Engineering Thermodynamics
Professor Jayant K Singh
Department of Chemical Engineering
Indian Institute of Technology Kanpur
Lecture 14
Example problems on properties of pure substances

Welcome back! Today we will be discussing few problems related to properties of pure substances.

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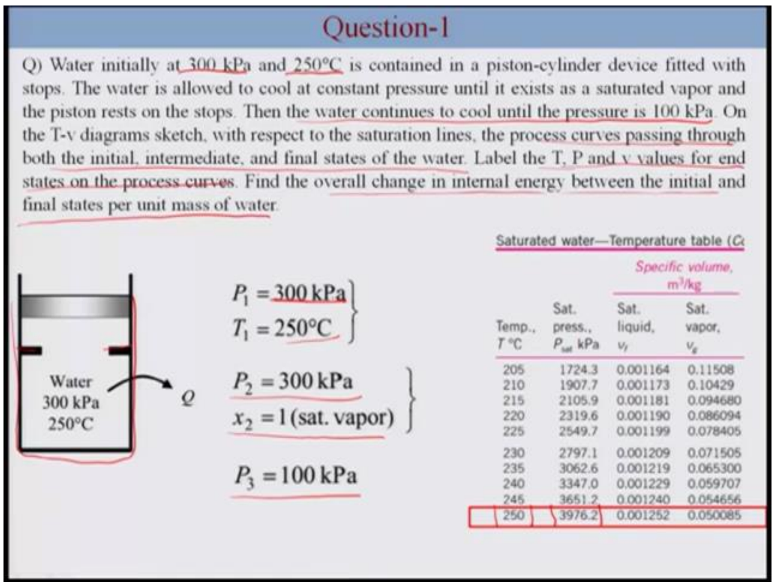

Question 1water initially at 300kilopascal and 250 degrees Celsius is contained in a piston cylinder device fitted with stops. So, this is a piston cylinder device, which has stops the water is allowed to cool at constant pressure until it exist as saturated vapor and the piston rest on the stops. So, initially pressure is 300kilopascal and temperature is 250 degree Celsius, then it is cooled further when the pressure remains 300kilopascal this is a constant pressure process and water becomes saturated vapor.

Then the water continues to cool un till the pressure is 100kilopascal, the water is cooled when the pressure decreases to 100 kilopascal. On T v diagrams sketch with respect to the saturation lines the process curve passing through both the initial intermediated final sates of the water. And we have to label the T, P and V values for end state of the process curves and find the overall change in internal energy between the initial and final states per unit mass of water.

So, initially water is at 300 kilopascal and 250 degree Celsius. If we see from steam tables of saturated water at 250 degree Celsius, the saturation pressure this value is 3976.2kilopascal. So, this pressure is much higher than the applied pressure which is 300kilopascal, it means that water add this state is in superheated state. So, values from this state we cannot take values from this table.

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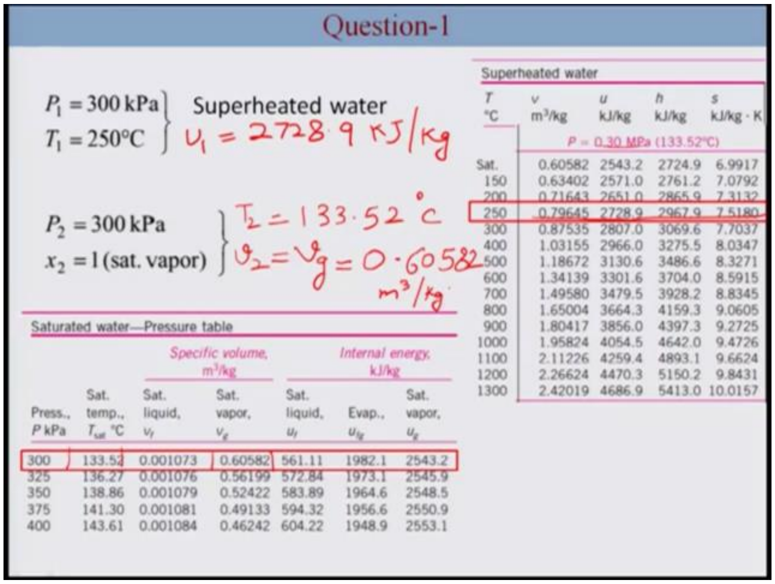

So, we need to look into superheated water table. In superheated water table at 250 degree Celsius and 300kilopascal which is equivalent to 0.3 mega Pascal. The values are these to the value of internal energy U 1 is 2728.9kilojoule per kg. In state 2, it is mentioned in the question that water is a saturated vapor and the pressure is same as initial pressure.

So, taking the properties of water from the saturated water table at a pressure of 300kilopascal, so it is a saturated vapor. So, the temperature at this state will be 133.52 this value. So, T 2 will be 133.52 which is the saturation temperature at this pressure and the value of specific volume will is equal to v g which is 0.60582 meter cube per kg.

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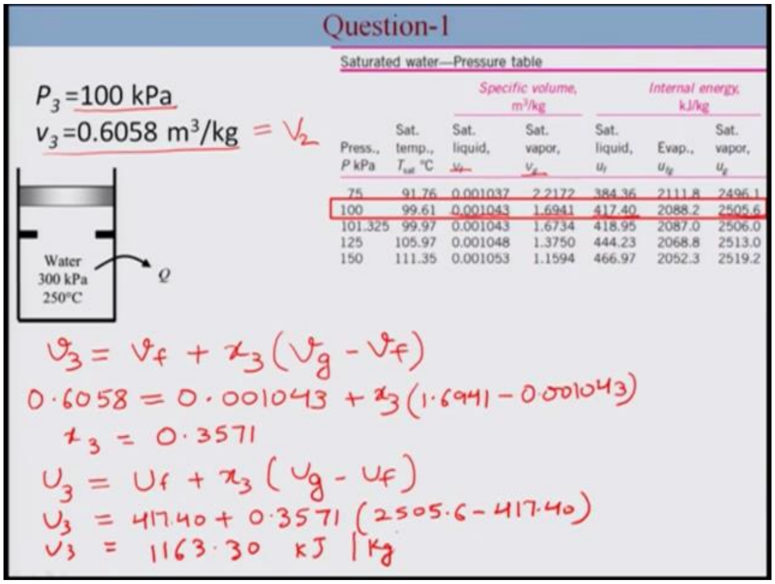

Next it is said that, now the piston rest on this stops and so it means that the volume of the piston cylinder device it is not changing and pressure is now decreasing. So, pressure reduces to 100kilopascal and the volume or specific volume is constant because mass is not changing overall volume is not changing.

So, specific volume is same as V 2. So, this V 3 is same as V 2, from this saturated water table if we see at 100kilopascal the saturation temperature is 99.61 degree Celsius and the values of specific volume of liquid which is 0.001043 and for vapor it is 1.6941.

So, this specific volume of our system lies between V f and V g, it means that the system is a mixture of saturated water vapor. So, we need to calculate the quality of this mixture. So, we can write that v 3, the specific volume at state 3 is equal to v f plus x 3 which is the quality multiplied by v g minus v f. V 3 is known which is v f is also known from the table plus x 3. So, v g minus v f is, so this gives a value of x 3, which is 0.3571. Now we know the quality of this saturated water vapor mixture.

To calculate the internal energy we can use similar formula for internal energy. So, U 3 is equal to U f plus x, U g minus U f so putting all the values we can calculate U 3. So, the value of U f is 417.40, x is 0.3571, U g is 2505.6 (min) this value this is x 3 minus 417.40. So, this gives a value of U 3, which is 1163.30kilojoule per kg. So, now we have the value of internal energy at all these states.

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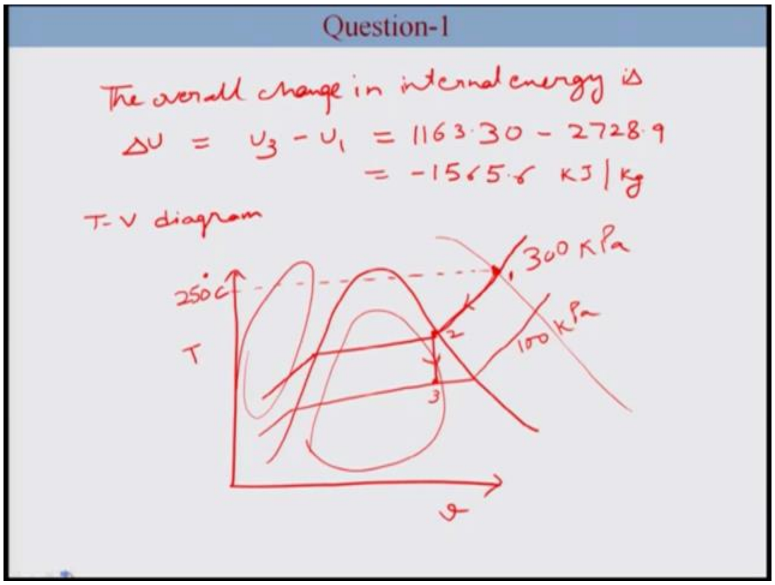

So, the overall change in internal energy is delta U which is equal to U 3 minus U 1, U 3 is as we have calculated 1163.30 and U 1 is 2728.9. So, this is equal to minus 1565.6 kilojoule per kg. Internal energy of the system is decreasing. Now we also had to plot T v diagram, so if we think what we have done this is T and v these are the saturation lines.

So, initially the system was in superheated state. So, this region here is a superheated here, this region is compressed liquid inside this is mixture of saturated water and vapor. Initially it was superheated, so somewhere in this region it should lie and the pressure was 300kilopascal.

So, if we draw a line corresponding to 300kilopascal. So, this point should lie at 300kilopascal and the temperature is also given which is 250 degree Celsius. So, the temperature here is 250 degree Celsius and pressure is 300kilopascal. Now it is cooled and the pressure is constant. So, it should move along this line as the pressure is constant and it becomes in the state 2 it becomes saturated vapor. So, this is the 0.2 where it becomes saturated vapor.

Then again it is cooled such that the pressure reduces to 100kilopascal, so, pressure is reducing, so for a 100kilopascal we will have some such a line. So, the pressure is reducing and

200kilopascal and the volume or specific volume is constant. So, it will be a vertical line, so this point represents the final state. So, this is the T v diagram of the entire process.

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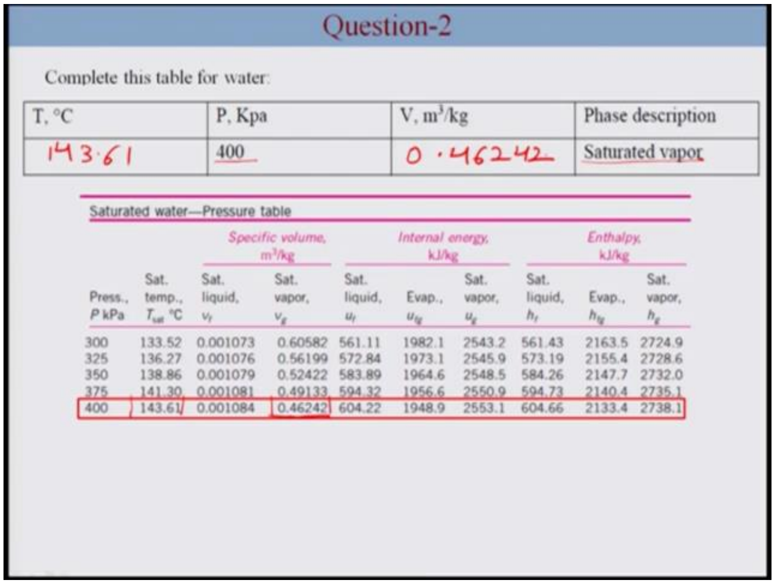

Moving on to the next question we need to complete this table for water. So, few properties are given and we need to find out the other properties with the help of steam table. In the first the temperature is given to be 50 degree Celsius and specific volume is given 7.72, we need to find pressure and the phase. So, if we look into saturated water table at this 50 degree Celsius we find that the specific volume which is given lies between V f and V g it means that this is a mixture of saturated liquid vapor.

So, phase is saturated liquid vapor but we need to know the pressure. So, pressure for a saturated liquid vapor mixture is same as the saturation pressure. So, the pressure of the system will be 12.352kilopascal, or the pressure of the system is given and it is given that it is a saturated vapor.

So, again looking into in the saturated water pressure table at 400kilopascal it is a saturated vapor so, temperature will be same as the saturation temperature. So, temperature is 143.61 degree Celsius and volume is V g because it is a saturated vapor. So, volume is 0.46242 meter cube per kg.

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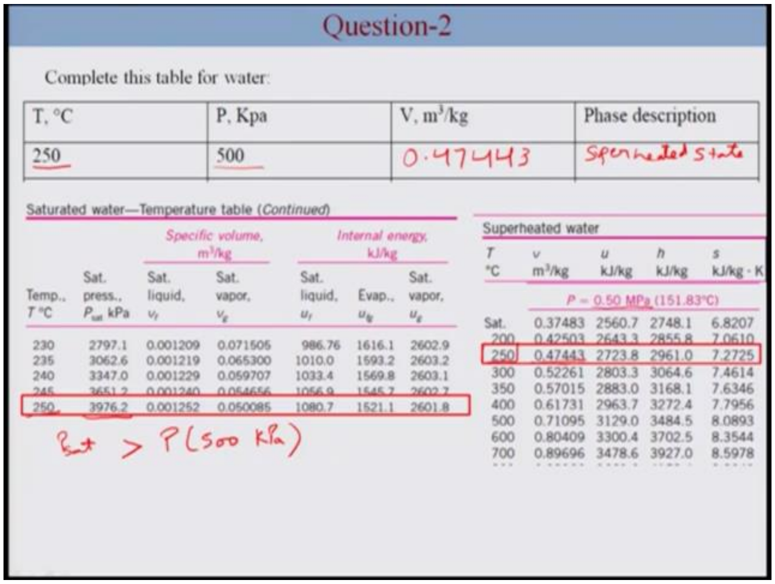

In the next case the temperature is given us 250 degree Celsius and pressure 500kilopascal (())(11:29) will look into saturated water table at 250 degree Celsius saturation pressure is 3976.2. P saturation is much greater than the applied pressure P which is 500kilopascal it means that the water is not in superheated state.

So, it is superheated state now to calculate the specific volume we cannot use this table. So, we need to look into superheated water table for the calculation of specific volume. So, at a temperature of 250 degree Celsius and a pressure of 500kilopascal which is same as 0.5 mega Pascal the specific value is 0.47443. So, in this case it is in superheated state and the volume is 0.47443.

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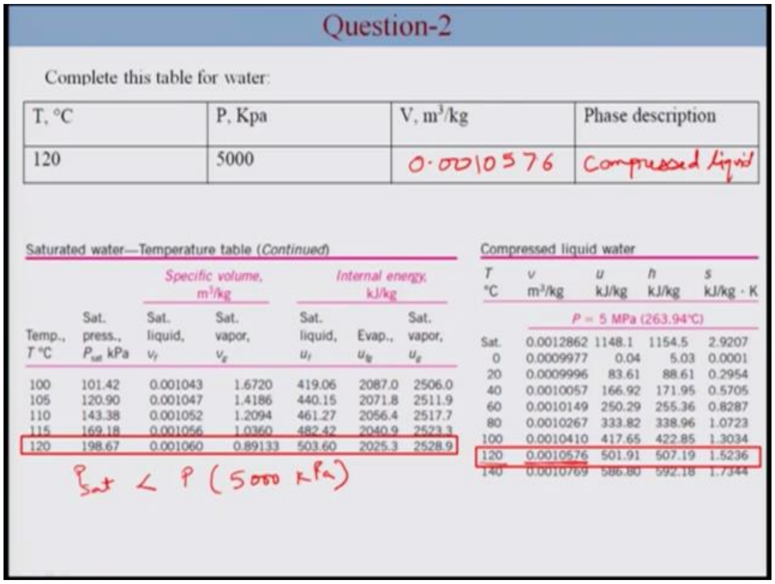

In the next case the temperature is given to be 120 degree Celsius and pressure is given as 5000kilopascal. In this saturated water table at 120 degree Celsius, the saturation pressure is 198.67kilopascal. So, this saturation pressure is less than applied pressure which is 5000kilopascal. It means that the water is in compressed state, so it is compressed liquid.

For calculating the specific volume we need to look into compressed liquid table at 120 degree Celsius, this specific volume of the compressed liquid is 0.0010576. So, this problem gives us in idea of different phases and how to find what kind of phase is exist at what properties.

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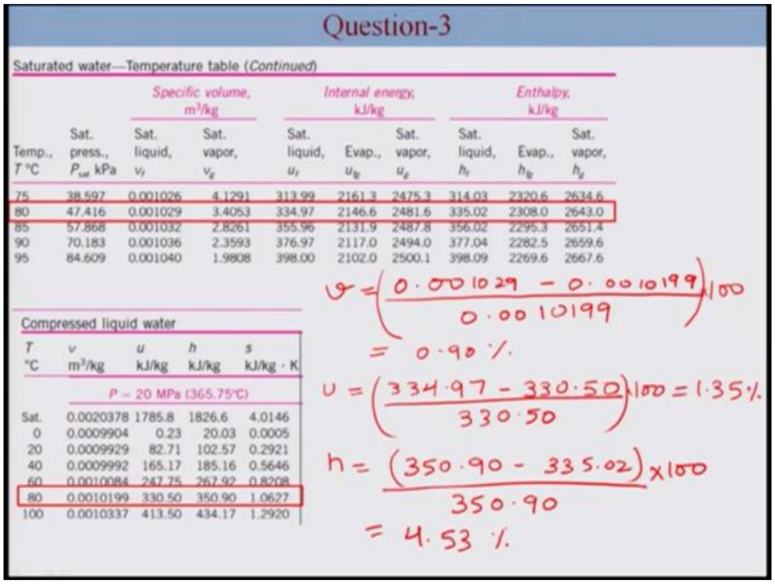

In the next question we have to determine the specific volume, internal energy and enthalpy of compressed liquid water at 80 degree Celsius and 20 mega Pascal using the saturated liquid approximation and compare these values to the once obtained from the compressed liquid tables using saturated liquid approximation the properties of compressed approximation the properties of compressed liquid can be approximated as the properties of liquid at the given temperature at 80 degree Celsius, from this saturated water table we see the specific volume V f is v equal to specific volume 0.001029 meter cube per kg.

The internal energy is equal to U f, so internal energy is equal to U f which is 334.97 kilojoule per kg and enthalpy is h f, this is the value 335.02 kilojoule per kg. We have to compare these values to the once obtain from the compress liquid table from the compressed liquid table at 80 degree Celsius. The specific volume is 0.0010199, internal energy is 330.50 and enthalpy is 350.90. So, there is a difference in the two values and if we compare the two values by calculating the errors.

So, error in specific volume is the, difference in the values from the saturated water table and compressed liquid table. So, it is 0.001029, so this is the value from the saturated water table, and this is from the compressed liquid. Dividing it by the value from the compressed liquid so, this gives a value of 0.90. So, the error is 0.90 percentages in this specific volume. Similarly in the internal energy the error is different in the value obtained using the saturated liquid approximation and that from the compressed liquid table.

So, this so multiplying it by 100, so this is equal to 1.35% percentage, expression also we need to multiplied by 100 to get the percentage. For enthalpy the value is 350.90 minus 335.02 divided by the value from the compressed liquid table multiplying by 100. So, this gives an error of 4.53%. So, the two tables have slightly different values, the error involved is low.

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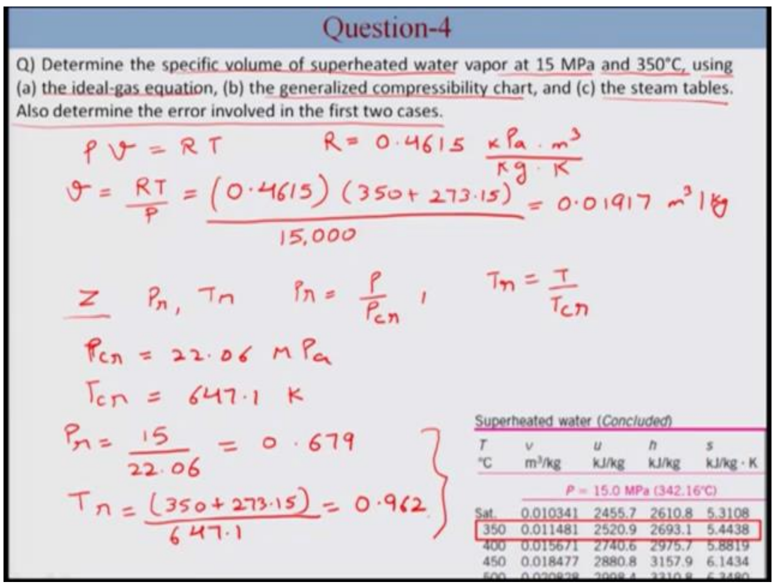

Moving to the next question in question 4, determine this specific volume of superheated water vapor at 15megapascal and 350 degree Celsius using the ideal gas equation is generalized compressibility chart and this steam tables also determine the error involved in the first two cases.

So, at 15 mega Pascal and 350 degree Celsius the water is in the superheated state. So, in the you was be ideal gas equation, so it is P v is equal to RT. For water R is 0.4615kilopascal meter cube per kg kelvin, v is equal to RT by P is 0.4615 temperature is 350 plus 273.15 divided by 15megapascal or 15000kilopascal. So, this gives a value of 0.01917 meter cube per kg.

So, this is the value of specific volume using the ideal gas equation, from the generalized compressibility chart for that we need to have the value of compressibility factor that is Z. For calculating that we should know P r that is reduced pressure and reduced temperature. And reduced pressure is P by P c, that is critical pressure and reduced temperature is T by the critical temperature.

The critical pressure is 22.06megapascal, critical temp is 647.1 kelvin. So, reduced pressure will be 15, which is the pressure divided by critical pressure 22.06. So, this comes out to be 0.679, for reduced temperature this is 350 plus 273.15, which is the temperature of the system divided by the critical temperature which is 647.1, so this is 0.962.

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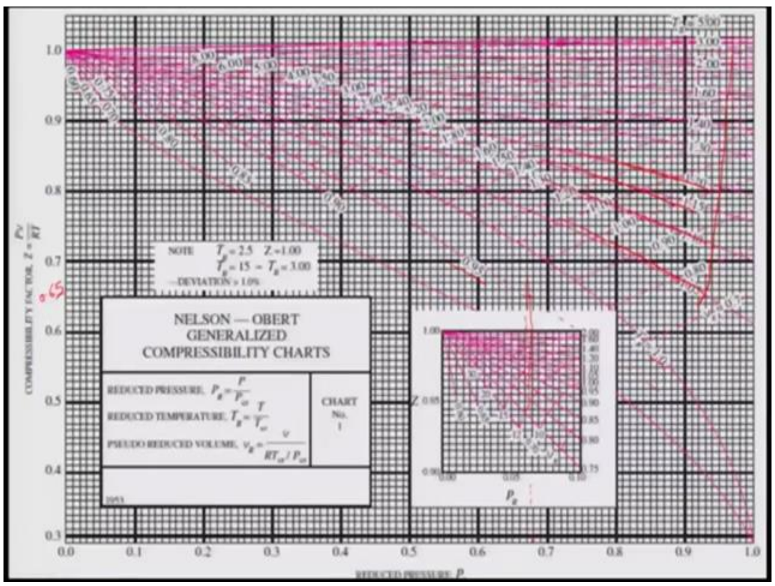

Now we need to calculate the value of compressibility factor Z using this value of P reduced pressure and reduced temperature from the compressibility chart. So, in the compressibility chart the value of P r is 0.679. So, it lies form here and the value of reduced temperature is 0.962. So, these are the different lines for different reduced temperature, so we have to look for a value of 0.962, this is around 1.0, this is a reduced temperature of 0.91.

So, a value will lie somewhere between these two, will lie somewhere like this. So, the approximately the value of Z V c, so this is around 0.65, so from this we get a value of Z which is closed to 0.65.

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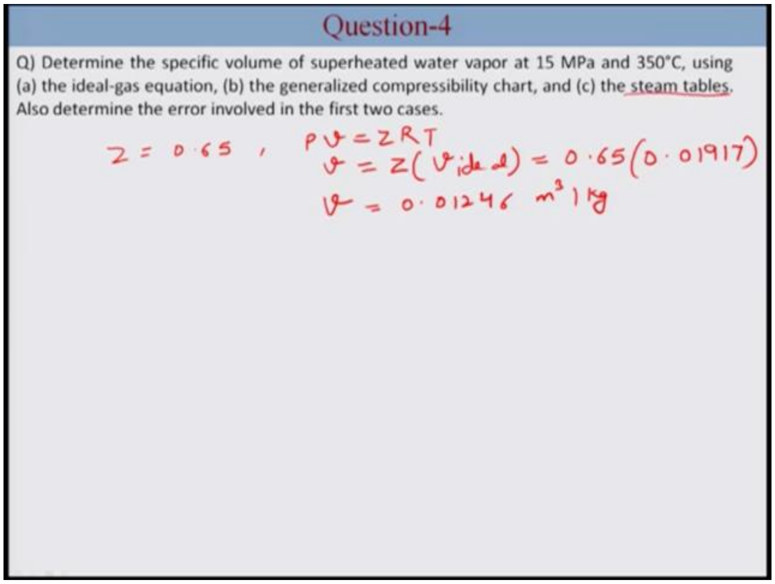

So now we have Z is equal to 0.65. We can apply the equation that is P v is equal to Z R T. This is also v is equal to Z multiplied by v, from the ideal gas equation which we have obtained earlier. So, this value is 0.65 multiplied by 0.01917, so the value of v is 0.01246 meter cube per kg. We also have to calculate the error involved in the two compare to this steam values to the steam table.

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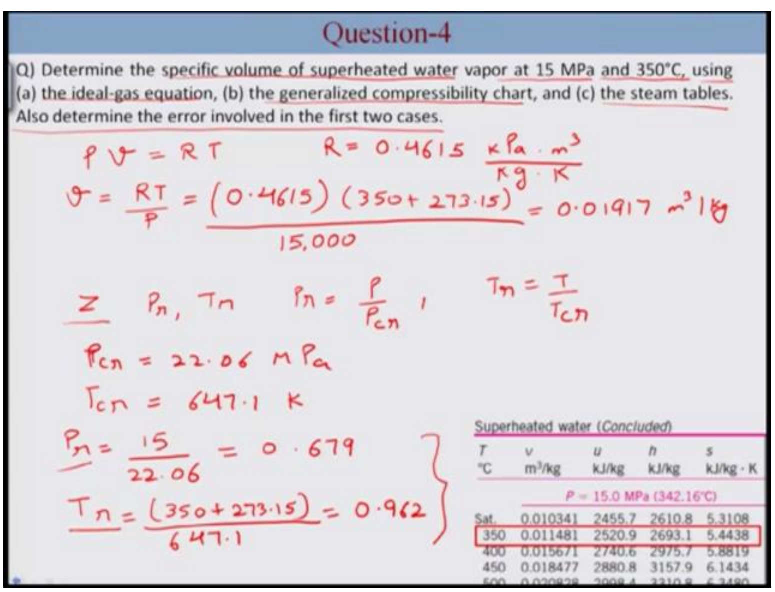

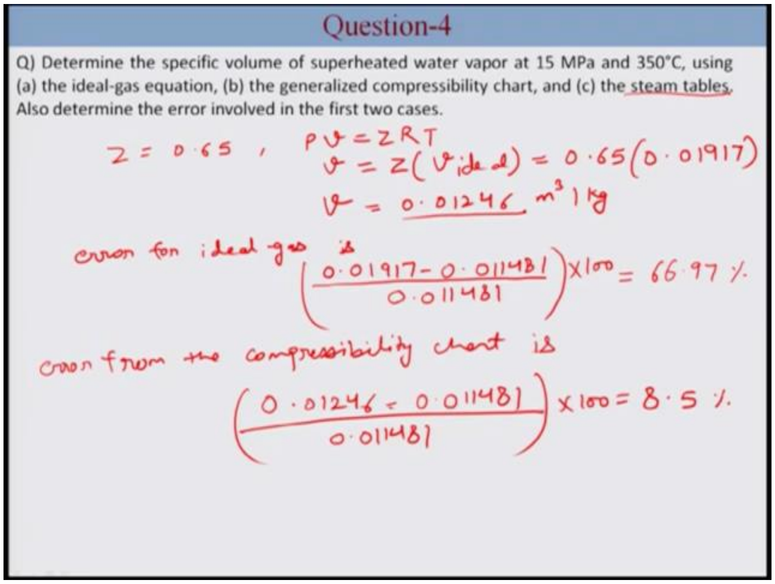

So, if we see in the steam table at 350 degree Celsius the value of v is 0.011481. So, error for ideal gas is 0.01917 minus 0.011481 divided by the value from the steam table multiplying it by 100 to get the percentage error. So, this comes out to be 66.97%, so the percentage error is very high. Similarly the error from the compressibility chart is 0.0. So, this is the value of specific volume obtained minus the value which is obtained from this steam table divided by the value from this steam stable multiplying this by 100, so this comes out to be 8.5%. So, the error has reduced considerably using this compressibility chart.

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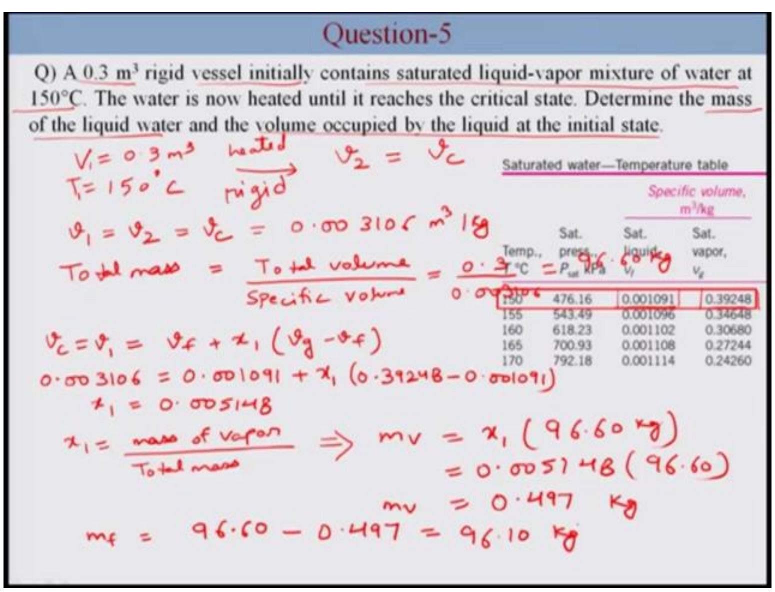

Moving on to the next question in this question a 0.3 meter cube rigid vessel initially contains saturated liquid vapor mixture of water at 150 degree Celsius. So, volume total volume is 0.3 meter cube and temperature is 150 degree Celsius. It is heated until it reaches the critical state, at critical state specific volume is equal to critical volume. This vessel is rigid and as no mass is going out or coming inside. So, the total specific volume initially is also same as v 2 which is same as the critical volume.

The critical volume of water is 0.003106 meter cube per kg. So, we can calculate the total mass of water in the vessel, total mass is total volume divided by specific volume. This is equal to 0.3 which is the total volume and the specific volume is 0.003106, this is equal to 96.60kg, so total mass is 96.60kg. Water is now heated until it reaches the critical state, we have to determine the mass of the liquid water and the volume occupied by the liquid at the initial state. We know that it is a mixture of saturated liquid vapor so, we can calculate the quality of this mixture.

So, from table of saturated water at 150 degree Celsius if we see the value of v f that a specific volume of liquid is this and this specific volume of vapor is this. We know the specific volume of the system. So, v c which is equal to v 1 is equal to v f plus x 1 multiplied by v g minus v f. So, putting the values of v c, v f is 0.001091 plus x 1 and v g minus v f, if this gives a value of x 1. So, 0.005148 this is the quality of the mixture in the initial state and we have to determine the mass of the liquid water and the volume occupied by the liquid at the initial state.

So, quality is mass of vapor divided by total mass. So, therefore total mass is known m v is equal to x 1 multiplied by total mass which is 96.60kg. So, x1 is 0.005148 multiplying it by total mass. So, mass of vapor is equal to 0.497kg. Mass of liquid is m f is equal to total mass 96.60 minus mass of vapor this is equal to 96.10kg. So, now we the mass of liquid water in the system…

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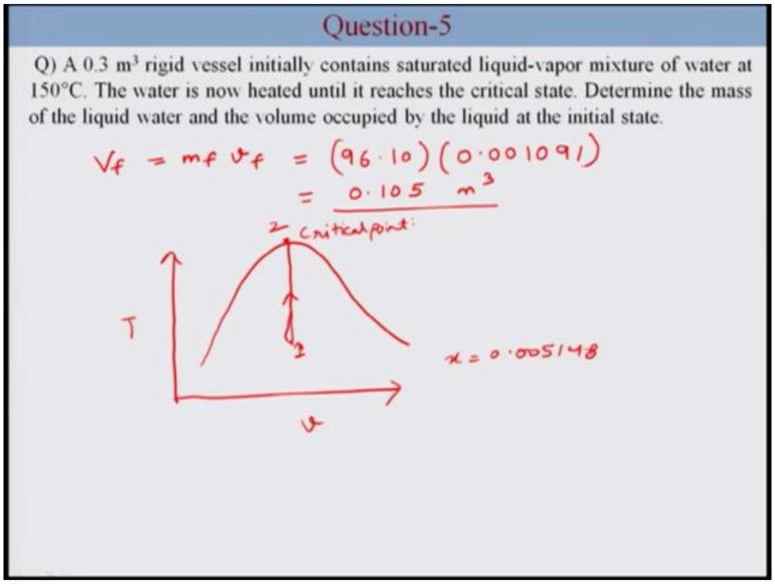

To calculate the volume occupied by the liquid v f is equal to mass of the liquid do specific volume of the liquid. So, mass of liquid is 96.10 and the specific volume of the liquid is 0.001091. So this is equal to 0.105 meter cube, so this is the initial volume occupied by the liquid.

If we draw the T v diagram for this this is T, v. So, some initially at point 1 it is a saturated liquid vapor mixture with x, which is 0.005148. And then the specific volume remains constant and it is heated such that it reaches a critical point. This is a vertical line and from this point it reaches to stage 2, which is a critical point, so this is critical point. So, with this we end this lecture, see you in the next lecture.