Engineering Thermodynamics
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Week-02
Lecture-10
Properties

Welcome, Namaskar. This is the third lecture of the property. We will continue the discussion we were having. In this lecture, we will focus on how to use the property table and what properties are there in that table. We will try to understand it through some examples and try to solve some problems by using it. The thermodynamic properties are very complex and confusing. directly measure it. It means that you cannot directly take it out in the experiment. So many times, with the thermodynamic relation with the relation and simple equation we measure the basic property and then we use it and evaluate the other property or take it out. That's why the most important fluids like water, water is used in power plants. Similarly, refrigerant is used in AC. So, we use the table for such important fluids and important substances. And the table that we are using is not made of wood, it took a lot of time to make it. It has been made for many years and therefore there is a lot of trust on that table because it has been examined and verified from many experiments. So, in a way, if the property table is there, it becomes very convenient for us, it becomes very easy for any job. Graph based data is easier to evaluate in the form of table. There is a lot of data available. Some graph-based data are simpler. We will talk about that later. Normally, the property is in the form of a table and graph. Now we will try to understand from the table. We will take two specific examples in this lecture. One is about the water table. And second is refrigerant. The gas used in AC and cooling requirements. Before we start the introduction of the table, we will introduce a property called Enthalpy. This is specifically introduced when you have a flow system where you keep a control volume. This is your control volume, this is your flow, this is your internal energy, which is associated with the flow, with the fluid. And along with that, there is a pressure and a molar volume which is flowing from the volume. So, we have already used this in previous lectures. This is also called flow work because it is in the form of work. When this fluid is flowing, it will have internal energy and flow work. We will try to use it because when we add it to the total energy, it will come here and here. So, it will be better to add it. And when we add it, it comes here U plus PV, and we call it Enthalpy. This unit is h, this is Enthalpy per unit mass. That's why its unit is kg. When you multiply this with mass, it will become H, which is internal energy plus P and V. Total volume will come. So, this type of combination U plus PV, you will always encounter where you have to do a control volume analysis. Where the flow system is. That's why we keep it together. We keep it together on the table. There are many types of units. Depending on whether you use SI unit or English unit. Since we are not using English unit, we will only use SI unit. So, it is relevant for us that it will be in kilo joules form when we write the total value. Or in per unit mass, it will be kilo joules per kg. Sometimes it can be done in a bar or in mega Pascal. So, these are the units in different forms. So, we have to always pay attention to the units. Whenever we have to solve problems, we have to write the units. Let's talk about water.

The table of water can be in any form. It can be in compressed liquid as we have studied in any phase diagram. It can be compressed liquid, mixed region, saturated liquid and saturated vapor or superheated vapor. So, the table properties are written either in compressed liquid or saturated. liquid vapor region or superheated vapor region or if you divide this you will get different tables The textbook we are following Table A4 is of saturated property under temperature What does this mean? This means We are not showing the whole table, this is a truncated, partial list. To present the display, we have shown only 4 columns of this table. And the first column is the temperature. And we see one row in this, like 85 degrees Celsius. Saturated pressure or saturation pressure which is in kilo pascal is called P-sat. So, at this temperature, the saturation pressure will be 57.868. At this point, the vapor is ready to be vaporized from the liquid and can form. Vaporization will start if you continue the process further. if you are coming from the compressed liquid region and in that two phase region your saturated liquid value will be this and the value of saturated vapor will be this which is the specific volume these are the values of the specific volume so if you want to understand it graphically then you can write it like this So if you want to understand it graphically, then bring it to the TV diagram.

This is your vapor-liquid equilibrium. This is your saturated liquid line. And this is your saturated vapor line. This is your TC, or critical point. Okay. Now what is this? This pressure is 85°C. If it is 85 degrees, then it means that the pressure of this line will be P-sat at 57.868 kPa. and this region will be your V fluid which will be your specific volume liquid this is 0.01 0.032-meter cube per kg so this is your Vg 2.8261 meter cube per kg okay So, we are writing the same information in this graph in the table. Now, after this fourth column, we have written the first column. After this fourth column, because there are only four columns in this table, which we are showing, although there are more columns. After this column, there will be more columns So you saw T, P sat Vf Vg This is your 4 column After that Vfg will come, Vfg is your difference of specific volume of vapor state minus specific volume of liquid state This is the information of the specific volume of the liquid state. There will be 3 columns in the specific volume. Then there will be 3 columns in the internal energy. If we can also write it as Vf, then it can be Uf or Ug. Then there will be Hf. The symbol has a per unit mass. And in every property, after the third column, the difference between the liquid and vapor is found. So, you will get such tables. In table A4,

you will have information about the specific column. There will be information on internal energy, then there will be information on specific enthalpy and after this there can be other properties that we will not discuss like entropy. So, we will not discuss that now. As I said in table A4, this is water under temperature, meaning the first column is its temperature and corresponding to that we are writing pressure and other things. Similarly, table A5 will also be found in all the books. That happens when you are in the saturation property, that is the same property, but this is under pressure, meaning we keep the pressure constant, we evaluate the pressure. This means the first column is pressure. So you can understand it as, basically, it is relevant for this type of plot that the pressure and volume are done, your stress is done and you, like, if you fix any pressure then its corresponding specific temperature is fixed so this is called T-sat, and after that, the other properties are taken out in the same way that below this is your Vf below this is Vg similarly, Uf, Hf and Similarly, other things will be there. So, we are presenting table A5 here in expanded form. As I said, the first column is of pressure, the second column is of temperature, which is saturation temperature. Whenever we write sat, it always represents this that it is a two-phase region. During this time, the temperature was always constant. And after this, you have the specific volume, internal energy and then enthalpy, as I said. Enthalpy means the same U plus PV. So, this is your saturated water pressure table, which we call table A5, this book which we refer to as a textbook. Let's understand it further. This is related to table A4. We will try both TV and PV diagram. First, if you have this table, and try to understand it graphically, this is the saturated liquid and saturated vapor state of water, which we have to represent in TV and PV, through this particular table. So, if we have to represent 90 degrees Celsius in the graph, this is your two-phase region. This side will always be a liquid region and this side will always be a vapor region. Since this is a line, this is a saturated vapor line. And this is a saturated liquid line. This region is a compressed liquid. and this region is super-heated. I am repeating it again so that you can remember it whenever you draw. And this point is called critical point. So, this data, which is on this particular row, this is 90 degrees, there is a saturation of 70.183 kPa. So, you can see this dash line at 90. At this point, an isotherm, i.e. the line where the temperature is constant in the process, will pass this line which We are repeating this again. At this particular point, the isobar where the pressure is constant, because the pressure is given by P sat, so this is your P-sat.

This is your graphical representation from the graph. This point is the saturated liquid at this particular temperature. Similarly, you can represent the point P versus V and this point is given in a two-phase region. So, what is the representation of these two points? The first one is a saturated liquid which is P 100 kPa. This point is the saturated vapor, but the P is fixed at 100 kPa. So, you can understand these two points like this. And what will happen to this region? This is a piston. This is a two-phased mixture. It has vapor and liquid. But this is 100 kPa. So, this is liquid and this is vapor. How much liquid and vapor are there depends on the point at which this system is. We will discuss that, how it is explained and how it is solved. So, this point that we have done PV. This was the TV plot. This is table A4 data This plot of PV data is relevant You can understand it from table A5 data So this is the simple table Now we will talk about saturated mixture In which vapor and liquid are there So how much vapor and how much liquid is there We normally represent it We define it So, the definition of the X is that the ratio of the vapor mass divided by the total mass. percentage or in terms of ratio is vapor. If it is 1, it means total mass is completely vapor. If it is 0, it means total mass is liquid. So that's why the range of x is between 0 and 1.

Now this is very valuable, we will use it as an example. When we use it, one important thing is that because in the system, vapor and liquid will usually be in this form that vapor will be above and liquid will be below but when we use it, we will assume that particularly when we are calculating this property which is the scalar value then we will assume that it is homogeneous it is just a convenience For convenience, we will assume that this is a completely homogeneous mixture. But there will be no impact on the quality of the answer. We are discussing the quality. The quality in general will be the amount of vapor and Mass of Vapor divided by Mass of Total of Amount. But we can also take out other properties like volume, we can also represent the volume. If we look at this system, we can represent the Saturated Vapor, VG and VF in an average specific volume. We will use it later, but it is only for convenience. We will define it mathematically.

$$m_{total} = m_{liquid} + m_{vapour} = m_f + m_g$$

$$x = \frac{m_{vapor}}{m_{total}}$$

$$v_{avg} = v_f + xv_{fg}$$

$$u_{avg} = u_f + xu_{fg}$$

$$h_{avg} = h_f + xh_{fg}$$

$$x = \frac{v_{avg} - v_f}{v_{fg}}$$

Let's talk about the quality. We take a mixture of vapor and liquid. Usually, when there is a system where vapor and liquid are together, we use it more than the quality. Quality means the amount of mass in the vapor. The definition of this is the ratio of mass of vapor and total mass. It means that if this is 1, Total mass, total m total will be transferred to the vapor. This means that the whole vapor is present. If it is zero, it means that it is still on saturated liquid. If you look at this diagram, POT is your specific volume. This is the tie line, which means it is in equilibrium from this point to this point. In this case, this is your saturated liquid state. So, this will be your quality 0 and this point will be your quality 1. And the quality between these points will be between 0 and 1. So the total mass will be liquid plus vapor mass, Mf plus Mg. And when we take out the quality, the mass of the vapor will be divided by the total mass. Now you can also take out this from this, the rest you can find out about the volume. Before deriving it, I must say that whenever you talk about saturated vapor liquid mixture if you have fixed its temperature whether it is P or T let's assume that it is P then its temperature gets fixed which means that when you fix the pressure then the T-Sat is fixed or if you fix the T then the P-Sat is fixed that's why temperature and pressure are dependent they are not independent when they are after the mixture So this is an important statement Now we understand that when we take the mixture of S and L, So this line that you have seen in the middle, we assume that its volume is very negligible, that is, it is zero. So, what will be the total volume? The volume of vapor of fluid which is liquid and this is your gas. This is the total volume. We can also write it as mass of liquid of fluid F which we are noting here. And this is specific. the volume of the fluid, specific volume of the fluid plus mass of vapor and we are multiplying it with specific volume of gas and vapor. This is your total volume. Now if we divide this, suppose we divide this with total mass, which I am saying is empty. So, this is your V is the specific volume of the mixture. Means the whole mixture has a specific volume. We can also call this average. That the average is of your vapor liquid. And this will be your Mf by Mt. So, Mf by Mt will be your 1-x. Because Mg by Mt, M vapor. Mg by Mt. This is your x. So, what will be Mf by Mt? 1-x. plus your x multiplied by vg we will rearrange this now we multiply vf and expand it so this is vf minus x vf plus x vg and this is vf minus instead we will do plus and this is vg minus vf We have defined this before. This is your Vf plus x Vfg. This is your V average. So, this is what we are saying that the average volume of your vapor liquid mixture in the tank or system is the specific volume of the fluid. the specific volume of the liquid plus x quality multiplied by the difference in the specific volume of the gas and liquid. So, this is how it works. Similarly, you can also derive other properties like internal energy and enthalpy. I am not deriving all of them. I have derived this. Similarly, you can also derive this. In general, any property of the Easter egg can be written as yavg is equal to yf plus xyfg y can be specific volume, specific internal energy or specific enthalpy Always remember that yavg is the system's property whether it is V, U or H is greater than equal to liquid or less than equal to If you look at this x, then x is the specific mass of the value. But now you can also get the value of x from the rest of the properties. If we rearrange this, then we can also take x as vavg minus divided by vfg. So, if you have a graph, suppose you have a PV diagram or a TV diagram and you know what is V average, what is the volume of the fluid then you can also take out the quality for the graph as shown here. If there is any diagram of P or T and you have V, the specific volume here and if you have this given B, the system property, then B is your system. So, the value of this is V average. So, what does X tell us? X tells us that V average minus F, means this distance, divided by this distance. So, graphically, if you draw a line, then this X is your A, B divided by AC. This length is done. So, graphically, you can also get the quality. Isn't it? Just remember one thing, that this Vaverage and V system will be Vf. equal to or less than and greater than or equal to than vf. so, as it is big graphically at this point, so we have used symbol of greater than and less than.

Now we have understood enough about how quality is defined, how to use quality, how to connect system with properties and how to use table now let's practice this with some examples This is the example of your rigid tank which has 10 kg water at 90 degrees Celsius. 8 kg water is in liquid form and the rest is in 2 kg vapor form. We have to extract pressure in the tank and volume of the tank. First of all, notice that this is a rigid tank. This is a closed system. It is said that it has liquid and vapor. Assuming that it is in rest, it means that it is in equilibrium. So this is a saturated liquid vapor system. So, this is a two-phase system. and equilibrium is there so this is saturated liquid vapor system, which is water. In this case, if the temperature is T is equal to 90 degrees, then what will be the pressure of this? Since it is in equilibrium, the pressure will be P sat, saturation pressure at T is equal to 90 degrees. So, in this, we will see the temperature of the saturation table, which is our A4. If you look at the A4, you will see that I have taken a small part of the A4. And at 90 degrees, your saturation pressure is 70.183 kPa. So, your P-set is 70.183 kPa. Okay. So, this is your first question. Now the second question is volume. Volume of the tank. This was your first question. What is the second question? The second part of the question is the volume of the tank. So, you can do volume in two ways. The first is simple. You are in V. So V is equal to V fluid plus V gas and you know that this is Vf and the fluid has 8 kg of mass and we will multiply it with specific volume plus, we can write it as this is basically mf plus mgVg So this is the mass of the liquid multiplied by the specific volume of the liquid plus mass of the vapor multiplied by the specific volume of the vapor. The mass of the fluid is known as mg is 2 kg and mf are 8 kg. So, if you multiply this then mf is 8, This is your Vf 0.001036 meter cube per kg and this is in your kg plus your mg is 2 kg multiplied by 2.3593 meter cube per kg. So, you have to solve this. You have to solve this. If you solve this, you will get 4.73 m3. So, you have solved this in one form or another. The second way is by using the quality. Now, in this you have given 2 kg of MF and 4 kg of Mf. So, what is the quality? The quality is Mg divided by Mtotal is 10 kg. So, 2 kg by 10 which is 0.2. So, the quality is 0.2. you have taken out the volume of the tank. In the last slide we read that the specific volume of the system, which is called V average, is Vf plus xVfg. Vfg in this particular condition, which is the arrow given, at 90 degrees Celsius is the saturation condition, on this you have 0.001036 plus 0.2 times Vfg, Vfg means Vg minus Vf so it is 2.3593 minus 0.001036 This is all done at meter cube per kg So this is the V average. V average will come out to be 0.473 m3. If you solve this, then this will come out. Now, how will you get the volume of the tank from V average? Because V average is your specific volume. So, what will be the total volume? Total mass multiplied by V average. four seven three so this is 4.73. So, both these are your same results. We have solved this in both forms. So, this was the first problem, the second problem is about refrigerant. This is also a very important gas or fluid; it is called working fluid. It is used in your refrigeration system and cooling system. The main question is that you have 80-liter vessel in which 44 kg of refrigerant is given at a pressure of 160 kPa Pressure is given, total mass is given and the container which we assume is rigid volume closed system is 80 liters, So the question is what is the temperature of this particular system? Second, the quality of the system. Is it in a two-phase system? Is it a vapor liquid? If it is, what is the quality? And how much is the enthalpy of this refrigerant? If the vapor has volume, then how much is the volume phase occupying? So, the first question is that you have to see that whether it is available in two phase regions whether it is a vapor liquid or not because any state can be state can be compressed liquid, superheated vapor or saturated mixture so we are talking about 1,3,4 refrigerant so first thing is what will be the state What is the state? Is it a compressed liquid? Is it superheated? vapor or this is a saturated mixture.

So, first of all, let's find out. As we saw in the previous slide, that any two phase region will have an average property. That property, whether we represented it as Y, it always less than equal to y fluid or sorry greater than equal to y fluid and less than equal to y gas. It means that y average is the property of liquid will be more or equal to the property of gas and the property of gas will be less or equal to the property of gas so this means that if we can find out any such property in the information and find out if it is between the property of saturated liquid and saturated vapor if less than that, like the left hand or the border here If it comes here or here, it means it is not in two-phase vision. Let's see what we have available to us. Here you have 80 liters and 4 kg. This means that you can extract specific volume. So, what will be the specific volume? V divided by total mass. V is given in liters, which you can convert into meter cube. You can change it to m3 in SI unit which will come like this You can write 80 L in 0.080 m3 and divide it into mass which is 4 kg So you have 0.02 m3 per kg Okay Now what is important is that you have to see this Saturated Because pressure is given So see the saturated pressure table But we have to check the refrigerant, not the water. So, the table is different in the test book. It is A12. And we have to see this. Specifically, we have to see 160 kPa. And we have to check that the V that we have given here, the one we have taken out, this is... It satisfies this or not? It actually removes the equality. If it is greater than Vf or less than Vh or Vg, then it is definitely in two phase region. If this happens, we can assume or convince ourselves that this is a Saturated mixture. Which means if this happens, we will say that this is a Saturated mixture.

Let's look at the table. This is the table. This is 1A12 and it has 160 here. On 160, it is minus 15.60 T-sat. value of Vg 0.123 we had taken out was 0.02 So 0.02 means it is less than Vg And Vf is 0.007 What does this mean? The value of 0.02 is definitely less than Vg or more than Vf at t equal to 160 Kp and the T-sat of this value is Let's see what is the T-sat. That is the value minus 15.6 degree Celsius. So, this is your table after accessing it. Now we have to take out the temperature. The temperature has been taken out. This is the T-Sat. At this temperature, because this is a two-phase region, the temperature will be the same as the saturation temperature. The saturation temperature is at this pressure. You have got it from the second column. This is your pressure. The corresponding saturation temperature is minus 15.6. Now the second question is quality. Now for quality we have to extract the value of v because we know that v is equal to vf plus xvfg So x is equal to v minus vf by vfg So we can extract vf from here Vg and vfg are known, so we will subtract them vf minus vf V minus VF and VG minus VF. VFG is VG minus VF. This data is already available. We can simplify it in this graph. I have written VF from the table and VG. Now we know the temperature. This is the saturation temperature. This is your PV diagram. This is your 160 kPa system. So, we got xn from here, if we put this information on it, 0.02 is the specific volume of our system, minus 0.00074 divided by 1.2355 minus 0.00074, okay, this comes out to be 0.157, okay? And this whole unit is meter cube per, So the quality of the system is accessible at 0.157. Now we can get the enthalpy of the system which is Hf plus xHfg. So, let's go back to the table. So, in this particular case, see that this is internal energy, and this is enthalpy. So, the enthalpy liquid is 31.18 kJ per kg. This is the difference between gas and liquid. And this is the vapor. If you note this, you will get Hf, Sg and the difference will be Hfg. which is 209.90 kJ per kg this comes out of the table so if you put this input in H then your value of H comes out to be 64.2 ok now let's see a new example this was the first example on water this is the second example which is refrigerant This is a working fluid like water used in power plant. Similarly, refrigerant is used in cooling systems. This is also an important fluid. So here the question is that you have 80 liters of vessel with 4 kg refrigerant which we call R134A and the pressure is given 160 kPa We have to find out what is the temperature, what is the quality and how much is the enthalpy of the refrigerant and how much volume is occupied by the vapor phase First, we have to clear the state of the liquid. This can be compressed liquid. It can also be superheated vapor. This saturated mixture can also be used. As we have read that if any property of the mixture is y, then it should be greater than or equal to y of the fluid and less than or equal to y of the gas. and comes in the middle of the gas then this is basically a two-phase mixture. So, what is the property that we can extract from this? If you look carefully, it has the volume of the vessel and mass. What does this mean? That you can extract specific volume. So specific volume V, total mass divided by total volume divided by mass. So, this is your point zero Because we have to take 80 liters in this unit, so 0.8-meter cube divided by 4 kg This is your 0.02-meter cube per kg Now you have got the information that how much is the specific volume of your system. Now the question is what the specific volume of the vapor in this particular condition is 160 kPa. Is the vapor less or more than the specific volume of the liquid. Similarly, is the liquid less or more than the specific volume of the liquid. For this you should have a table. The table that will be useful for us will be This is the saturated pressure table which is given as A12 This is the saturated pressure table, so this is how it looks like. Now pay attention to this. You have 160 kPa which is the pressure given to you. So, you saw the pressure column. And this is 160 kPa. The corresponding temperature of this is the saturation temperature. That will be your system temperature. Because This is the pressure given to you and you can see it. On this table, you have 160 kPa of pressure. In the corresponding of this table, you can also see what happens to your saturation table in this condition. But is this system a two-phase system? This is a different question. To answer this question, you have to find out the specific volume that you have taken out, Let's see what Vf and Vg is. So, this is Vf, and this is Vg. Vf is corresponding to Vg. Vg is more than 0.02 Vf is less than 0.02 This means that our V This condition meets and satisfies the condition. This means that V is between these two. This means that this is a two-phase region. Now we can find out its quality. This means that this is a two-phase region. Since this is a Vf condition, this is a saturated mixture system. What does this mean? What will be the temperature? T will be your T-Sat at P equal to 160 kPa which you can remove. This is your T-Sat. So, this is your minus 15.60 degrees Celsius. So, this is your temperature system. Now the question is about the quality. So, you know the quality v is equal to vf plus x vfg this is your two-phase region so you can write it like this. We know vf and vfg so what will be the quality? v minus vf we know v vf vfg which is vg minus vf information table vfa vg 0.0074 divided by 0.12348 minus 0.0074 so if you solve it then 0.157 so this is your quality Now C is your enthalpy

Now enthalpy of the refrigerant means the enthalpy of the system So, as you have taken out a specific volume of the system which was the average of liquid or vapor similarly enthalpy will be there So you can write enthalpy as Hf plus x Hfg and this is given on your table If you see ahead on this table So this is your Hf This is your Hfg This is your Hg So what do we need? Hf or Hg? We need Hf or Hfg So you put this in here 31.18 Plus 0.02 Plus 209.96 This is your kilo joules per kg. So, its value is 64.2 kilo joules per kg. This is your enthalpy of the refrigerant. Now comes the volume occupied by vapor. How much volume can be occupied by vapor? We will solve this now. We can also represent it graphically. As we can see, That was the information. These things can be represented graphically as well. Like you have P V So this Your corresponding P equal to 1.16 kilopascal and this is your T which is 15.60 Celsius and this is your Vf this is your Hf or it is Uf then this is your Vg Hg Hf and this is your quality somewhere in the middle 0.157 It can be in the center of the Kujoori Niyeh or in the sides of the Kujoori Niyeh. We don't know that. We will have to graphically find out. But you can also present it graphically. Now our third question is the total volume of the vapor phase. So this is the total volume of the vapor This is the mass of the vapor phase multiplied by the specific volume of Vg We know this from the table Because 0.12348 m3 per kg Now we have to extract mg To extract mg, we need xxmg Approximately 0.628 kg So this is the mass of the vapor Now if we multiply this with Vg So this will come out to be 0.628 kg And the volume is 0.12348 m3 per kg So effectively this will come out to be 77.5 So this is 77.5 x 10-3 m3 which is 77.5 L So, if you simplify this, you will get this. So, this amount of volume is occupying the gas. Rest, which is the amount remaining, because it was 80 liters, so 2.5 liters remaining, this will occupy your liquid. So, it's a long calculation. If you do it systematically, then these are simple calculations. You just have to remember the definitions. And you have to understand... The property diagram is also important. How to present it, table is also important. Reading it is also important. Which table to use. Pressure table or temperature table. All these are important. So, these practices will come to you. So this was your last example in this particular lecture. We will make a couple of more examples in the next lecture. We will try to understand them in different forms. There is also Superheated, there is also Subcooled. We have to understand all these tables. So, I will stop here. We will meet again in the next lecture. See you soon.