

Engineering Thermodynamics
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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-1

Q) Water initially at 300 kPa and 250°C is contained in a piston-cylinder device fitted with stops. The water is allowed to cool at constant pressure until it exists as a saturated vapor and the piston rests on the stops. Then the water continues to cool until the pressure is 100 kPa. On the T-v diagrams sketch, with respect to the saturation lines, the process curves passing through both the initial, intermediate, and final states of the water. Label the T, P and v values for end states on the process curves. Find the overall change in internal energy between the initial and final states per unit mass of water.



$$\left. \begin{aligned} P_1 &= 300 \text{ kPa} \\ T_1 &= 250^\circ\text{C} \end{aligned} \right\}$$

$$\left. \begin{aligned} P_2 &= 300 \text{ kPa} \\ x_2 &= 1 \text{ (sat. vapor)} \end{aligned} \right\}$$

$$P_3 = 100 \text{ kPa}$$

Temp., T °C	Sat. press., P _{sat} kPa	Specific volume, m ³ /kg	
		Sat. liquid, v _f	Sat. vapor, v _g
205	1724.3	0.001164	0.11508
210	1907.7	0.001173	0.10429
215	2105.9	0.001181	0.094680
220	2319.6	0.001190	0.086094
225	2549.7	0.001199	0.078405
230	2797.1	0.001209	0.071505
235	3062.6	0.001219	0.065300
240	3347.0	0.001229	0.059707
245	3651.2	0.001240	0.054656
250	3976.2	0.001252	0.050085

Question 1 water 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 3976.2 kilopascal. So, this pressure is much higher than the applied pressure which is 300 kilopascal, 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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Question-1

$P_1 = 300 \text{ kPa}$
 $T_1 = 250^\circ\text{C}$

$P_2 = 300 \text{ kPa}$
 $x_2 = 1 \text{ (sat. vapor)}$

Superheated water

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
<i>P = 0.30 MPa (133.52°C)</i>				
Sat.	0.60582	2543.2	2724.9	6.9917
150	0.63402	2571.0	2761.2	7.0792
200	0.71643	2651.0	2865.9	7.3132
250	0.79645	2728.9	2967.9	7.5180
300	0.87535	2807.0	3069.6	7.7037
400	1.03155	2966.0	3275.5	8.0347
500	1.18672	3130.6	3486.6	8.3271
600	1.34139	3301.6	3704.0	8.5915
700	1.49580	3479.5	3928.2	8.8345
800	1.65004	3664.3	4159.3	9.0605
900	1.80417	3856.0	4397.3	9.2725
1000	1.95824	4054.5	4642.0	9.4726
1100	2.11226	4259.4	4893.1	9.6624
1200	2.26624	4470.3	5150.2	9.8431
1300	2.42019	4686.9	5413.0	10.0157

$u_1 = 2728.9 \text{ kJ/kg}$
 $T_2 = 133.52^\circ\text{C}$
 $u_2 = v_g = 0.60582 \text{ m}^3/\text{kg}$

Saturated water—Pressure table

Press., P kPa	Sat. temp., T _{sat} °C	Specific volume, m³/kg		Internal energy, kJ/kg		
		Sat. liquid, v _f	Sat. vapor, v _g	Sat. liquid, u _f	Evap., u _{fg}	Sat. vapor, u _g
300	133.52	0.001073	0.60582	561.11	1982.1	2543.2
325	136.27	0.001076	0.56199	572.84	1973.1	2545.9
350	138.86	0.001079	0.52422	583.89	1964.6	2548.5
375	141.30	0.001081	0.49133	594.32	1956.6	2550.9
400	143.61	0.001084	0.46242	604.22	1948.9	2553.1

So, we need to look into superheated water table. In superheated water table at 250 degree Celsius and 300 kilopascal which is equivalent to 0.3 mega Pascal. The values are these to the value of internal energy U 1 is 2728.9 kilojoule 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.

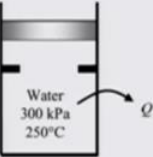
So, taking the properties of water from the saturated water table at a pressure of 300 kilopascal, so it is a saturated vapor. So, the temperature at this state will be 133.52 this value. So, T 2 will be 133.52 which is the saturation temperature at this pressure and the value of specific volume will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

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Question-1

Saturated water—Pressure table

$P_3 = 100 \text{ kPa}$
 $v_3 = 0.6058 \text{ m}^3/\text{kg} = v_2$



Press., P kPa	Sat. temp., T _{sat} °C	Specific volume, m ³ /kg		Internal energy, kJ/kg		
		Sat. liquid, v _f	Sat. vapor, v _g	Sat. liquid, u _f	Evap., u _{fg}	Sat. vapor, u _g
75	91.76	0.001037	2.2172	384.36	2111.8	2496.1
100	99.61	0.001043	1.6941	417.40	2088.2	2505.6
101.325	99.97	0.001043	1.6734	418.95	2087.0	2506.0
125	105.97	0.001048	1.3750	444.23	2068.8	2513.0
150	111.35	0.001053	1.1594	466.97	2052.3	2519.2

$$v_3 = v_f + x_3 (v_g - v_f)$$

$$0.6058 = 0.001043 + x_3 (1.6941 - 0.001043)$$

$$x_3 = 0.3571$$

$$u_3 = u_f + x_3 (u_g - u_f)$$

$$u_3 = 417.40 + 0.3571 (2505.6 - 417.40)$$

$$u_3 = 1163.30 \text{ kJ/kg}$$

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.

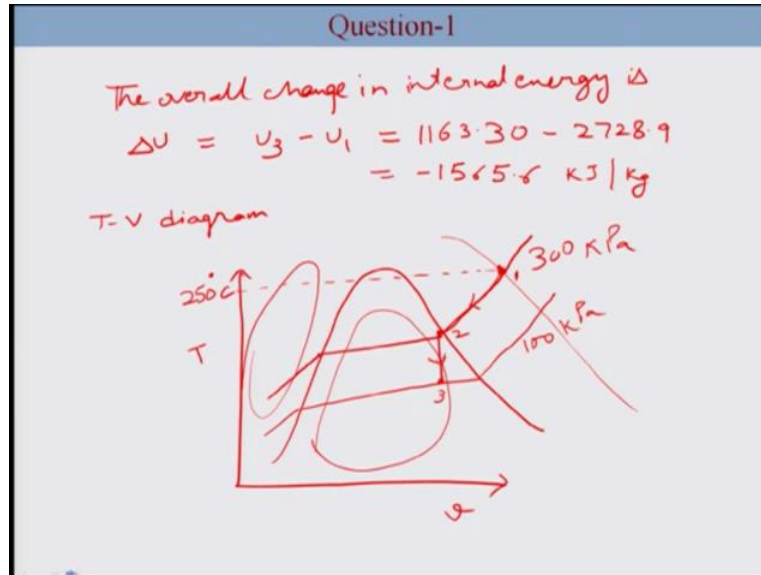
So, specific volume is same as V 2. So, this V 3 is same as V 2, from this saturated water table if we see at 100kilopascal the saturation temperature is 99.61 degree Celsius and the values of specific volume of liquid which is 0.001043 and for vapor it is 1.6941.

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 1163.30 kilojoule 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 ΔU 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 300 kilopascal.

So, if we draw a line corresponding to 300 kilopascal. So, this point should lie at 300 kilopascal and the temperature is also given which is 250 degree Celsius. So, the temperature here is 250 degree Celsius and pressure is 300 kilopascal. 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 100 kilopascal, so, pressure is reducing, so for a 100 kilopascal 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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Question-2

Complete this table for water:

T, °C	P, Kpa	V, m ³ /kg	Phase description
143.61	400	0.46242	Saturated vapor

Saturated water—Pressure table

Press., P kPa	Sat. temp., T _{sat} °C	Specific volume, m ³ /kg		Internal energy, kJ/kg			Enthalpy, kJ/kg		
		Sat. liquid, v _f	Sat. vapor, v _g	Sat. liquid, u _f	Evap., u _{fg}	Sat. vapor, u _g	Sat. liquid, h _f	Evap., h _{fg}	Sat. vapor, h _g
300	133.52	0.001073	0.60582	561.11	1982.1	2543.2	561.43	2163.5	2724.9
325	136.27	0.001076	0.56199	572.84	1973.1	2545.9	573.19	2155.4	2728.6
350	138.86	0.001079	0.52422	583.89	1964.6	2548.5	584.26	2147.7	2732.0
375	141.30	0.001081	0.49133	594.32	1956.6	2550.9	594.73	2140.4	2735.1
400	143.61	0.001084	0.46242	604.22	1948.9	2553.1	604.66	2133.4	2738.1

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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Question-2

Complete this table for water:

T, °C	P, Kpa	V, m ³ /kg	Phase description
250	500	0.47443	Superheated state

Saturated water—Temperature table (Continued)

Temp., T °C	Sat. press., P _{sat} kPa	Specific volume, m ³ /kg		Internal energy, kJ/kg		
		Sat. liquid, v _f	Sat. vapor, v _g	Sat. liquid, u _f	Evap., u _{fg}	Sat. vapor, u _g
230	2797.1	0.001209	0.071505	986.76	1616.1	2602.9
235	3062.6	0.001219	0.065300	1010.0	1593.2	2603.2
240	3347.0	0.001229	0.059707	1033.4	1569.8	2603.1
245	3651.2	0.001240	0.054656	1056.9	1546.7	2602.7
250	3976.2	0.001252	0.050085	1080.7	1521.1	2601.8

But > P (500 kPa)

Superheated water

T °C	v m ³ /kg	u kJ/kg	h kJ/kg	s kJ/kg · K
P = 0.50 MPa (151.83°C)				
Sat.	0.37483	2560.7	2748.1	6.8207
200	0.42503	2643.3	2855.8	7.0610
250	0.47443	2723.8	2961.0	7.2725
300	0.52261	2803.3	3064.6	7.4614
350	0.57015	2883.0	3168.1	7.6346
400	0.61731	2963.7	3272.4	7.7956
500	0.71095	3129.0	3484.5	8.0893
600	0.80409	3300.4	3702.5	8.3544
700	0.89696	3478.6	3927.0	8.5978

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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Question-2

Complete this table for water:

T, °C	P, Kpa	V, m ³ /kg	Phase description
120	5000	0.0010576	Compressed liquid

Saturated water—Temperature table (Continued)						Compressed liquid water					
Temp., T °C	Sat. press., P _{sat} kPa	Specific volume, m ³ /kg		Internal energy, kJ/kg			T °C	v m ³ /kg	u kJ/kg	h kJ/kg	s kJ/kg · K
		Sat. liquid, v _f	Sat. vapor, v _g	Sat. liquid, u _f	Evap., u _{fg}	Sat. vapor, u _g					
<i>P = 5 MPa (263.94°C)</i>											
Sat.	0.0012862	1148.1	1154.5	2.9207							
0	0.0009977	0.04	5.03	0.0001							
20	0.0009996	83.61	88.61	0.2954							
40	0.0010057	166.92	171.95	0.5705							
60	0.0010149	250.29	255.36	0.8287							
80	0.0010267	333.82	338.96	1.0723							
100	0.0010410	417.65	422.85	1.3034							
120	0.0010576	501.91	507.19	1.5236							
140	0.0010769	586.80	592.18	1.7344							

$P_{sat} < P (5000 \text{ kPa})$

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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Question-3

Saturated water—Temperature table (Continued)

Temp., T °C	Sat. press., P _{sat} kPa	Specific volume, m ³ /kg		Internal energy, kJ/kg			Enthalpy, kJ/kg		
		Sat. liquid, v _f	Sat. vapor, v _g	Sat. liquid, u _f	Evap., u _{fg}	Sat. vapor, u _g	Sat. liquid, h _f	Evap., h _{fg}	Sat. vapor, h _g
75	38.597	0.001026	4.1291	313.99	2161.3	2475.3	314.03	2320.6	2634.6
80	47.416	0.001029	3.4053	334.97	2146.6	2481.6	335.02	2308.0	2643.0
85	57.868	0.001032	2.8261	355.96	2131.9	2487.8	356.02	2295.3	2651.4
90	70.183	0.001036	2.3593	376.97	2117.0	2494.0	377.04	2282.5	2659.6
95	84.609	0.001040	1.9808	398.00	2102.0	2500.1	398.09	2269.6	2667.6

Compressed liquid water				
T °C	v m ³ /kg	u kJ/kg	h kJ/kg	s kJ/kg · K
P = 20 MPa (365.75°C)				
Sat.	0.0020378	1785.8	1826.6	4.0146
0	0.0009904	0.23	20.03	0.0005
20	0.0009929	82.71	102.57	0.2921
40	0.0009992	165.17	185.16	0.5646
60	0.0010084	247.75	267.92	0.8208
80	0.0010199	330.50	350.90	1.0627
100	0.0010337	413.50	434.17	1.2920

$$v = \left(\frac{0.001029 - 0.0010199}{0.0010199} \right) \times 100 = 0.90\%$$

$$u = \left(\frac{334.97 - 330.50}{330.50} \right) \times 100 = 1.35\%$$

$$h = \left(\frac{350.90 - 335.02}{350.90} \right) \times 100 = 4.53\%$$

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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Question-4

Q) Determine the specific volume of superheated water vapor at 15 MPa and 350°C, using (a) the ideal-gas equation, (b) the generalized compressibility chart, and (c) the steam tables. Also determine the error involved in the first two cases.

$$Pv = RT \quad R = 0.4615 \frac{\text{kJ} \cdot \text{Pa} \cdot \text{m}^3}{\text{kg} \cdot \text{K}}$$

$$v = \frac{RT}{P} = \frac{(0.4615)(350 + 273.15)}{15,000} = 0.01917 \text{ m}^3/\text{kg}$$

$Z = P_r, T_r \quad P_r = \frac{P}{P_{cn}}, \quad T_r = \frac{T}{T_{cn}}$

$P_{cn} = 22.06 \text{ MPa}$
 $T_{cn} = 647.1 \text{ K}$

$P_r = \frac{15}{22.06} = 0.679$
 $T_r = \frac{(350 + 273.15)}{647.1} = 0.962$

Superheated water (Concluded)				
T	v	u	h	s
°C	m ³ /kg	kJ/kg	kJ/kg	kJ/kg · K
P = 15.0 MPa (342.16°C)				
Sat.	0.010341	2455.7	2610.8	5.3108
350	0.011481	2520.9	2693.1	5.4438
400	0.015671	2740.6	2975.7	5.8819
450	0.018477	2880.8	3157.9	6.1434
500	0.022828	2998.4	3310.8	6.3480

Moving to the next question in question 4, determine this specific volume of superheated water vapor at 15 megapascal 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.

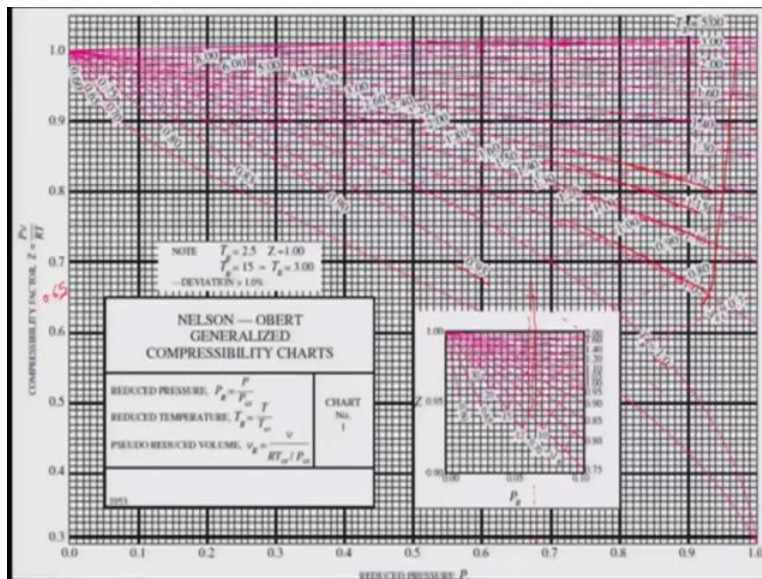
So, at 15 mega Pascal and 350 degree Celsius the water is in the superheated state. So, in the you was be ideal gas equation, so it is P v is equal to RT. For water R is 0.4615 kilopascal meter cube per kg kelvin, v is equal to RT by P is 0.4615 temperature is 350 plus 273.15 divided by 15 megapascal or 15000 kilopascal. 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/P_c , that is critical pressure and reduced temperature is T/T_c by the critical temperature.

The critical pressure is 22.06 megapascal, 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_r 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 from 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 at P_r , so this is around 0.65, so from this we get a value of Z which is closed to 0.65.

(Refer Slide Time: 22:10)

Question-4

Q) Determine the specific volume of superheated water vapor at 15 MPa and 350°C, using (a) the ideal-gas equation, (b) the generalized compressibility chart, and (c) the steam tables. Also determine the error involved in the first two cases.

$$Z = 0.65, \quad P v = Z R T$$

$$v = Z (v_{ideal}) = 0.65 (0.01917)$$

$$v = 0.01246 \text{ m}^3/\text{kg}$$

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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Question-4

Q) Determine the specific volume of superheated water vapor at 15 MPa and 350°C, using (a) the ideal-gas equation, (b) the generalized compressibility chart, and (c) the steam tables. Also determine the error involved in the first two cases.

$$P v = R T \quad R = 0.4615 \frac{\text{kJ} \cdot \text{Pa} \cdot \text{m}^3}{\text{kg} \cdot \text{K}}$$

$$v = \frac{R T}{P} = \frac{(0.4615) (350 + 273.15)}{15,000} = 0.01917 \text{ m}^3/\text{kg}$$

$$Z = \frac{P_n}{P_c n}, \quad T_n = \frac{T}{T_c n}$$

$$P_c n = 22.06 \text{ MPa}$$

$$T_c n = 647.1 \text{ K}$$

$$P_n = \frac{15}{22.06} = 0.679$$

$$T_n = \frac{(350 + 273.15)}{647.1} = 0.962$$

Superheated water (Concluded)				
T	v	u	h	s
°C	m ³ /kg	kJ/kg	kJ/kg	kJ/kg · K
P = 15.0 MPa (342.16°C)				
Sat.	0.010341	2455.7	2610.8	5.3108
350	0.011481	2520.9	2693.1	5.4438
400	0.015671	2740.6	2975.7	5.8819
450	0.018477	2880.8	3157.9	6.1434
500	0.020828	2998.4	3310.8	6.3480

Question-4

Q) Determine the specific volume of superheated water vapor at 15 MPa and 350°C, using (a) the ideal-gas equation, (b) the generalized compressibility chart, and (c) the steam tables. Also determine the error involved in the first two cases.

$$Z = 0.65, \quad Pv = ZRT$$

$$v = Z(v_{\text{ideal}}) = 0.65(0.01917)$$

$$v = 0.01246 \text{ m}^3/\text{kg}$$

error for ideal gas is

$$\left(\frac{0.01917 - 0.011481}{0.011481} \right) \times 100 = 66.97\%$$

error from the compressibility chart is

$$\left(\frac{0.01246 - 0.011481}{0.011481} \right) \times 100 = 8.5\%$$

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 table 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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Question-5

Q) A 0.3 m³ rigid vessel initially contains saturated liquid-vapor mixture of water at 150°C. The water is now heated until it reaches the critical state. Determine the mass of the liquid water and the volume occupied by the liquid at the initial state.

$V_1 = 0.3 \text{ m}^3$ heated
 $T = 150^\circ\text{C}$ rigid $\rightarrow v_2 = v_c$

$v_1 = v_2 = v_c = 0.003106 \text{ m}^3/\text{kg}$

Total mass = $\frac{\text{Total volume}}{\text{Specific volume}} = \frac{0.3 \text{ m}^3}{0.003106 \text{ m}^3/\text{kg}} = 96.60 \text{ kg}$

Temp., °C	Sat. pres., kPa	Sat. liquid, v_f	Sat. vapor, v_g
150	476.16	0.001091	0.39248
155	543.49	0.001096	0.34648
160	618.23	0.001102	0.30680
165	700.93	0.001108	0.27244
170	792.18	0.001114	0.24260

$v_c = v_1 = v_f + x_1(v_g - v_f)$

$$0.003106 = 0.001091 + x_1(0.39248 - 0.001091)$$

$$x_1 = 0.005148$$

$x_1 = \frac{\text{mass of vapor}}{\text{Total mass}} \Rightarrow mv = x_1(96.60 \text{ kg})$

$$= 0.005148(96.60)$$

$$mv = 0.497 \text{ kg}$$

$$m_f = 96.60 - 0.497 = 96.10 \text{ kg}$$

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, x_1 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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Question-5

Q) A 0.3 m^3 rigid vessel initially contains saturated liquid-vapor mixture of water at 150°C . The water is now heated until it reaches the critical state. Determine the mass of the liquid water and the volume occupied by the liquid at the initial state.

$$V_f = m_f v_f = (96.10)(0.001091)$$
$$= 0.105 \text{ m}^3$$

$x = 0.005148$

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.