Engineering Thermodynamics
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Week-03
Lecture-16
Energy Analysis of Closed System

Welcome to the energy analysis of closed system in Bhagcha. In this lecture, we will discuss specific heat and how to connect specific heat with energy and what is its relation. Particularly, we will discuss the ideal gas. There is common knowledge that if you take water and iron, it is metal. If you want to change the temperature of these two, then it requires different energy. You can understand it in such a way that if you turn on the stove, and take 1 kg iron and 1 kg water, and turn on the stove for 5 minutes, then the water will not be as hot as your iron. Iron needs less energy to change 1 degree and water needs more energy. You can understand it in another way.

If you take 1 kg iron and change it in 20-30 degrees, you need 4.5 kJ. If you take 1 kg of water and change it in 20-30 degrees, you need 41.8 kJ. Approximately 9 times more. So, water has more capacity to store energy. You can understand this from the difference between both. So, if we generalize this, that any mass, any mass is 1 kg and if we are changing its temperature, we are changing the temperature to 1 degree Celsius. and it takes 5 kg of juice, so its specific heat is 5 kg of juice per 1 kg per degree Celsius. Now, we can call it degree Celsius or Kelvin because it is a change in temperature. If the change is in temperature, then there is no difference between degree and Kelvin. So, the definition of this specific heat is that the amount of energy required to change a unit mass by 1 degree is called specific heat. This specific heat depends on the process. That's why we use two types of specific heat. Specific heat at constant volume. In which the unit mass required to raise the temperature is 1 degree, but the volume is maintained. In the second case, we call it constant pressure. specific heat kind. Specific heat in constant pressure will always be more for constant volume. Because if there is constant pressure, the volume can change. When you are applying heat, the volume will change to maintain pressure and expand. And that's why your energy is extra, which you need for expansion. That's why Cv is more than Cp. We will try to understand it from this method of helium gas. If we take 1 kg of helium gas and keep the volume constant, then if we want to change delta T to 1 degree, then we need this much energy, 3.12 kJ. That is why Cv has 3.12 kJ per kg, degree Celsius. If you keep the pressure constant, then its value will be more, 5.19. Because it will also have to expand to make the pressure constant. So, this is an example that Cp is greater than Cv and it has a relation to the ideal gas which will come out as Cp. We will talk about that later. This is for ideal gas. Let's move forward with this discussion. Now, if we take a fixed mass in a stationary closed system, which is in constant volume where the boundary is not working, then we can write the energy balance in this way. Because your dE in minus dE out, this is in differential form, delta in delta out is equal to d of e this is differential form here it will come delta because it is path dependent and here comes absolute which is state property and e is because it is not involved in mass, it is stationary it means delta ke delta pe is zero That's why we can write E only in U and that's why it becomes dU. So, if you want to write per unit mass, then this is your E. Per, something small happens. So, this is delta E in minus delta E out is equal to dU. if you pay attention to this left-hand side, then what is this? We always call it Net Energy Transfer. Degree temperature. So net energy transfer per degree temperature is called CV. So, CV definition, yes, because it is a constant volume, so I am taking CV. This tells you that this energy changes or transfers. means how much energy is required per delta t per unit mass that's what we are saying if you see per unit mass so if this is total net energy transfer, We can write it as Cv, which is per unit mass. Per unit mass is U. We will add delta T and multiply it. Because per unit is delta T. If we multiply it with delta T, we get energy transfer per unit mass. This is your left-hand side. We can write it as dU. So, we have equated the system's energy change with Cv delta t. Now this is what I have written here as well. Cv delta t. And since this is in differential form, we will call it Cvdt. So, this is your Cvdt is equal to du. So, delta is absolute, so we will call it dT in small differential form. We can also write it as Cv is nothing but partial derivative U or with respect to T, you can derive it as V constant. You can also derive Cp in this way. The constant process, expansion and compression process, we defined, you will remember, in which we took Qe minus W other is equal to delta H, we adopted that process, Qe constant pressure process, and by adopting that process, we can write the expression of ACP by doing the equation. Okay, so... This is a summary of the equation. If Cv is equal to partial derivative, this is called partial derivative. This is partial derivative d by d dv. There are other properties, which we are keeping constant. So, v is constant, and p is constant. This is a change in internal energy with this is change in Cv. Change in internal energy. with temperature at constant volume. Cp is changed in enthalpy with temperature at constant pressure. So, this is your definition. It is very applicable, you can apply it everywhere, on any substance, under any process. Because this specific heat is partial derivative on other properties like internal energy, enthalpy, state properties. So, this means that this specific heat will also be state property. And since it is state property and this is also a property, then it depends on your independent intensive property like temperature and pressure. Isn't it? Since this is your partial derivative of a state property, if it is a property, then it will depend on your intensive property like temperature and pressure. Like U depends on you. temperature, pressure, temperature volume or pressure volume. Similarly, it will do two independent intensive processes because it is talking about some substance. So, what does this mean? This means that the energy required to change 1 degree will also depend on different temperature and pressure. This means that if you take air and take 1 kg, and you want to change it from 300 to 301 Kelvin, then it needs this much energy. But the same thing, which is to be done from 1000 to 1001 Kelvin, then it needs more energy. See, so it depends on temperature, it depends on the same pressure. So Cv is related to the change in internal energy and Cp is related to enthalpy. This is the common unit, but we can also call it Kv instead of C. So, the common unit, which I said, the specific heat can be kilojoules per kg degree Celsius or Kelvin can also be used because this is the change in the temperature in the denominator. changing temperature of the cells with it and the calving with it. So, this unit is identical. As I said, the answer is yes.

Now let's discuss ideal gas. Joule had done an interesting experiment a long time ago. In which he filled a tank with water. This one is in a big tank. And inside it, I connected two small tanks with the valve I kept the air pressure on high This is high pressure, and this is vacuum Now this system is brought in equilibrium and then this wall was opened so it expanded the initial pressure was too high, the final pressure was less than the initial pressure and the volume increased too. So, the volume increased more than the initial pressure. So, the volume increased, the pressure increased, and they saw that there was no change in the temperature. There is no change in the temperature here. This is an assumption. But since there is no change in the temperature, there is no heat exchange here. There is some exchange between water and air. If your energy balance is not taken out, then Q-W is equal to delta U. We are assuming stationery. So, Q is also not there. And since your work, your boundary work is not there, it is expansion within the system. If we assume the system is like this. So, this is also zero, this means delta u is also zero. So, delta u is zero, but its final pressure and volume are different from initial. So, the pressure and volume have changed. So, delta u is still zero. So, this was assumed, this particular experiment was also understood that when we take an ideal gas system, I considered this as an ideal gas, so change in u is on pressure and is not dependent on volume, it is only dependent on temperature. Because the temperature has not changed, that is why it is called dependent on temperature T.

$$h = u + pv$$

$$pv = R\mathrm{T}$$

$$h = u + R\mathrm{T}$$

$$\mathrm{h{=}h(T)}$$

$$C_v = (\frac{\partial u}{\partial T})_v$$

$$C_v(T) = \frac{\partial u(T)}{\partial T}$$

$$du = C_v(T)dT$$

$$\Delta u = u_2 - u_1 = \int_1^2 C_v(T)dT$$

$$\Delta h = h_2 - h_1 = \int_1^2 C_p(T)dT$$

So, the question is that if you want to get the change in internal energy, then the relation of Cp should come out at a certain temperature. Somewhere in some form or the other. So, if you want to get the delta U between two states, then you should know this relation. The function of Cp should be known at a certain temperature. And this is an important thing that we will try to solve in three ways. measure and take out at this temperature and plot it like normally at low pressure the real gas approaches the behavior of the ideal gas means it starts behaving like that and we see this thing that if we plot it at very low pressure which we call as zero pressure specific heat or ideal gas specific heat In this case, your data is kilo joules per kilo mole per Kelvin. That's why we have CP bar. Normally if kilo joules Normally if kilo joules were kg, then it would be in Cp. So, Cp bar P0 means ideal gas specific at zero pressure or at very low pressure or as a function of temperature. As I said, all real gas behaves on ideal gas, so it only behaves on temperature, but this behavior varies. Different gases behave differently. Your noble glasses behave like this, they are constant. Look carefully. hydrogen, oxygen, air, etc. So, this is a little bit of a polynomial or quadratic behavior. So, on the third-degree polynomial, we normally fit all these data. So, one way is that you experiment and then you fit it. And we made a table. And we write the table in this form, A2. So, this is the idle gas specific heat for all the common gases.

Now you have the data, you can use it to get the cp delta t and delta u or delta h. Here cp delta t or integral of cp, you can get the delta h from dt. You can also get the u from there. For u, you need cv. You can get the relation of cv and cp in the idles class case. This is related to RC, gas constant. So, the use of this data, which has the coefficients of polynomial of 3rd degree, is its range and its error is also there, but the range is important. Usually it is from 0 degrees, because it is a reference of 0 degrees, to 1800 Kelvin. And this data, because it is on low pressure, and use it at moderately high pressure till it deviates from the ideal gas behavior One way is to use this CP data from the table. Sometimes integration takes a lot of time. In this case, you can use this table directly. Where it is already integrated and your value is given, your enthalpy is given at any temperature, your internal energy is given, this is specific internal energy, specific enthalpy. This is a reference of the integrated value. And this reference is 0 Kelvin. So the second method is to take the table directly and take the value from there. The third method is that the temperature difference is very small in the process. In such a case, we multiply delta U by cv average by delta T. Whose Cv average? Suppose this is the process in which T1 goes to T2 or T2 goes to T1. So, in this case, we take out the corresponding Cp average of T average and use it in this case. So here is an example in the case of pressure. So here Cp average is taken out at T average, and this is multiplied by T2-T1. Here Cp average is taken from T average and multiplied by T2-T1 and here H2-H1 is taken So sometimes we take delta H or delta U at small temperature intervals as an average You take the final temperature average and take out Cp or Cv and multiply it by delta T But one thing is very important to understand that if your process The pressure constant is not the same as delta u cv delta t because delta u cv delta t is a universal statement You can apply it to any process Unless you know Cv.

So now let's summarize what we have read in the assumption You have to use specific enthalpy which is the energy required which is used to change 1 degree of any substance in a unit mass. It depends on the process, whether it is constant pressure or volume. Accordingly, Cv or Cp is used. What are the options you have? You have tabular data in the table form which has already been given energy in the form of U and H. You can use it, or you can use Cv or Cp relation or you can choose the average in the case where the temperature difference is very less. So, these are the three options that you can choose according to the problem. So, I hope you understood the concept of specific heat and how to use it. That's all for today, we will meet in the next lecture on new topics.