL Refrigerator So in this, as we have developed exergy expand, and this is Exergy recovered. So, Exergy recovered. expand it. In this case, the Exergy will be recovered at high temperature. We will understand more about this in the next video.

If you take heat exchanger, you add two types of fluids. One type of heat transfer from one fluid to another fluid is the one that is expanded and recovered. You can understand this, we will think of it as an example. But let's take a particular example, which is electric resistance. So, if there is electric resistance, because we have Heat engine, refrigerator, etc. Let's talk about electric resistance heating. So, electric current is heat. So, the electric current produced by the work of the W minus E is converted into heat So, 100% of the work is converted into heat So, what will happen in eta in this case? Eta is the second efficiency in electric current If we think of it according to the definition, then it is X expanded. If X is the definition in exergy, if it is the symbol, then it is X expanded and X recovered. So, this is the electric heater. So, this X recovered is basically the total heat generated. Because the purpose of your heat recovery is to heat. So, this is called X heat. And this is your electric current. And this X heat, which is recovered, let's assume that suppose you have hit this work cook, you have to converted to total Q by which means? by Carnot engine If you want to convert the heat that you get in the form of Exergy to room, then you will have to use a reversible processor. For this, you will have to use a Carnot engine. Assume that Q is 1 minus T0 by TH. So, this exercise recovered is basically the energy content in the heat which we have converted through the work in the heat, which is in the electric form you will convert that through the Carnot engine and transfer it to the whole room. So, in a way this expression comes out because if you put the Carnot engine from here, then you use the heat of the heater. Q multiplied by Q dot E and this will be Th by We. Now We will be same because you are taking heat from the electrical energy you will assume that total is same First law is a consideration because it says that W is equal to Qv. We assume that there is no loss. So, eta comes from the simple form of electricity. 1 minus 0 by TH. So, this is your eta. You can also use it as an example. Here is a simple example. Here it is given that a dealer advertises that he has an electrical resistance heater which can be used in homes, and he said that it is 100% efficient. and it is selling it. You saw that the room temperature that you have to maintain is 21 degrees Celsius and outside is 10 degrees Celsius. So, the question arises that how much is the second law of efficiency? And first, think about what this advertisement means. The efficiency that the dealer refers to is called as the first law of efficiency. He is saying that if you consume one unit of electric energy, the heater will give one unit of energy heat form. You consume one unit of electric energy, and that same electricity will give you. This is the first law of balance. That is why its COP is 1. So, this is what it refers to.

Now we are trying to solve this. So, what should be the actual COP of this? It is said that it is COP is 1, but what should be the actual COP of this? If we consider it as a heat pump, then COP of this thing is 1-Tl by Th and Tl is your low. So, 1 minus 10 plus 273 divided by 21 plus 273. So, 0.7 is the COP. COP is 26.7. What is efficiency? The efficiency is the COP which is the actual and the COP which is the reversible. We defined it by the second law of efficiency. So, this is 3.7 percent. It means that it has 90 something plus so it is completely inefficient. We can't do anything about it. We just took out the ETA 2 electric heater. You can use it directly. If you use it, then ETA 2 should be the same thing. 1-T0 by TH if you remove this also, it will come out So, both the forms are the same. The same expression will be used if you look carefully. So, the same expression will be used. So, now you can think that the 3.7% of ETA2 electric heater is actually 3.7%. So, naturally, if we consider 100% first law efficiency and buy it, then it will be a little stupid. We have to use eta2 second law of efficiency. and use it to compare both the things but note that 96.3% of the heat that is being used can never be converted into electrical energy so it is completely getting lost so anyway, you got it that first thing is that to check any device's performance first law of thermodynamics is not a good reference For this, we used a definition of exergy which is the maximum useful work and it depends on the specific condition. The environment is called a dead state because when the system is in equilibrium, it dies. differentiates the efficiency of the first and second lock. We will try to understand this in the process later. Normally, the efficiency of the engineering device and any other process will not reach the dead-sit. So, we have to understand how to use the exergy to understand the capacity of any system. We will discuss that in the next lecture. until then, bye.