Engineering Thermodynamics
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Week-11
Lecture-51
Thermodynamic Property Relation

Namaskar! Welcome to the Thermodynamic Property Relation part 5. In this lecture, we will learn about Jules Thomsen coefficient and its application. We will understand the process of real gas without any detailed example. We will try to understand it as exposure. Let's start with Jules Thomson coefficient. If you remember that we discussed refrigerator condition. So, we used throttling valve somewhere. So, when we used throttling valve in refrigerator, its purpose was to reduce the temperature. So, if you consider that a plug or capillary tube or ordinary valve flows from temperature T1 and P1, then there is some hindrance here or there is a porous filter, or Restrictions were there. There is a kind of a barrier in the flow. In such cases, the pressure drops. And as we have used the refrigerator and air conditioner, the temperature also drops. In general, the fluid cools down. But this is not necessary. In this lecture, we will see that the temperature can increase and can remain constant. To understand the behavior of temperature in this process, we will define a parameter, a property, a coefficient, which is a mu, del T by del P at constant H. This is not a property of the fluid, because we get a process here. So, we will understand this more through coefficient. This depends more on the process. So, to say that this is a property would be wrong. This is a coefficient which is defined for any process in the behavior of the process fluid. And you can understand that if you are doing it in any process, then after a moment It is possible that the temperature can change. So now you will understand how this coefficient explains this. So, this coefficient is defined as Joules-Thomson coefficient mu, which is dou T by dou P. Dou T by dou P means partial derivative temperature with respect to pressure. What is the constant? H is constant. So, it means that if you plot temperature versus pressure, if you take the constant process of H, then you have to remove the slope. This is what it means.

Let's understand further. If we look at it further, suppose this is the process in which we have initially fixed P1 and T1. And if we are taking an exit in different conditions, then if you start a fixed P1 and T1 page, where its enthalpy will be constant, because P1 and T1 are fixed, so this enthalpy will also be constant. and this is your porous plug. If you change the size of the plug, then your exit condition will change. But if it operates on constant H, if this is your capillary tube, plug 4, porous plug, system, then if you measure P2, T2, you are experimenting on different conditions, suppose. Suppose you are experimenting, you have fixed P1 and T1, H, and you are only changing the size of the porous plug. So, when the exit condition comes out, P2 and T2 will change. So, if you start from here, from this condition, P1 and T1, then this is the fixed condition. But when it is exiting outside, then it is using different experiments, in which the porous plugs are using different materials. And this has come out in different conditions. But this Line is H is equal to constant line because it is fixed. If you change P1 and T1, then this line can be changed. This can be a different line. So, this line you see is your enthalpy constant line. And notice that the condition can be such that on one side we are changing, on the other side the process is done. So, it is coming from right to left. So, it is coming from high pressure to low pressure. Notice here that the temperature increases this way and decreases this way. And this is the maximum value where your slope is changing. If we talk about this mu , then this slope is what will come? This slope is less than zero. And this slope from this point to the left from the maximum point is your Jt. greater than zero and here what will happen? Jt will be equal to zero. So, there are three options, or three possibilities exist in this. That mu jt can be less than zero. If it is less than zero, then the temperature increases here. If it is equal to zero, then the temperature is constant in this process. If it is greater than zero, which is on this side, means in the process, if it is on this side, if it is on this side, then the temperature is decreasing here.

As we said, Jules-Thomson coefficient is a coefficient that measures the temperature change when you change the pressure in the constant enthalpy process. So, this is an example of a constant enthalpy process. If the sign is different, then the temperature change will also be different. The temperature increases in less than zero sign, and in greater than zero sign, the temperature. This is the cooling process. We will want to take the process condition in the refrigeration system or air conditioner. This is the process condition. This is the heating. Here the temperature increases. As I said, if you repeat this from different initial conditions. different conditions, different lines will come out. Different constant enthalpy lines will come out. And in such a case, in general, your maximum is coming here. This is the maximum in this line. This is the maximum. But it is not necessary that you get the maximum in every line. So, if you add this, this maximum, then this is the maximum temperature where this slope is 0. This line is called the inversion line. This is the maximum inversion temperature. This is called the line that passes through these points. This is called the line point. mu Jt is zero so if we add this point to mu Jt then the line that you are generating is called inversion line. so this is important to understand and this line that intersects this point is called maximum inversion temperature ok so what is this line? this is P equal to zero line maximum in present temperature and this temperature which is you The cross that intersects the constant H line is H is equal to constant and this is the inversion line The constant that intersects this line is called inversion temperature So this is all inversion temperature Let's talk about it again. This is your inversion line which is made by combining all the points of mu Jt equal to zero. And this maximum point on which mu Jt is zero is called the inversion temperature. And this line intersects with P equal to zero, so this is called the maximum inversion temperature.

Now let's discuss a little bit on this. If you see here, it divides the graph into two parts. This part in the right part of the line is mu Jt less than zero. Because the process is happening from the right-hand side, from the left-hand side, so if the process exists in this part, then in the throttling process, the temperature here is because this is the process, so the temperature is increasing. And in this part, the temperature will decrease. this also makes it clear that if you want to cool, then the temperature of the process should be below this, from the maximum inversion temperature, because then your mu JT will come out greater than zero. But if this temperature is below room temperature, then it will be very difficult to process. you will have to install additional systems like if you have inversion temperature like in the case of hydrogen it is minus 68 degrees Celsius then to do that throttling process will be very difficult so in general it is also important that this application is very efficient when its maximum inversion temperature is above room temperature then throttling with the help of walls can cool the fluid. So, this is a general description of Joule-

Thomson coefficient. Now, let's try to understand it mathematically. So, mathematically, we will use this expression for Joule-Thomson coefficient which we derived earlier.

$$dh = C_p dT + \left[V - T\left(\frac{\partial V}{\partial T}\right)_P\right] dP$$

For an h= constant process we have dh=0. Then this equation rerarrange to give

$$-\left(\frac{1}{C_p}\right)\left[v - T\left(\frac{\partial V}{\partial T}\right)_P\right] = \left(\frac{\partial T}{\partial P}\right)_h = \mu_{jt}$$

$$\mu_{jt} = -\left(\frac{1}{C_p}\right)\left[v - T\left(\frac{\partial V}{\partial T}\right)_P\right] = \left(\frac{\partial T}{\partial P}\right)_h$$

$$PV = RT \rightarrow V = \frac{RT}{P} \rightarrow (\frac{\partial V}{\partial T})_P = \frac{R}{P}$$

$$\mu_{jt} = -\left(\frac{1}{C_p}\right)[V - \frac{TR}{P}]$$

$$\mu_{jt} = -\left(\frac{1}{C_p}\right)[V - V] = 0$$

That is, in the process, mu JT will remain zero. So, if you are processing, suppose, temperature and pressure, from P1 to P2, like this, then this will always be constant. Why? Because your mu JT is zero, the slope is always constant. If enthalpy is constant in the ideal gas, because enthalpy is a function of temperature, if enthalpy is constant, it means T is constant. So, you can also think of this as well, if h is equal to hT, if h is constant, then T is constant, and T is constant, then del T by del P will be zero. So, if we want to plot like this, then this plot is between p1 and p2. This is how the plot will come out. There is no curve in this. There is a simple flat line. Now let's talk about real gas. If we want to make changes in enthalpy, entropy and internal energies, then how will we make changes? So far, we have said that we will do it at zero pressure. As we believe in the ideal gas, we can easily make changes. But in the real process, the temperature is at zero. It will not work on very low pressure, in general the pressure will be high or moderate. So, if you want to get delta H or delta U or delta S, then how to get it? Let's understand this by using the example of delta H. This is the temperature versus entropy plot. And if the temperature is going from T1 to T2 in general and the pressure is going from P1 to P2, then the actual process is supposed to be from 1 to T2. This line is the initial point, and this is the final point. So, this is the point where temperature is T2, and pressure is P2. And here the temperature is T1, and pressure is P1. So, this is the actual process. And if you see this, the expression that we had taken out earlier, we had taken out the expression of delta H, so this was the expression. Approximation data and basic definitions were used. Now, if we take out the same expression, how can we do it? Because for T1 and T2, and P1 and P2, you need Cp for all these things, you need information del V by del t, and for del V by del t, you need PVT diagram, or PVT data, or you need equation of state.

$$h_2 - h_1 = \int_{T_1}^{T_2} C_P dT + \int_{P_1}^{P_2} [V - T\left(\frac{\partial V}{\partial T}\right)_P] dP$$

$$h_2 - h_1 = (h_2 - {h_2}^*) + ({h_2}^* - {h_1}^*) + ({h_1}^* - h_1)$$

$$h_2 - {h_2}^* = 0 + \int_{{P_2}^*}^{P_2} \left[V - T\left(\frac{\partial V}{\partial T}\right)_P\right]_{T=T_2} dP = \int_{P_0}^{P_2} \left[V - T\left(\frac{\partial V}{\partial T}\right)_P\right]_{T=T_2} dP$$

$${h_2}^* - {h_1}^* = \int_{T_1}^{T_2} C_P dT + 0 = \int_{T_1}^{T_2} C_{P0}(T) dT$$

$${h_1}^* - h_1 = 0 + \int_{P_1}^{{P_1}^*} \left[V - T\left(\frac{\partial V}{\partial T}\right)_P\right]_{T=T_2} dP = -\int_{P_0}^{P_1} \left[V - T\left(\frac{\partial V}{\partial T}\right)_P\right]_{T=T_2} dP$$

$$(h^* - h)_T = -RT^2 \int_0^P (\frac{\partial Z}{\partial T})_P \frac{dP}{P}$$

You can also say that because H is the state point and state property, state property will not depend on its path. The delta H is at the final two points. You can use this property or this information. How? You should not go from 1 to 2 like this, first you bring this fluid directly to 0 pressure so this is your first difference so this is your first difference after that you go to 0 pressure, i.e. the ideal gas and from here you go to 2, to 2' and after that you go back to 2 from 2' or 2' to 2 so we approximated this process it is not approximate, it is exact you had to go 1-2 so we called this process first 1 to 1' after that 1 star to 2 stars and after that 2 star to 2 stars So the delta H that comes out here is the same delta H that comes out here that is, we get the delta H of all individuals because this is state property Now you can use this expression of every delta H that I have done here How? For example, if you have S2 We have to find out h2 minus h2' because h2' is at p0 equal to 0. In this case, we will take cp as cp0. So initially, if you see, this process is constant temperature. This is your constant pressure, and this is your constant temperature. So, what are we doing? We have divided h2 minus h1 into three parts. We always call these terms in the form of enthalpy departure. So, there will be three types of sums. H2 minus H2' is this one, which is here. H2 minus H2' star. And this way, H2 star minus H1 star is this part. If we call it 1, 2, 3. So this is 3, this is 2, this is 1. So, let's look at 3. S2 minus S2'. This is the constant temperature. So, the first term is this term. This is 0. The second term is P2 star. From P2 to P2. P2 star. From P2 to P2. Now what is P2 star? It is P0. Because it is at constant pressure, it is on the P0 line. So P2 is 0. So, V-T is this. Del V by del T P. So, this is P0. Here you can see V minus T, V by del T at P and temperature constant. Here the temperature is fixed. So, what is the temperature fixed? The temperature will be T2 because it is running at fixed temperature. So, we will use T2 here. Similarly, H2 minus H1 will be. Because it is at constant pressure, the second term will be zero. Only this will be the first term. T1 minus T2, CpU. And we will use CpU, Cp0, which means low pressure. What will be the first word term? First term is again at constant temperature but the temperature is fixed at T1 so first term is 0 and second term is T equal to T1 and it is at P1 star from P1 because here it is P1 and from here you are going to P star which is P0 so as I have written here P0 is P1 and notice that in this P1 to P1 star, if you want to write P0 to P, you have to use negative sign here. So here negative sign came, P0 to P1, and this expression came. So, you can use these expressions like this. Now it depends on where you have this data from, because you will get this information more or less. This information, for this, this information, which has a different temperature. Pressure is also changing. For this you need data. You need PVT data. If you don't have PVT data, then you will have to use Compressibility graph or equation of state where you can use Compressor factor. Like if PV is equal to ZRT Or you can use it as a graph to calculate the temperature. This process is very tedious, but it is the real way to find real gases. So, it is very important to find this. And for this you need... You can write this expression in this form as well. We can write this as well. If you replace this with del V by del T, then this expression will come out from here. So eventually you have to use H star minus H in the form of Z compressible factor. And this is a separate exercise for this. In the next video, we will discuss more about the higher level of thermodynamics, particularly in chemical engineering thermodynamics. But I thought that it should be exposed in a way that you have to consider the real gases through the question of state, data or chart. And its exercise is a little more extensive, so we will not study it in this particular focus. I hope you understood the Joule-Samson coefficient in this lecture which tells about temperature, whether it will increase or decrease in throttling process and how it is used and what is its practical meaning In this entire lecture series, in which the thermodynamic property is in relation we saw the methods of how to relate the properties to PVT data and CpCB Especially your free energies Whether it is Enthalpy, internal energy, or Helmholtz free energy We understood about this We understood how it is derived first And its special purpose is that you cannot directly extract these free energies in the experiment And that is why we used change in free energy in the form of partial derivative After that we used Maxwell relation We also found out how to replace entropy or partial derivative in PVT data. Then we understood the Clapeyron equation and how to remove enthalpy vaporization from PVT data measurement. And we understood the Clapeyron equation which is used especially for liquid vapor and solid vapor. Then we found out about general relations. using Cp, Cv, D, Deltah, U, Deltah S or how to develop relations and what are the relations It is a little more mathematical but we understood how it was derived and you can refer it as a reference expression and finally we understood that In real gas, we have to use Departure Functions as we have used in this lecture and for that you will need Compressibility Chart or Factor and you will have to go deeper in all that which we have said that this is outside the scope we will not read so much about it in this course but you will get to read all this in the next course So that's all for today's lecture See you in the next video. Till then, I will take your leave. Bye-bye