Engineering Thermodynamics

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Week-08
Lecture-37
Exergy

Welcome to part 3 of exergy lecture. In the previous lecture, we studied exergy, how exergy is used for non-flowing and flowing systems. And especially how we represented exergy change in useful work, which happens between state 1 and state 2 of any process. Let's move forward with this topic. And especially the three aspects of exergy We will discuss about these contributions. In general, as we have discussed earlier, in any system, it can be transferred, it can come out or in, but it can be done in three ways. One, through heat, it can increase or decrease, through work and through mass flow. When there is work, work is completely converted but heat is a little disorganized that means you can't do 100% conversion of it we have already read about it because heat is disorganized energy some portion of it can be converted and for this we have already discussed how to do maximum and for that you have to apply reversible process and for that we use Carnot engine which is reversible and its efficiency is written here 1minus T0 by T using this you can find out how much work you can get from heat and that will be your exergy transfer so the formula of exergy comes out this is simply eta into TH so this is your eta part so if you multiply eta of heat so much then you will get exergy This is your exergy transfer by heat. When you write it in a differential form, if you are giving any delta Q to the system, if you put a heat engine on it, then this amount of dX will come and it can integrate it. Now, the direction of the heat transfer of the exergy is also the same as the direction of the heat transfer of the exergy when the temperature of the system is more than the surrounding environment. Now, as this wall is medium here, this is more than T1 to T2, so the heat transfer is more than constant distance. But entropy, as we know, if we consider entropy as reversible, then the entropy transfer will be simple. Q by T1 will be here, but when the entropy of the other side is increasing, it will increase. and that will be Q by T2 because T2 is less and Q is fixed, so entropy increases and that amount of entropy is generated but when we talk about exergy is 1 minus T0 eta by theta reversible Q so 1 minus T0 by T1 that T0 is considered to be surrounding and that will be fixed so this amount is big but when On the other side, the temperature decreases, the exergy decreases and some exergy is destroyed. But the direction is the same as it changes. If the environment is less temperature than the system, which is called cold medium, then its direction will be opposite. We will not discuss this topic. You can read the reference book for this. You will know more about it in detail.

Let's talk about the work transfer of XCG. If there is no boundary work, then the work will be totally converted. If there is a boundary like piston cylinder, then the work of XCG will be W-W surrounding. If it is expanding, it will be lost. If it compresses, it will gain. I have discussed this earlier. So, this x work is written as W minus W surrounding. If there is mass, then as we talked in the previous lecture, we have to take the exergy flow system for mass. This is the per unit mass. So here H minus H0 T minus T0 S minus S0 plus kinetic energy plus potential energy. We have also studied this in the previous lecture and explained how to use delta psi to do some work.

Now let's add this concept to the concept that if any system is processing, then as we said that if any system is under process, then finally entropy will be generated or will be zero. It will depend on how you are doing the process. Is it irreversible or reversible? Similarly, we will establish how exergy is also connected to this. So, we know that the generation of entropy in any process is greater than or equal to zero. And we will prove that the waste that will be destroyed in the isolated system is greater than or equal to zero. So, this is the principle as we have already studied the principle of entropy. So here comes the decrease of exergy principle. That is, there has to be x destruction. So, exergy has to be reduced in the process. This is the alternate statement of the second law. In which we said that first entropy will increase, or it will remain zero. Means change will be zero. Means there will be some other change. But it is always said that in general entropy keeps increasing. only in reversible case which is an ideal case that entropy is static similarly we will say that greater than or equal to zero. And we will prove that will be reduced or constant. so, this is your decrease of greater than or equal to zero. And we will prove that principle and it will happen only when it is a reversible process to understand this we take an isolated system which is this. if you balance the energy in your isolated system E in minus E out is equal to delta I system Since it is isolated, no energy is coming or going, so delta A system is 0 equal to E2 minus E1. And if we balance entropy, as we did before, S in minus S out, plus S generation is equal to delta S system. Now Sin and S out, because you need mass or flow to change entropy, so that is also not there and S generation is equal to S system so delta S system so S generation is equal to S2 minus S1 now let's simplify this if you consider this as equation 1 and this as equation 2 and I say that If we multiply t0,2 minus T0 as generation or s1 can set me in a care s2. God hand the idea. You're probably goanna call the key system. You're actually change your go S2 minus S1. E2 minus even plus P zero V2 minus V1 minus T0 S2 minus S1. Note key. I have not used it; I have used E instead. So, it is the same thing, we are assuming that the rest of the kinetic energy is zero. Or we can plug in the same thing, there is no problem. But this is the general definition of the system, that total energy has come. Now, note that E2 minus E1 plus P0 V0 minusV1 is isolated. And in general, there is no volume change in this. So, in this process this term will be 0 because there is no boundary work in this so this part P0 V2 minus V1 will be 0 so this is X2 minus X1 and this is same this is minus T2S generation so this is minus T2S generation we know that S generation is greater than or equal to 0 so the change in exergy is will be less than equal to zero. What does this mean? Will exergy be less or constant? This is what it says. This is the decrease of exergy principle. We can write delta X isolated as such. This decrease will be due to irreversibility. So, either the irreversibility or the entropy will increase. The second meaning is that this exergy will destroy you. then your useful energy and useful work can be converted.

Energy balance: $E_{in} - E_{out} = \Delta E_{system} \rightarrow 0 = E_2 - E_1$

Entropy balance: $S_{in} - S_{out} + S_{gen} = \Delta S_{system} \rightarrow S_{gen} = S_2 - S_1$

$$-T_0 S_{gen} = E_2 - E_1 - T_0(S_2 - S_1)$$

Exergy change: $X_2 - X_1 = (E_2 - E_1) + P_0(V_2 - V_1) - T_0(S_2 - S_1)$

$$X_2 - X_1 = (E_2 - E_1) + P_0(V_2 - V_1) = T_0(S_2 - S_1)$$

$$-T_0 S_{gen} = X_2 - X_1 \leq 0$$

what is this irreversibility? The friction, mixing, chemical reactions, heat transfer, the difference between the finite temperature or the expansion of the energy or non-quasi equilibrium compression expansion all of these are brought into your irreversibility system. And what we call this change, X2 minus X1 isolated This will come out according to the destruction. Because this is a change, so this is a loss. So, this delta S is called S destroyed. So, S destroyed, which is called exergy, decrease in exergy, this is done. exergy destroyed, this will come out, T0 Sg. So, this will become a relation, that the loss of X destroyed is proportional to the entropy generation. Now you can also remove it in a relation. Since you have this relation, x destroyed will be 0 when there is a reversal process. And it can never be negative. And it will always be greater than 0 in the irreversible process. Now let's move forward with this concept. And then we say that now we try to balance x and g in the closed system. So, in any system, you will have x in or x out is the heat that is brought in and out of the system. If it is to come through the system, it will come through the heat or the heat of the work. Similarly, Xout is the heat of the work. If you balance the system, the total Xout entering is minus the total Xout going out and plus the total destruction. It should be equal to a change in total exergy of the system. So, this is exergy balance. As it is a matter of law, we are not discussing law here. This is an engineering way of solving problems. Remember, whether they are talking about entropy balance or exergy balance, we have taken it out so that we can easily evaluate things, take things out and compare devices. This is called the engineering way of treatment. There is no particular law in this but yes, you can balance it like this. So, this general statement is that X in minus X out, net exergy transfer, heat work and mask through minus X destroyed which we can directly connect to entropy. And this is delta S system. Your dot comes in the form of rate. Note it. And when it is reversible, then X destroyed will be zero. Note it. Xheat is in the form of Rate, so it will come here. Xwork is simple and useful. In the form of Rate, dot will come. And Xmass will come here, which is in the exergy Flow system. This is Flow, note it. Now we can apply for this too. If we see this close system, Xheat-Xwork-Xheat x destroyed is connected to this system if you give heat and it is working then this is in inlet and this is in outlet minus destroyed is equal to delta x system as we said here total exergy entering which is entering is only exergy through heat and the outside work which is going outside is only work is outlet this is x worked xheat can be written in any form, but also in an integral form or in a sum form. If heat is transferred from any point, then we can sum the boundary of the heat. If heat is transferred from k point, then we can sum the boundary of the heat. This will contribute to the heat excitation. work have minus which is doing on surrounding so you have to do minus and x destroy we know that we can do t0 as generation and delta x system x2 minus x1 we can write it in rate form by writing dots so here the only difference is that this is your v2 minus v1 which we have given dv system minus because this is p0 delta v which is change in the system the volume change in the system will be the same volume changing in your surrounding that's why you P0ΔV and that is normally in rate form you have to write it in d by dT and rest is in rate form so this is your basic definition.

(total exergy entering) – (total exergy leaving) – (total exergy destroid) = (change in total exergy of the system)

General: $X_{in} - X_{out} - X_{destroid} = \Delta X_{system}$

General rate form: $\dot{X}_{in} - \dot{X}_{out} - \dot{X}_{destroid} = \frac{dX_{system}}{dt}$
As $\dot{X}_{heat} = (1 - \left(\frac{T_0}{T}\right))\dot{Q}$, $\dot{X}_{work} = \dot{W}_{useful}$ and $\dot{X}_{mass} = \dot{m}\Psi$

Closed system,

$$X_{heat} - X_{work} - X_{destroid} = \Delta X_{system}$$

Or

$$\sum(1 - (\frac{T_0}{T_k}))Q_k - [w - P_0(V_2 - V_1)] - T_0 S_{gen} = X_2 - X_1$$

Rate form:

$$\sum(1 - (\frac{T_0}{T_k}))Q_k - \left[\dot{w} - P_0\frac{dV_{system}}{dt}\right] - T_0\dot{S}_{gen} = \frac{dX_{system}}{dt}$$

Now, it is time to solve the question how we understood it so we will ask 2-3 questions for this so that you can understand how to use the exergy balance whether you can extract exergy destruction or any other question interesting questions you can solve so in this example what is there is a steady heat transfer which is given by a brick in which 5 meter by 6 meter so 5 meter by 6 meter means you have 5 meter by 6 meter brick and the thickness 30 cm, so this is 5 m x 6 m brick and thickness is 30 cm given a day, means if any day the temperature is 0 degree outside and the temperature of the house is maintained at 27 degree so suppose this is the house, so it is basically a house inside it is maintained at 27 degree this wall is at 20 degree, outside wall Of course, the heat transfer is outside the wall. And the rate of heat transfer is 1035 Watt. So, this is the watt. Now, we have to calculate the rate of energy destruction in the wall and the rate of total energy destruction associated with the heat process. What is the exergy destruction in this valve and what is the total exergy destructions in this process? So, first of all, you can apply exergy balance. In exergy balance, X in minus X out is in the rate form, so dot is applied. And we know that this X is basically the rate which is through heat or work or mass. Because it only has heat, so only the inlet will come. Q dot 1 minus T0 by T in. T is zero surrounding and T is according to your system. Now, we have written two things in this. One is that this is the in and this is the out. The destructions are this. And since we are assuming the rate as steady, this part is zero. In this, you have to understand one thing. The first question is what is the extra destruction in the wall? So for this, first of all, we take a system that is your wall.

So, in the first question, X in wall you noticed that if the wall is a system, the surrounding of its inlet, the boundary T, this T is 20 degrees Celsius and this is 5 degree Celsius. This is T. And T0 is 273. because it is in environment condition so your xin which came out from here this is your xin q dot 1 minus t0 dot t in and this is your 1 minus t0 dot t out and this is minus x dot destroyed so now we are talking about the wall, which is in the wall Now, since the rate is steady state, so the rate of destruction will be 0. So, dx by dt is 0. In this, we should remember that t0 is 273. And what is t in? T in condition is 293. 273 plus 20. And what is t out condition? 278 is the

Kelvin. So, if we do this, the AC is 1035 W. So, X. will come out to be 52.0 W. So, this is your destruction. X dot destruction. This is what is happening in the wall. Rate of destruction is happening in the wall. Now, the second question is, if you talk about total destruction, The temperature difference between the wall and the wall is 20 degrees and 5 degrees. If we take the entire system like this, then what happens? If we take the entire system, then on one side the boundary from where the heat is, it becomes 27 degrees. Because the room temperature and the other side becomes zero. Now we have an extended system. If we take system plus additional immediate surrounding, then we have extended system. In which the temperature of your room is on the boundary. Similarly, your environment is also on the boundary. So, from here, you can apply from the extended system. This is the same as xin minus xout is equal to dx system by dt, which is 0. In this case, we will remove the total destruction x in which is minus x out minus x dot destruction this is zero and this is in dot, and this will be q dot 1 minus t0 by t in minus q dot 1 minus t0 by t out Now the question arises Now, minus X destruction. Now, this destruction is the total system. Wall plus immediate surrounding. Now, you have to see how to do this part. The main thing you have to understand is that this T, T0 will be 273. But this T, this is the boundary T. This T in the boundary tree will come to 300 K. Because it is 27 degrees Celsius. And this T, which is out, is 27. 273 Kelvin. This means that this part is zero. This means that X destruction will come out to be 93.2 watt. And in the difference between the two, the first case is connected to the wall, and in the second case, the total destruction is 41.2 watt difference, which tells us that the exergy is destroyed. the air between the two layers is destroyed. And if you want, you can do this with the entropy generated and you can show how this is connected to T0S generation. And you can show this term separately by generating entropy and you can extract X destruction from there. So, you can practice that too.

Now let's take another question which is related to piston cylinder device. In this case, you have state 1 which is 0.05 kg of steam, 1 MPa 300 degree Celsius. And steam expands to final state which is state 2. In this process, this heat loss goes towards the surrounding heat. which loses 2 kg of joules The surrounding temperature is 25 degrees Celsius and 100 kilopascal We have to find out the exergy of the steam in the initial and final state The exergy change of this system is related to the steam And the exergy destroyed is the second law efficiency of the process I will not solve this question in detail But I will write the steps so that you can understand how to solve it. Rest of the data is in your tables, if you plug it in, you will get the answer. Let's start it. So, the first thing is that you have to find out how much is the initial and final state of the exergy steam. So, let's start with the definition of exergy. But we will assume some things, like kinetic energy and potential energy, like So we will not consider the negative part of the system. Now the question is that you can remove the initial and final state of P1 and T1 from the table. If you remove it, you will see that table A6 is important and for dead state you have to see A4. V0 and S0 and U0, V0 and S0 we will approximate them U of F V of F and S of F at 25 degree Celsius From here you will get reference data of dead state Now you will get data of state 2 and table 1 from A6 Here you will get data of u1, v1, s1, u2, v2, s2 Now we have to get x from initial state u1 minus u0 minus t0 s1 minus s0 plus p0 v1 minus v0 so in this t0 is the surrounding p0 and rest u1, u0, s1, s0, v1, v0 we have already taken out these so you will get x1 from alarm because mass is also m which is 0.05 So this is 35.0 kJ Similarly, you can also extract X2 because you have everything This is also given to you And you also have other information So this is 25.4 kJ So in this process, from state 1 to state 2 You have to get delta X The change is delta X That is X2-X1 This is minus 9.6 kJ. This means that we have lost so much. We have lost so much of our XRG. If we were to reverse this process, then we would have done so much useful work with the amount of 9.6 kJ. So, this is an exergy change of the system. Now the second question is that you have to remove the total exergy destruction. In total accelerated destruction, you have to see that if you can capture the hit loss by any means, you will also get the mood. So, for this we have to do that when we talk about total, we have to capture the surrounding as well. The best way for that is to do extended system. Consider system plus emitted surrounding as an extended system. So that the boundary of the surrounding environment becomes the boundary of the environment. So there its temperature will be T0. So that no need to add any exergy transfer from the boundary of its immediate surrounding. So, because it will be exactly T0, exergy transfer will be 0. For this we have to take the extended system. So that we can say that this system and here is the initial P1T1 and this is T0 so we assume that this boundary is T0 so if we assume that this is Xin- delta X system X2 minus X1 because it will have additional work x out because you have taken the boundary so x out in general is zero because now no heat transfer is happening from the extended system boundary because work is happening here this work is there because the piston is moving so this work is minus x work out okay, it is happening on the surrounding this is zero, minus x destruction So this is x2 minus x1 So here x destruction is x1 minus x2 minus w which is the useful work that we are doing So this is the useful work, boundary work that will deliver like the system will expand Now to remove this you will have to do some exercise For this you will have to balance the energy So E in minus E out is equal to delta E system so minus WB out is equal to delta U and to get WB out minus delta U is equal to 2 kilo joules minus M and we can write delta U as M U2 minus U1 From here, the data will be 8.8 kJ But this work also includes the surrounding work So we have to remove that too And from there, W will come out WU out is W which we have just removed Minus W surrounding So this B out is your surroundings, we have already taken out the B out. So, B out is 1.8 kilojoules of watt surrounding. So, this WB out is minus P0MV2 minus V1, So to remove this, since there is air outside, so the air is the concept. This is your steam change, specific volume. And this mass is also your steam, this is 0.05 kg. This P0 is your atmospheric pressure, P0. So here you will multiply it. And after that you will subtract this 8.8, which comes out as 5.3 kJ. So, once you get this. So, you can extract xDestroyed which will be 4.3 Kilo Joules. You can extract this answer from S generation also. So, if you see here, xDestroyed is T0 S generation. And S generation is M S2 minus S1 plus the Q surrounding of heat transfer divided by T0. So, Q surrounding is 2 kJ and T0 is 298 K S2 and S1 are already taken out from the steam state 1 and state 2 T0 you know is 298 K When you plug in this value you will get exactly the same amount 4.3 kJ So you can also take it out like this, so this is a little simpler Isn't it? Now the last part is to extract eta2, the second law of efficiency of this process. For that, we had to use the general definition that exergy is recovered divided by exergy, which we have spent. Expanded. So, expanded is the same as delta x. And recovered is w. So, this is the 5.3 that we extracted. and delta x is 35 minus 25.4 so this is 0.552 which is 55.2% this means that 44.8% of the exergy is wasted in this process so you saw the answer to this question how we have done it systematically you can practice this and where you can use exergy, you can do it there You can also do this question with entropic generation. But this is a way to understand the process. So, in some places it is more important in exergy analysis. So, this is exergy.

So, let's do one more last question in this lecture. This is your insulated air tank in which this air is 1 kg. 140 kPa, initially 20 degrees Celsius and it is working. And its temperature is reversible in this process and the temperature goes from 20 degrees to some extent. So, you can easily solve this type of question that how much work you have to do to change the temperature. You can also solve this type of problem. So, you can do this simple exercise whether you are considering reversible work. So xin minus xout is equal to as destruction Since it is reversible, it will always be 0 So you can write w in reversible in is equal to x2 minus x1 Because here if it is insulated And reversible And the same is happening So xin is also w reversible in xout is your 0 And this is x2 minus x1 which is e2 minus e1 plus this Since this is a closed system So this volume is not changing So, we can write E2 in the internal energy. So, this is a simple change in internal energy minus T2, T0 change in entropy. So, you can easily remove this. If we take air in this condition, we take the ideal gas, then it will come out to 1 kJ. And the total change in internal energy is 20.6 kJ if the final temperature is 54 degrees Celsius in this experiment. You can understand this step by giving a reversible heat pump which has a Wnet 1 kJ Initially, the ambient temperature was 20 degrees Here, 19.6 kg Effectively, you increased the initial internal energy, and the final was 20.6 kJ Initially, it was 19.6 kJ, and the final internal energy was 20.6 kJ There are thought processes like this that can solve the problem. And you can use the concept of exergy to develop. But you can solve such problems in many ways. Not only with exergy, but if you have questions about exergy, then you can use it. So, I hope I was able to explain to you what the purpose of exergy is When we introduced exergy. and how you found the value of change in exergy from useful work and how it is connected with S generation and how decrease in exergy principle is connected with increase in entropy and we will keep this discussion going and in next lecture we will discuss about exergy balance and control volume in flow system till then, I am Fait So, goodbye and see you in the next lecture.