

Engineering Thermodynamics
Dr. Jayant Kumar Singh
Department of Chemical Engineering
Indian Institute of Technology Kanpur

Week-02
Lecture-11
Properties

Hello and welcome to this lecture. We were studying about properties. In the last lecture, we introduced tables. We saw only two specific tables. One is of water, pure substance, and the other is of refrigerant. R134A. There are many types of tables. What we have read so far is only a saturated liquid vapor mixture. There are two types of tables in this. In one, the pressure is fixed. So, your table is under pressure. And in which the temperature is fixed, and the rest of the things are changed according to it. So, it is under temperature. We have used two types of tables for water. Similarly, we will use two types of tables for refrigerant. We have used some examples of how to use this table. We studied it in the last lecture. We will move forward with this lesson. Let's try to study it further. There are two parts to this lecture. After that, we will also discuss superheated vapor and compressed liquid. We will also discuss how to use these examples and tables in examples. We are still discussing this on objective no. 4, and we are trying to understand this more in the form of examples. So, let's start here. Assume that you are in a tank of 200 gm of saturated liquid water which is completely vaporized in this process which is at a constant pressure of 100 kPa 200 gm saturated liquid water completely vaporized 200-gram Saturated liquid water completely vaporized at 100 kilopascals. And what we have to extract is volume change. How much volume change happened when this whole process was completed? Which is saturated vapor made from saturated liquid water. How much volume change happened in that? Second, how much amount of energy was transferred from the liquid to the vapor in this process? So, the first part, volume change, so we can understand it diagrammatically that this is your pressure versus volume curve property diagram, and this is at 100 kilopascal Initially, the system you consider it as a closed system But as the volume increases, you can understand it through the piston cylinder. Initially, there is a saturated liquid in your cylinder, 100 kPa. Means at this point. This is your initial state. Consider that it is heated. In this process, the pressure is 100 kPa. And the temperature is fixed at this pressure. Because it will be a saturated temperature. In this process, it will come into the vapor form. Which will be completely vaporized. So, what will the volume change? V_g minus V_f , this is your total specific quantum change. And ΔV , what will happen? The mass, if we multiply it with ΔV , or you can call it Vfg , so this is your total change in volume. Now to get this information, you have to use the table with the pressure table.

So, this is your A5. A4 is your temperature, saturated water temperature table. In which the first column will be the temperature. In this case, this is the pressure table, so the first column is the pressure. So, 100 kilopascal Comes here and in this case your saturation pressure is 99.61 degree Celsius This is the specific volume of the vapor and liquid. And we also have internal energy

available. So, our first question is volume change. So, we have to get V_{fg} . So, we can easily take this. This is your V_g . V_g minus this term. So, your V_{fg} will come. So, 1.6941 minus V_f is your V_{fg} . and multiply it So your total volume is... The second question is the total change in volume. When we multiply it with mass, the total change in volume is there. The second question is the amount of energy transferred to the water. Since this is a closed system, the flow network is not connected to it. So, we will not use enthalpy. We will basically use internal energy. So, what is the change in energy? In this, your delta the amount of energy transferred in this you have this is your closed system but, in this boundary, work is also connected together So, the total energy of this will be Intel Energy plus $P \Delta V$ which means you will have to use Enthalpy to change. So, initially for this state, H_f is there and here H_g is there. So, the amount of energy transferred will be only H_g minus H_f and then you have to multiply it by mass as you have taken it out for volume change. So for this, you should first know that specific enthalpy is 100 Kilo Pascal saturation table so if you see here, you have H_f H_g and H_{fg} are also given so naturally I will use this only I don't need to subtract you have H_{fg} in this table so you simple M mass multiplied by H_{fg} if you multiply it, you will get 0.2 kg multiplied by 2257.5 kJ per kg so this is your total change in change in enthalpy and this is your energy transfer. So, this is the first question. You can also do the same problem in the refrigeration system. For this you will have to use a different table. Since the table is given, there can be many types of problems.

For example, we are talking about energy transfer. But it can also be that you have to give an energy transfer and you have to find out what temperature and pressure it is. This is very valuable information for the table. You can solve many problem statements with this. Now let's talk about Superheated Vapor. So, you have read the saturated table. Now we will see the graph of Superheated Vapor on the right side of the table. T and P are the right-side region of the table. In the acid table, you will not have H , F or G . Because the state is the same. There is no liquid or vapor in it. There is no liquid together. We call it vapor only. That's why the tables are simple, like specific volume, specific energy or enthalpy. To define an acid state, like if you want to define this point, you have to define temperature and specific volume. Either pressure or specific volume, or pressure or temperature, enthalpy, basically you need two parameters. So usually, in such cases, temperature and pressure are independent properties. Both can behave independently. Whereas in the case of saturated mixture, as soon as you fix the pressure, the temperature is also fixed. That is why they become dependent. They are not independent. So, in the case of superheated vapor, the table will be in this form. Your first wave is saturated at this point. After that, the temperature will change, or the pressure will be fixed, and the temperature will vary. For example, note that this is a temperature versus enthalpy plot. As the temperature versus specific volume is here, we can also add enthalpy as a variable. There will be no change in the curve, there will be no change in the behavior in terms of plot. So, it behaves similarly. So, if the temperature is enthalpy, this black line is the isobar, which means pressure fix. And this region on the side is superheated. And if you are going on this line, because it is a process, then at this point, all the points, states, will be your superheated state. And the condition of this is that this enthalpy is more than the gas and vapor enthalpy, which is saturated vapor enthalpy. So, the condition will be that your enthalpy will be more. Similarly, you can also say that V is more than V_g . If you want to do it from this side, then you can do it from this side. This is your V_{eg} . The specific volume of the regions that are in the super heterogeneous region will be more than this. You can use this kind of table as an example. A question has been asked in this. Determine the temperature of water at a state. You have to check the temperature of the water and the state of the water. As we said that we need two variables in superheated conditions.

In general, you have to check two variables. Which is 0.5 MPa. Which is 500 kPa. And H is enthalpy, which is 289 kPa. So, the first question is that we have to find out in which state. Is it in a superheated state or in a saturated state? What is this state? So, for that we have to find out that H because H is given, not V So is this more than Hg? Or is this H fluid and H gas in between? So, these questions We have to check the condition of the enthalpy. For that we have to see the table. Which table should we see? Since the pressure is given, we will see A5. Since it is water, we will see A5. I have copied the specific row of A5 in this. Here I have 500 kPa. And here I have highlighted specifically. I have pressed it. Hg is 27481 at 500 kPa in saturated condition means if you see the red line on this line this is your temperature enthalpy plot and on this line which is 0.5 MPa on this line this point this is your Hg and this Hg comes out at 27481 which is less than the Hg of our state which means that the Hg is greater than Hg this point, this state, this black dot is on this side so this exists in the superheated region of the vapor now what will be the temperature of this? Because the temperature will definitely be more than the saturation temperature. T will be more than the saturation temperature. Because it is in this lane. So, to show this, we will have to check the temperature of the superheated vapor. So, the superheated vapor is A6 of water. And this A6 is in the textbook that we are following. So, for this, they will be on different pressure, so we have to see that it is 500 kPa which is 0.5 MPa like here you see P is 0.01 MPa in this bracket is the corresponding saturation temperature ok so here they are not given This is the saturation temperature. And when the temperature changes, then we will introduce a specific volume in terms of energy, enthalpy and so on. We will tell you about that. That is entropy. So, what we have to see is 0.5. So, it is not in this range. So, let's move ahead. So, we took this out and copied it. This is your specific table, which is 0.5 Mpa. And in this we have to find out what is its state, the state of enthalpy. So let's see again, this is VUHS, so we are interested in H. H is 2890 2890 exists between these two this and this means this exists between 200 and 250 so 200 and 250 exists between these two so how to measure the temperature? because you have 200 kC corresponding to 2855.8 kJ per kg and at 250 kC you have 2961.0 kJ Now, to remove this we have to do an interpolation. We assume that the range changes are linear. So, to do this we have to do a simple interpolation. So, what are we doing in interpolation? We can define it as suppose this temperature T is in the middle which is 2890 kJ per kg so Assume that the slope of delta H, like H250-H200, will be same as Ht-H200-T-200 So this is how the assumption is used in basic interpolation So now I have typed this thing here Now I know the 250, 200 and the temperature. I know its enthalpy but not the temperature. I know its enthalpy and the corresponding temperature. Now you will rearrange it and remarks. If you simplify it, you will get T 200 plus S250 and S200 S250-200 S216.3 So, you have to interpolate the changes in the industry. So, this is the medium we have solved, and it is very important. So, that's why interpolation is important.

The basic concept is that we have considered delta H by delta t as a constant. And that's why in both cases, from 250 to 200, and from t to 200, this is considered the same. That's why your delta H by delta T1 which is 250 to 200 this is same as delta h by delta t T2 200 So you can expand it and write it properly and then re-arrange it and you will get this answer Now let's discuss the compressed liquid We have discussed about superheated vapor Now let's talk about compressed liquid which comes in this side, in left side Superheated vapor will come in right side and compressed liquid will come in left side So how is compressed liquid characterized? How is it identified? If you look at this line, temperature versus U is here. As I told you earlier, you can do V, H, S in this. So, when there are no changes in this type of plot in terms of behavior, so here specifically we have taken internal energy. And this is your constant pressure line. which is

called isobar, and it is 500 kPa its corresponding temperature which is T-Sat is 151.83 and this line which goes down here is saturation liquid vapor mixture and this line goes into superheated vapor and this line which goes down the pressure is constant, but the temperature is decreasing. The temperature is decreasing because of the T-Sat. This specific region is compressed liquid. In the case of compressed liquid, the temperature will be less than T-Sat. The temperature will be less than T-Sat. The temperature will be less from the T side. Now you can change the conditions by rotating the T side. If you talk about the specific volume of the T side, then if the specific volume was V , then V would definitely be less than V_f . Because V_f is here. If U is less than U_f , then H_b is less than H_f . So, this condition will be standard, whether it is lower specific volume, less internal energy, less enthalpy, note that the temperature is less than T set at given P. If P is fixed, then P is less than T set at given P. Now if you do this thing in a different way. Because instead of temperature, we use pressure, suppose. we use the pressure ok so this line is of any constant temperature This is your P-sat which is at T and this line which you see here this line in which I am making a circle this line will come in compressed liquid range this pressure will be greater than P-sat So, there are two conditions. One is that your temperature should be less than T set if you have given pressure for compressed liquid. Or the pressure should be greater than P set if you have given temperature. So, these are the two conditions. That T less than T set at P and P greater than P set at T and any other property like specific volume, internal energy, enthalpy, entropy, etc. will always be less than the corresponding property of the fluid at any temperature pressure which comes in this range as we have summarized here so this is the definition of compressed liquid that the property depends less on the pressure. Because it is a liquid form, when you change the temperature, the properties change faster. And if you change the pressure, the dependence on the pressure is less. So that's why... So sometimes we approximate the compress liquid property V , U , H V_f at T, U_f at T and H_f at T So given P and T, we sometimes approximate it Assume that it will be equal, so this assumption is common But when we do assumptions, we lose some of them. So, if you don't have a table of compressed liquid properties, then you can assume this. So, this is an engineering assumption. But if you want an accurate relation, for example, enthalpy is of enthalpy, then in enthalpy, this is an accurate relation that the value of H_f is plus $V_f \Delta P$. and this is your v_f at t multiplied by $p - p_{sat}$ ok so, one way we can derive this later but it represents that you can get accurate relation and you can use it only this is valuable only you are told this because this part the second correction term is very less compared to your value H_f so that's why we sometimes ignore it we don't consider it we assume that it is zero the rest is only this so when we derive the property in the next lectures then we will understand it better Now let's come to the important question that is your table has any reference or not? So first we have to understand whether it is an experiment or some other method the values that we are taking out, U , H , U , N , H , and later we will discuss entropy, but S is also in that table we can never directly measure it can't directly calculate. So, the values that are given, in a way, are a reference. Because we can evaluate change in property, and we can never evaluate it directly. Therefore, the reference state on which basis you have told the property is very important in the table. Understanding it. We normally zero the reference state and the value. Notice that the reference state of water is 0.01 degree Celsius, and the reference end is minus 40 degree Celsius. So, like a saturated water temperature table, the corresponding value of 0.01 is this. Of course, there will be liquid and vapor in it, the energy we cannot calculate is energy. So, this is the value of energy. This is zero. Notice this. So, for reference, you have done that the liquid, the saturated liquid is zero. Similarly, in the case of refrigerators, at minus 40, your enthalpy is zero. So, we have zeroed enthalpy, entropy and here also we have

zeroed entropy. So, one way to understand this is that there will be a reference state on the tables and on the reference state, for convenience, we zero some property. And normally, this property is something that we cannot measure directly. It is energy. Energy is different, like enthalpy, internal energy, entropy. Therefore, it is very important to zero. This also means that some properties can be negative. Because if you have chosen a reference state that goes below it, then it can be negative. But this does not make much difference from our reference state. Because what matters to us, what is important to us, is that delta means change in property. So, we calculate maximum change in property in our thermodynamics. That's why our reference state is not much affected. But it is important to understand that whatever table is in our books, or we tell, it has some reference state, and it is written on that table. So, you can't ignore it, you can't ignore it. So, in these two lectures we studied property. Particularly, we studied about tables, how to use them, problem solving, water related problem, refrigerant related problem. But similarly, all the different gases can be used, or different kinds of fluids can be used. But the process of problem solving has not much changed. They will do similar things if the table is given. So, we will discuss in the next lecture how to evaluate the property using the equation of state in the table. In the next lecture, we will discuss how to use the equation of state in PVT and how to evaluate the property. And we will also introduce some other things like compressibility and the usual use of the equation of state. I hope that you have got clarity in these two or three lectures about property table and property diagram how to use PV diagram, TV diagram, PT diagram and in this lecture we have used pH and TH not only specific volume we have used enthalpy and internal energy in property diagram which is valuable and represents the process easily I hope you understood this and will meet again in the next lecture See you soon