Engineering Thermodynamics
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Week-06
Lecture-31
Change in Entropy

Welcome to the entropy lecture. In this lecture, we will discuss the topic of entropy that we discussed in the previous lecture. Till now we have defined that entropy is a property. In this lecture, we will try to understand the change in entropy, how its relation is, and the temperature is precious. and we will learn about the relation of entropy. But let's start to understand what entropy is. We have told you that entropy is related to the inequality of entropy. But if you think about entropy carefully, we usually say that entropy is associated with disorder. And if you melt solid, then if you make a liquid, if you transfer heat from liquid, so it vaporized, vapor became. And we say that as we are transferring heat, its entropy increases. So, in gas, entropy will be more, in liquid it will be less and in solid it will be less. So, molecules move and the more your heat is, the faster molecules will move from here to there. And disorder will increase. It is not surprising that this intuition comes automatically to your mind that if something is flowing more than its entropy is more. Whether it is seen as a gas or whatever is moving more, its entropy is more. So, through this diagram, we have shown that entropy is less than solid and as it increases, the phase changes, meaning heat is being transferred or heat is being used to convert from one phase to another phase, and from liquid to gas, so entropy is increasing. But this is a disorder in this. It is not as organized as entropy, especially because molecules will move randomly from here. So, the more entropy there is, it does not mean that your energy is useful. Here, it is especially so that if you use any direction, if you apply energy, like molecules are moving from here, It does not affect the load or the work. Therefore, it is very important to have direction in the movement. It is very important to have direction in the molecules. It is very important to organize your energy if you want to make it useful, if you want to do the work. So, if it is random, like some people are pulling it like this, your load is not changing anywhere, it is not moving. No matter how much energy you put in, it doesn't mean that your work can be done. The directions of the molecules, whether they are energy, should be organized. And as the temperature decreases, the molecules' movements start to decrease. And in this way, we say that when the temperature is absolute zero, then the molecules don't move from anywhere. And the vibrations also get suppressed.

So, we assume that when the temperature is zero, then entropy is zero. So, this is the third law of thermodynamics. And in this particular condition, we assume entropy is zero. So, this is a reference condition. As I said, the movement of molecules matters a lot. If you take an isolated system, and in any thermodynamic condition, like it is isolated, and the number of particles is fixed, volume is fixed, initial temperature is fixed and isolated, then in this condition, an energy will come out, a final energy will come out, which will be of the system. But the molecules here inside will keep moving because you have temperature, so you have kinetic energy, so it will keep moving. So, in any instance, you will get many configurations and these configurations can be like this some particles are like this some are like this, and all conditions will be same, N, V, T, particle is fixed, volume is fixed, temperature will be fixed, and energy will be fixed, average energy. So, to maintain this energy, to maintain this temperature, molecules can be of various configurations. the number of configurations will increase. As we said, the entropy of the gas is high, so the temperature of the gas will be high, and it is moving too. So, it can attend many configurations. So, if the configuration is high, then the entropy will be high too. So, the relation of entropy is from a configuration. Sometimes we call it microstate. Like this one is microstate, this one is second. In this way, there can be many. Now, if you see, microstates can be very large. In the case of crystals, there is no microstate. Suppose there is only one in this case. Because the crystals cannot move. So, when there is one, we say entropy is zero. So, to say, this relation is in the logarithmic form. So, this is your zero. And omega keeps on increasing as your temperature keeps on increasing. So, it will be the highest in gas, it will be less in liquid and less in solid. So, this is one number of microstates, the configurations, the way you can arrange your particles, the molecules that you can place in the system, which is emitting your conditions like NVT. This concept comes out from your statistical thermodynamics. and here the relation S is proportionally constant k lnω this relation is called Boltzmann relation so in Boltzmann relation k is 1.380 x 10 to the power of minus 23 Joules per Kelvin.

Let's move forward with this discussion. Let's try to understand what the difference between organized and disorganized energy is. In this case, you see there is a rotating shaft. There will be molecules in this too. But since it is in form, if you rotate your movement, all these particles and whole shafts move in the same direction. Rotating shafts are used in an organized form because every molecule is rotating in the same direction. In this case, we can do useful work in an organized form. In this case, when we rotate the weight, it rises. And because of this, no disordered Ness is created. and if you believe that there is no fiction, then there is no disorder. So, in such a case, you can say that the work that you are doing, because you have done the work, this work is an organized form of energy, and it is free from disorder and entropy. So, the most important thing would be that the work that we have done, the work is an organized form of energy in which it is free of disorder and entropy. Means it is free from disorder and entropy. So, this is a very important thing. You can also say that when energy transfer is happening through work, like in this case, your potential energy is increasing in weight, then no entropy is being transferred. So, if energy is being transferred through work, then entropy is not being transferred in such cases. That is why you notice the Clausius inequality that we used and when we said that it will be internal reversible, then the change ds, we can say it is del Q by T. So here also you saw that it is connected to heat, not to work. So, there is no entropy association with work because it is an organized form of Now, take this one. There are different ways we have done it. We have done it in a different way. Here, there is a shaft. This is a paddle wheel. It is rotating here. Now, what are we doing? We have not lifted any additional weight in this. So, in this case, paddle wheel is the work. In this, we have to use this paddle. We are not increasing the height of the worker. We are increasing the temperature of the worker by converting the work into internal energy. Because when we rotate the worker, the temperature will increase. The previous model was that we are increasing the potential energy of the worker. We raised the weight properly with the organized form. So, this type of thing can generate electricity and weight. And in the second case, we converted the internal energy of this work. We converted the internal energy from this work. And in this case, the temperature increases. And when the temperature increases, the disordered energy increases. So here, the organized work, which is the shaft work, this is the organized work, it is converted into a disorganized form. In such cases, if your energy is converted into an ignorant form, and you want to get useful work out of it, then only a few portions can be extracted from it, as we have discussed earlier. And to get it out, you will have to use a heat engine. You can also say that the transfer of energy in this way, the quality of energy is degraded. Because your organized form was made into an intelligent form, it was degraded. Whereas in the other case, it was not like that. Potential energy was converted into potential energy. There are some thought processes and examples in this. You might have noticed them, but you might not have thought about them. So, pay attention to them.

Another thing is that entropy in general, as entropy increases, your quality also changes. The quantity of energy is conserved but the quality of energy is not conserved. And the quality decreases as entropy increases. So, it is very important that we need higher quality to do anything. So, let's pay attention to that. Now, as an example, we say that if the temperature is 80 degrees from the hot body, if you transfer some heat to the cold body, whether it is 10 kilojoules or not, So, the entropy of the hot body will also decrease because you transferred heat and the entropy of the cold body will increase but, who will increase the entropy? Cold body will increase because the total amount of entropy transferred the change that has happened is positive So, your entropy has increased at lower temperature this means the energy that has been transferred, 10 kJ, the quality of the energy that has been transferred, you have reduced it. If it was on the hot body, the same 10 kJ, then its quality would have been better, we could have used it more in work. Whereas in the cold body, the same 10 kJ energy, due to its entropy bandage, its quality has decreased, and because of that you cannot use it so much, you cannot make it a useful work. So, this is a very important thing. So, we have summarized it here. That heat that is transferred is a disorganized energy. And your work is organized energy. So, in heat transfer, your net entropy will increase. Entropy of the cold body will be more than entropy of the hot body. And the process that we have told here, in this process, the energy transferred of 10 kJ has been reduced. Because, effectively, its entropy will increase in the body.

Now, let's move forward with this discussion. And now, let's try to understand how to get rid of the tedious relation. So, to understand this,

$$dS = (\frac{\delta Q}{T})_{int,rev}$$

$$(\delta Q)_{int,rev} - (\delta W)_{int,rev,out} = dU$$

$$TdS = dU + PdV$$

$$h = u + PV$$

$$dh = du + PdV + VdP$$

$$TdS = dh - VdP$$

So basically,

$$ds = \frac{du}{T} + \frac{P\,dv}{T} = \frac{du}{T}$$

$$ds = \frac{du}{T} = \frac{CdT}{T}$$

Since C_p= C_v= c and $du = cdT$

Liquids, solids: $s_2 - s_1 = \int_1^2 C(T)\frac{dT}{T} \cong c_{avg}\ln\left(\frac{T_2}{T_1}\right)$

Isentropic: : $s_2 - s_1 = c_{avg}\ln\left(\frac{T_2}{T_1}\right) = 0$

If we assume that this is an isentropic process, then the isentropic process will become S constant, S2-S1 will become 0, in such cases T2 will become constant, means T will become constant. So, if we take the isentropic process, for incompressible substances like liquid and solid then your constant temperature will come out. So, now our interest in this course will be mostly related to gas when we are talking about entropy change and later, we can also take liquid, working fluid so tables are made for that. And tables are made for gas too. We will tell you about those tables A17 and the other two tables. Now, we can use it if it is already calculated. So, if we take gas, particularly, we take idle gas, then we can draw this relation. We can consider PV as equal to RT. In such a case, note that in gases, du is CvdT, dh is CpdT. We are talking about idle gas. Now, we draw the same relation that we drew two relations.

Here from the first Tds relation,

$$ds = \frac{du}{T} + \frac{P\,dv}{T}$$

$$ds = \frac{c_v dT}{T} + \frac{R\,dv}{V}$$

$$s_2 - s_1 = \int_1^2 \frac{c_v(T)\,dT}{T} + Rln\left(\frac{V_2}{V_1}\right)$$

$$s_2 - s_1 = c_{v,avg}\ln\left(\frac{T_2}{T_1}\right) + Rln\left(\frac{V_2}{V_1}\right)$$

From the second TdS relation

$$ds = \frac{dh}{T} + \frac{V\,dp}{T}$$

$$dh = c_p dT \ and \ V = \frac{RT}{P}$$

$$s_2 - s_1 = \int_1^2 \frac{c_p(T)\, dT}{T} - Rln(\frac{P_2}{P_1})$$

$$s_2 - s_1 = c_{p,avg} \ln\left(\frac{T_2}{T_1}\right) - Rln(\frac{P_2}{P_1})$$

Now we can approximate this also. If we approximate this, then let's say that this is an average temperature. Let's say that Cv is a constant, but average between temperature T1 and T2 or state point between T1 and T2 then this comes out. So similarly, we can take this also like this. In this case, the average is Cv and Cp. This is a proximate analysis. It becomes easy in such cases. But we can check later how much difference it makes. If the temperature difference is less, then there is no difference. When it is more, then there will be a little difference. And pay attention to its unit too. It is kilojoules per kg per Kelvin. As I said, if we go from state point 1 to state point 2, where temperature is T1 and T2, then we take the middle average as T, and the corresponding Cp average. So, this is your approximate. And you integrate this part on Cp. Now, in this and in this, there will be a slight difference, let's see it through the example. But if there is a very small temperature difference, then there is very little difference between T1 and T2. So, you can easily approximate it. No problem. Now, you can also call this expression as per mole because we have written kg. You can also call it per mole. So, we have added this bar which is similar to the test book. And your R has also changed. It has become the U, universal gas constant. Now, we can do another approximate analysis. If we temperature 0 is used by reference so in S2-S1, S1 is 0 and temperature T1 is 0 so this is CpT by Tr so this relation, specifically relation which we will call S0 we defined S0 0 to T, this term second term we have not done So this term is specifically referred to as reference. That you are only changing the temperature, the zero city is more, and we have called it S0. So, let's assume this by definition. So, if you assume this by definition, then you can call this particular relation, which has 1 to 2, where the reference temperature is given, as S2-S1. Because every point will be in reference to 0 Kelvin. And the same data is given on your A17 table which is on S0. So, here S0 means reference is on 0 K So this is absolute entropy And the benefit of this is that you can directly remove it from the gas If there is any difference, then here For example, if you want to remove the entropy difference Then you can directly remove the difference between 310 and 320. So in a way, this has made the work a little easier The benefit of this is that you can write the first term in the form of S2-S1. The second term will remain the same, which is telling you the pressure difference. It is telling you the contribution of pressure variation. And this is your unit mass. If you want to write it in moles, it comes out and your gas constantly changes. So, in a way, they are using the table to find the expressions to find the entropy differences, to find the change in entropy. And note that we are talking about the ideal gas. This whole expression depends on the ideal gas. and the second thing is that S0 is only noted at the temperature. It depends on the temperature. Now, as an example, we take the S-entropic process, which we had done before, when we used solid or liquid. So, as we said that the process is isentropic and incompressible, the temperature should be constant.

Now, let's consider the same thing on the idle gas. If there is an isentropic process, then what condition will come out? So, for the isentropic process, we again took this expression as an example. We have considered only this expression. And here, if we make it equal, because it is isentropic, S2-S1 is zero. So, this is the result. Now you rearrange this, so V1 by V2, R by C1 will come. R by Cv will come. You know that in ideal gas, Cp is equal to Cv plus R. So, Cp minus Cv is equal to R. So, this is what I have written here. And K is the ratio, Cp by Cv. So, it is written here. Now we have to use this. We will do its rearrangement. Note that R by Cv is equal to k-1. So, T2 by T1 is equal to V1 by V2 k-1. So, this is the result. Now, this is the ideal gas, so you can rearrange this. Because I know that PV is equal to RT, which is the same gas that we take. So, P1V1 is equal to RT1, now P2V2 is equal to RT2. Now, if you divide this, then you can get many relations. P1V1, P2, V1V2 is equal to T1. You can also change the relationship between V1 and V2. Similarly, you can change V1 and V2. So, the same expression has been used. If you change V1 and V2, you can show that this relationship can be written as well.

So, this is the specific relation that will be obtained. Similarly, you can show that this is the complete relation that will be obtained. This part and this part will be obtained. Effectively, we can show that T2 by T1 is this and P2 by P1 is this relation. So, if we summarize this particular relation, then we get this step. P1 power k1-1 divided by k and this is the same thing that comes out in v1 by v2 power k-1 so these are the relations ok so I have not derived it properly you can do it yourself so this relation is valid for ideal gas and for the isentropic process and heat capacity is considered constant that is why this is considered constant so these are the three conditions Simplifying this, we can see that the isentropic process in the ideal gas, when entropy is constant and constant heat capacity is considered, then we can consider that Tv to the power k-1 is constant or this is constant. All are of the same relation. Or Pv to the power k is constant. So, the relation of all three tells you that this is S constant, and C is constant, constant heat capacity. So, these three relations are there which you can use in any process. So, if you have been given the process that this is the ideal gas, its isentropic process, the pressure and volume are given from here, and finally, if the second condition is given, then you can calculate the rest of the unknown variables which you have not calculated, you can take it out from this process, if K is given. Or You know the relation of Cp by Cv, as you know in many gases. You can use the table also. So, these expressions are very valuable expressions. And it is very useful for calculating idle gas.

Now before closing this lecture, let's take an example. In this case, we have compressed air in the initial state of 100 kPa at 17 degrees, now we have to find the property value from air table in the air compression and the average specific heat. If the property is table, then we can directly take S2-S1-R ln P2 by P1. Because we have given pressure, we have taken P2 by P1. The conditions are given on the temperature, so you can directly take it out of A17. The second one tells us that it is an average specific. So, we have taken CP average, ln T2 by T1. So, this will be T1 plus T2 by 2, which will come out to 37 degrees Celsius. We will take it on this. So, if you see this S2 minus S1, you will get this from A17. So, when you calculate, you will get data from this step. As we said before, this step is your data. This is the value minus 0.3844 kilo joules per kg kelvin and this CP average we will take from table A to B Cp average of air specifically air and when we insert T2 and T1 and P2 and P1 So this value is minus 0.3842 kJ per kg. So, in this case, we used table A17.

As an example, I will show you that you will get this type of table at the end of the book. We took out S10 and S12 from here. So, we took out this. We used R from here. And of course, the pressure is 600 kPa divided by 100 kPa. So, we took out this from here. In the second case, we had to take out the average specific heat. So, we took out Cp at 37 degrees Celsius. And we did the same process of ln, T2 and T1. And we got this at minus 3. 3842 kilo joules per kgK. It is very close if given carefully. And the reason for this is that your temperature is very close. So, you can use the table when the temperature is close, or you can use the average heat capacity. So, this was an example of how to understand entropy. And we used statistical thermodynamics to understand the Boltzmann expression. Then we understood about the isentropic process. and how to treat the ideal gas coke and how to treat the relations of the gas and the property relations PV is equal to constant These three relations are very valuable, and you will understand them by using examples I hope you understood this lecture and we will meet again in the next lecture where we will talk about reversible steady flow relation till then, bye