Engineering Thermodynamics
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Lecture 12
Thermodynamic properties of a pure substance

Welcome back! So we were discussing properties and we will continue the discussion.

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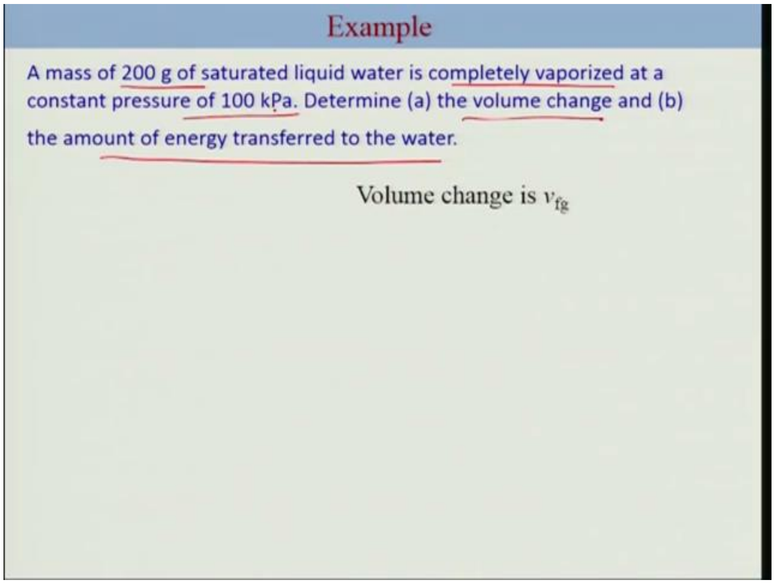

Example

A mass of 200 g of saturated liquid water is completely vaporized at a constant pressure of 100 kPa. Determine (a) the volume change and (b) the amount of energy transferred to the water.

Volume change is v_{fg}

We will take another example example of a saturated liquid water of a mass of 200 gram which is completely vaporized at a constant pressure 100 kilopascal. So, what we have to determine is the volume change and a amount of energy transfer to the water and why there is to take make use of that tables in order to solve the problem okay.

So, let us look at it to what kind of table we should study, we have been given a 100 kilopascal as a constant pressure.

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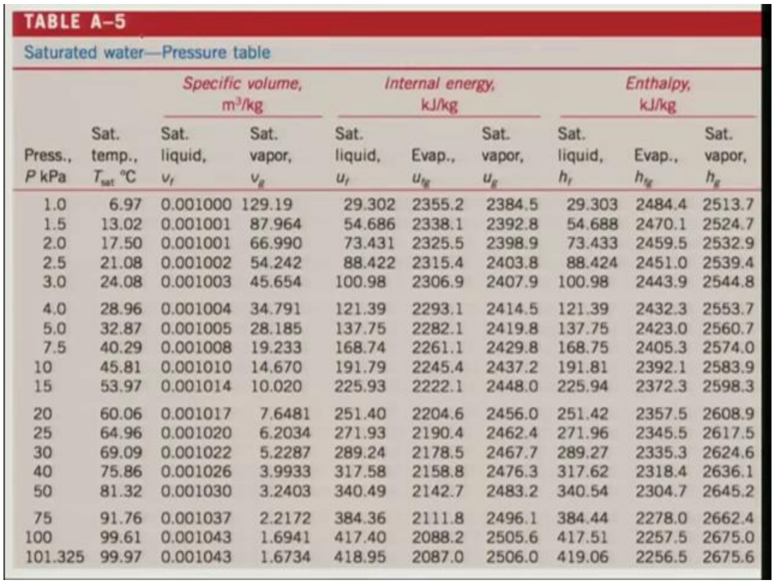

TABLE A–5

Saturated water—Pressure table

Press., P kPa	Sat. temp., T_{sat} °C	Specific volume, m³/kg Sat. liquid, v_f	Sat. vapor, v_g	Internal energy, kJ/kg Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Enthalpy, kJ/kg Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8
4.0	28.96	0.001004	34.791	121.39	2293.1	2414.5	121.39	2432.3	2553.7
5.0	32.87	0.001005	28.185	137.75	2282.1	2419.8	137.75	2423.0	2560.7
7.5	40.29	0.001008	19.233	168.74	2261.1	2429.8	168.75	2405.3	2574.0
10	45.81	0.001010	14.670	191.79	2245.4	2437.2	191.81	2392.1	2583.9
15	53.97	0.001014	10.020	225.93	2222.1	2448.0	225.94	2372.3	2598.3
20	60.06	0.001017	7.6481	251.40	2204.6	2456.0	251.42	2357.5	2608.9
25	64.96	0.001020	6.2034	271.93	2190.4	2462.4	271.96	2345.5	2617.5
30	69.09	0.001022	5.2287	289.24	2178.5	2467.7	289.27	2335.3	2624.6
40	75.86	0.001026	3.9933	317.58	2158.8	2476.3	317.62	2318.4	2636.1
50	81.32	0.001030	3.2403	340.49	2142.7	2483.2	340.54	2304.7	2645.2
75	91.76	0.001037	2.2172	384.36	2111.8	2496.1	384.44	2278.0	2662.4
100	99.61	0.001043	1.6941	417.40	2088.2	2505.6	417.51	2257.5	2675.0
101.325	99.97	0.001043	1.6734	418.95	2087.0	2506.0	419.06	2256.5	2675.6

So, essentially we should take a look at the saturated water table A 5 okay. Because you have the pressure, so let us look at it.

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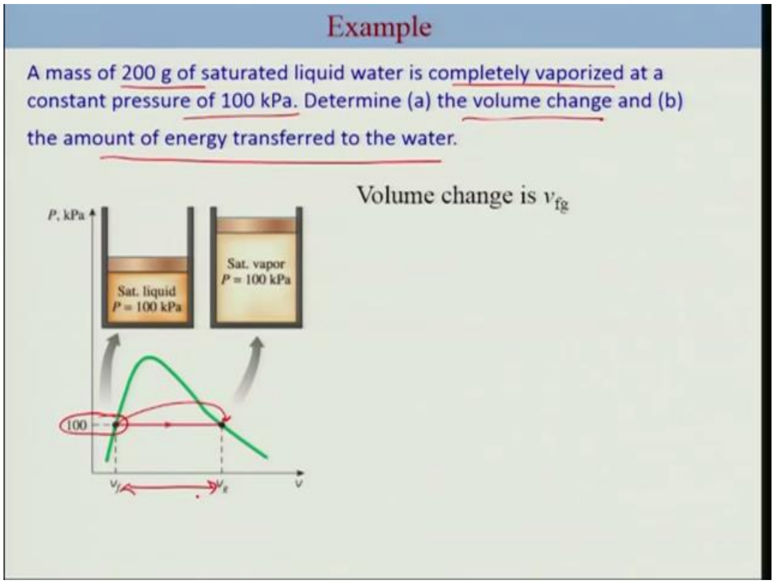

Example

A mass of 200 g of saturated liquid water is completely vaporized at a constant pressure of 100 kPa. Determine (a) the volume change and (b) the amount of energy transferred to the water.

Volume change is v_{fg}

So, the idea behind this question it is that you have a saturated liquid water which is completely vaporized which means at 100kilopascal this fluid is vaporized to the gas or the vapor and then we need to find out the change in the volume.

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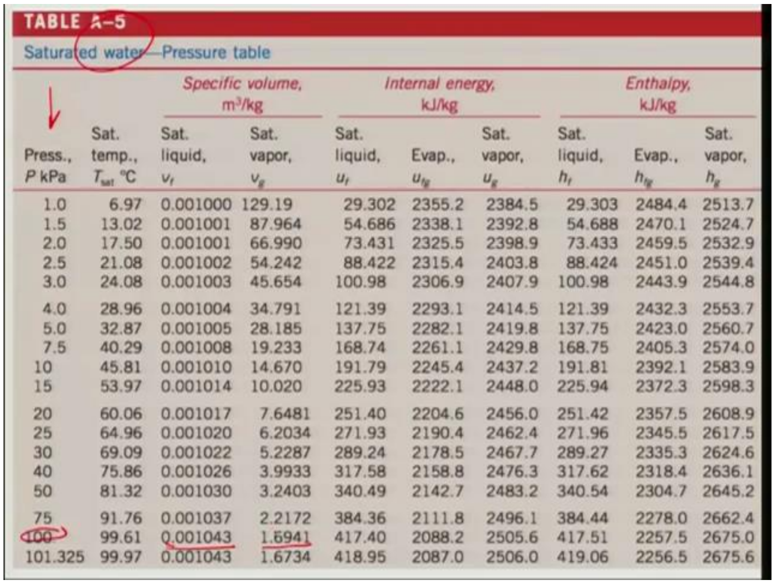

TABLE A–5

Saturated water—Pressure table

		Specific volume, m³/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg		
Press., P kPa	Sat. temp., T_{sat} °C	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
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7
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5.0	32.87	0.001005	28.185	137.75	2282.1	2419.8	137.75	2423.0	2560.7
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101.325	99.97	0.001043	1.6734	418.95	2087.0	2506.0	419.06	2256.5	2675.6

So, let us look at the table over, so this is a 100kolopascal table A 5 okay. You have looking at the pressure and the corresponding 100kilopascal the saturated liquid value for this specific volume is given here and as for the corresponding vapor is here okay. So, we are going to make use of these two values and then we are going to plug in.

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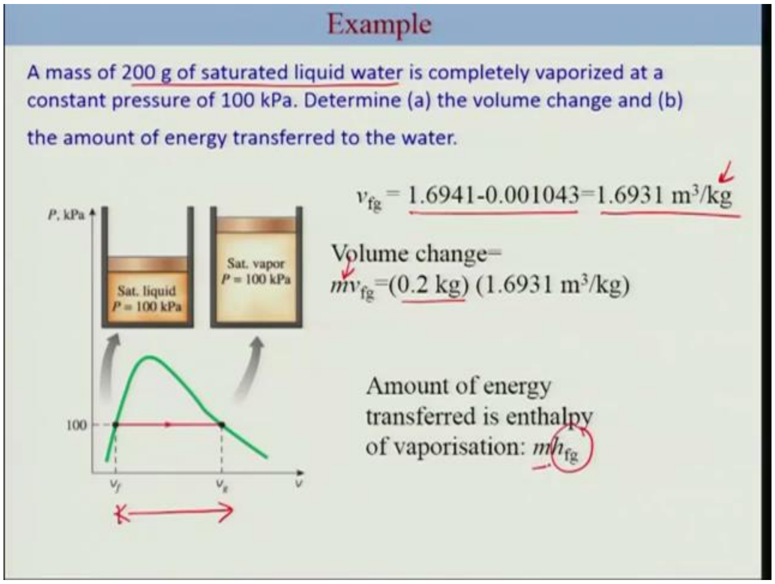

Example

A mass of 200 g of saturated liquid water is completely vaporized at a constant pressure of 100 kPa. Determine (a) the volume change and (b) the amount of energy transferred to the water.

v_{fg} = 1.6941-0.001043=1.6931 m^3/kg

Volume change=
mv_{fg}=(0.2 kg) (1.6931 m^3/kg)

Amount of energy transferred is enthalpy of vaporisation: mh_{fg}

So, we find out the difference because we wanted the change in the volume okay. But this is per unit mass. So, this difference is given in this from, so then we need to multiply this value which we found or which we based on the table by the mass of the saturated system which is given as 0.2 kg and thus the total volume can be calculate.

So, that is a part 1 or 2 find out the volume change what about the amount of energy transfered in a similar line you can also find out first the h f g and then we multiplied by your mass okay.

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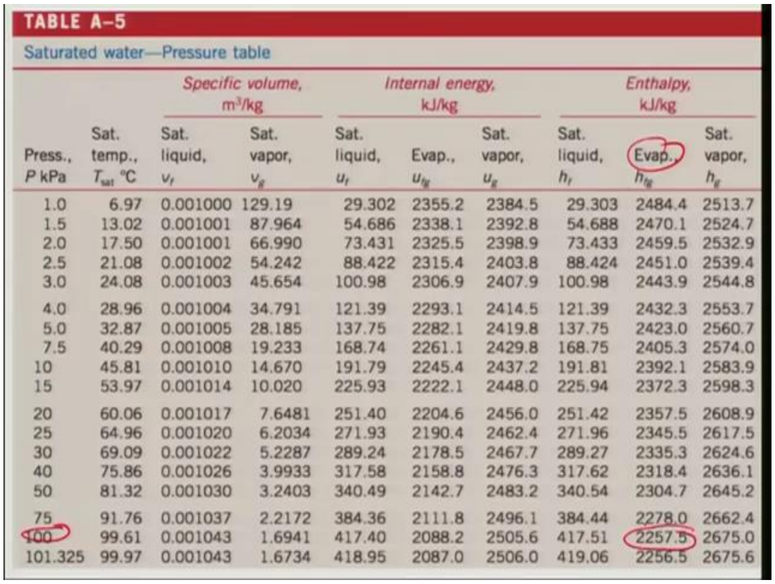

TABLE A–5

Saturated water—Pressure table

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Press., P kPa	Sat. temp., T_{sat} °C	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
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Then just look at again the table here the corresponding 100 kilopascal the h f g is given already this is the evaporation enthalpy and this is values already given to you.

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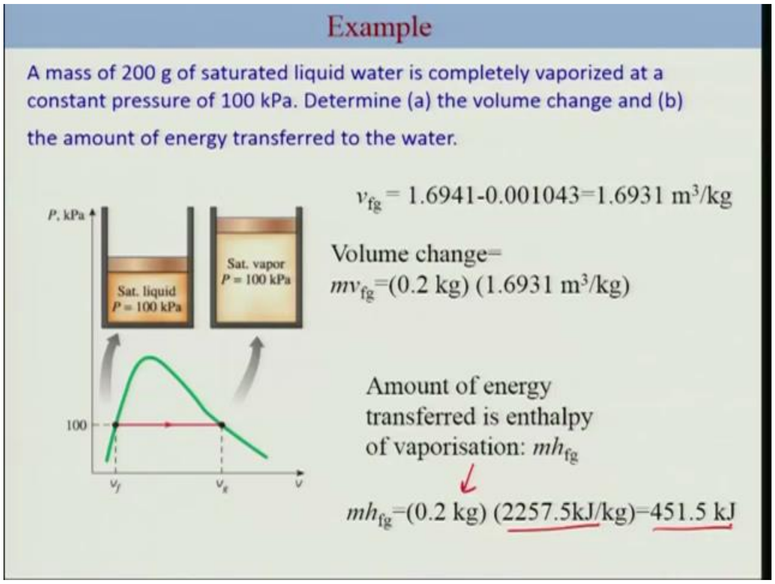

Example

A mass of 200 g of saturated liquid water is completely vaporized at a constant pressure of 100 kPa. Determine (a) the volume change and (b) the amount of energy transferred to the water.

$v_{fg} = 1.6941 - 0.001043 = 1.6931\ \mathrm{m^3/kg}$

Volume change=
$mv_{fg} = (0.2\ \mathrm{kg})\ (1.6931\ \mathrm{m^3/kg})$

Amount of energy
transferred is enthalpy
of vaporisation: mh_{fg}

$mh_{fg} = (0.2\ \mathrm{kg})\ \underline{(2257.5\mathrm{kJ/kg})} = \underline{451.5\ \mathrm{kJ}}$

So, we just take the value we multiply again by mass and we get this value okay. So, that is how we are going to calculate, the total amount of energy transferred to system in order to vaporize.

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TABLE A–11

Saturated refrigerant-134a—Temperature table

		Specific volume, m³/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg·K		
Temp., T °C	Sat. press., P_{sat} kPa	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	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
−40	51.25	0.0007053	0.36064	−0.036	207.42	207.38	0.00	225.86	225.86	0.00000	0.96869	0.96869
−38	56.86	0.0007082	0.32718	2.472	206.06	208.53	2.512	224.62	227.13	0.01071	0.95516	0.96588
−36	62.95	0.0007111	0.29740	4.987	204.69	209.68	5.032	223.37	228.40	0.02137	0.94182	0.96319
−34	69.56	0.0007141	0.27082	7.509	203.32	210.83	7.559	222.10	229.66	0.03196	0.92867	0.96063

TABLE A–12

Saturated refrigerant-134a—Pressure table

		Specific volume, m³/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg·K		
Press., P kPa	Sat. temp., T_{sat} °C	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	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
60	−36.95	0.0007097	0.31108	3.795	205.34	209.13	3.837	223.96	227.80	0.01633	0.94812	0.96445
70	−33.87	0.0007143	0.26921	7.672	203.23	210.90	7.722	222.02	229.74	0.03264	0.92783	0.96047
80	−31.13	0.0007184	0.23749	11.14	201.33	212.48	11.20	220.27	231.47	0.04707	0.91009	0.95716
90	−28.65	0.0007222	0.21261	14.30	199.60	213.90	14.36	218.67	233.04	0.06003	0.89431	0.95434
100	−26.37	0.0007258	0.19255	17.19	198.01	215.21	17.27	217.19	234.46	0.07182	0.88008	0.95191

So, by as we already discuss in the last lecture there were other fluid tables available that is for saturated refrigerant.

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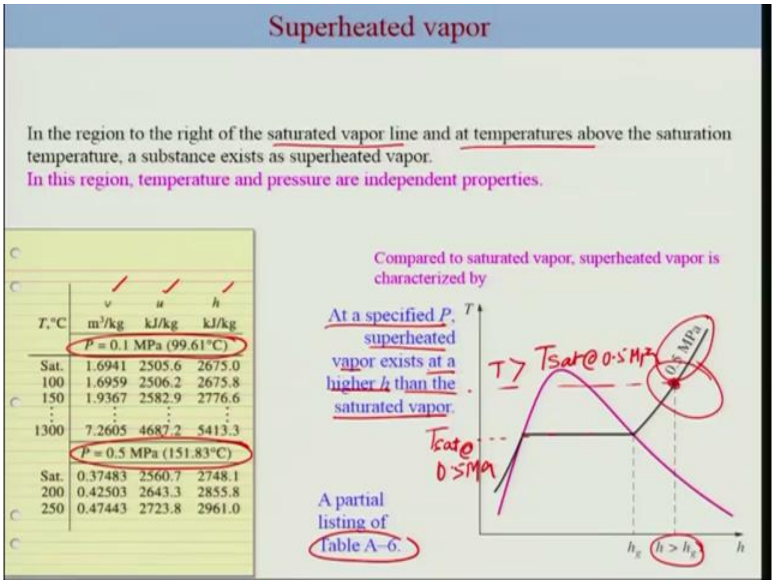

Superheated vapor

In the region to the right of the saturated vapor line and at temperatures above the saturation temperature, a substance exists as superheated vapor.

In this region, temperature and pressure are independent properties.

T, °C	v m³/kg	u kJ/kg	h kJ/kg
	P = 0.1 MPa (99.61°C)		
Sat.	1.6941	2505.6	2675.0
100	1.6959	2506.2	2675.8
150	1.9367	2582.9	2776.6
⋮	⋮	⋮	⋮
1300	7.2605	4687.2	5413.3
	P = 0.5 MPa (151.83°C)		
Sat.	0.37483	2560.7	2748.1
200	0.42503	2643.3	2855.8
250	0.47443	2723.8	2961.0

Compared to saturated vapor, superheated vapor is characterized by

At a specified P, superheated vapor exists at a higher h than the saturated vapor.

A partial listing of Table A–6.

Now let us look at a now the superheated vapor case okay. This is the case were it is going to be away from the saturated vapor line in the right side of the saturated vapor line and at a temperature above the saturation temperature.

So, what does it mean that means let say you take a pressure, the saturation temperature is here corresponding to this pressure 0.5 mega Pascal. So, this particular point which is represented by the circle the temperature here is greater than T sat at 0.5. So, this is indicating superheated vapor okay. And it is also where you ())(3:35) if you look at this diagram that enthalpy of superheated vapor should be more than the corresponding value at saturation h g. The reason is that you have also imported more heat to the system and apparently that this transfer into the enthalpy okay.

So, at a at a specified pressure superheated vapor exist at a higher h than the saturated vapor. So, to help in order to solve problems a separate table is given for superheated water and a table looks like is given like a specific volume, specific internal energy, and specific enthalpy okay for different pressures and this is a partial list.

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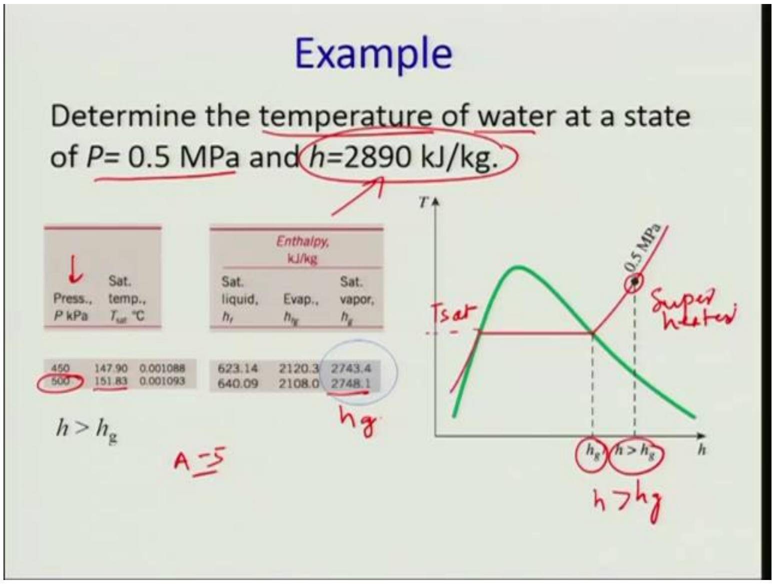

Example

Determine the temperature of water at a state of $P = 0.5$ MPa and $h = 2890$ kJ/kg.

Press., P kPa	Sat. temp., T_{sat} °C	
450	147.90	0.001088
500	151.83	0.001093

Enthalpy, kJ/kg		
Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g
623.14	2120.3	2743.4
640.09	2108.0	2748.1

hg

$h > h_g$

A-5

So, you can do an example, so this is a the problem where we have to find the temperature of a water at a state 0.5 mega Pascal and what we have been given is there specific enthalpy. So, the first thing you have to find out what is the state of such a water because there nothing is mentioned value this is a compress liquid or saturated liquid or superheated the first thing is to identify it is state and you can look at the table for example.

So, the first thing which we have going to do is find out the corresponding T sat. We know the T sat from the table we go back and look at the table A 5, where the pressure is given and we have to find out the saturation temperature.

So, this is the 500 kilopascal equivalent to 0.5 mega Pascal and the corresponding temperature is here and the h of g which is here is given by this value 2748. So, at this corresponding saturation temperature the enthalpy of the vapor is less than the value which is given that mean enthalpy of the system. So, that means h is more than h g. So, this indicates that this particular state should be higher along this red line because this is at a constant pressure okay.

So, this must be a superheated vapor okay. Now what you need to do in order to find the temperature, so you have to go and to the another table which this all the properties for superheated our water okay.

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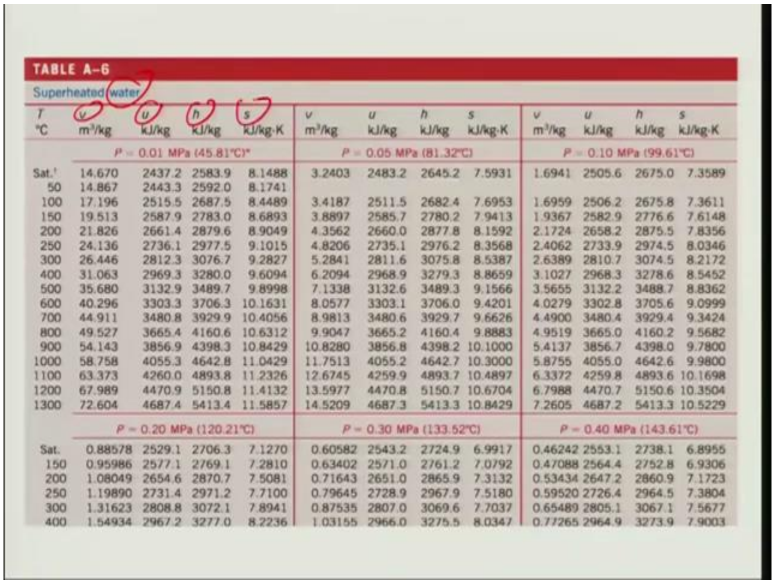

TABLE A–6

Superheated water

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
	P = 0.01 MPa (45.81°C)*				P = 0.05 MPa (81.32°C)				P = 0.10 MPa (99.61°C)			
Sat.†	14.670	2437.2	2583.9	8.1488	3.2403	2483.2	2645.2	7.5931	1.6941	2505.6	2675.0	7.3589
50	14.867	2443.3	2592.0	8.1741								
100	17.196	2515.5	2687.5	8.4489	3.4187	2511.5	2682.4	7.6953	1.6959	2506.2	2675.8	7.3611
150	19.513	2587.9	2783.0	8.6893	3.8897	2585.7	2780.2	7.9413	1.9367	2582.9	2776.6	7.6148
200	21.826	2661.4	2879.6	8.9049	4.3562	2660.0	2877.8	8.1592	2.1724	2658.2	2875.5	7.8356
250	24.136	2736.1	2977.5	9.1015	4.8206	2735.1	2976.2	8.3568	2.4062	2733.9	2974.5	8.0346
300	26.446	2812.3	3076.7	9.2827	5.2841	2811.6	3075.8	8.5387	2.6389	2810.7	3074.5	8.2172
400	31.063	2969.3	3280.0	9.6094	6.2094	2968.9	3279.3	8.8659	3.1027	2968.3	3278.6	8.5452
500	35.680	3132.9	3489.7	9.8998	7.1338	3132.6	3489.3	9.1566	3.5655	3132.2	3488.7	8.8362
600	40.296	3303.3	3706.3	10.1631	8.0577	3303.1	3706.0	9.4201	4.0279	3302.8	3705.6	9.0999
700	44.911	3480.8	3929.9	10.4056	8.9813	3480.6	3929.7	9.6626	4.4900	3480.4	3929.4	9.3424
800	49.527	3665.4	4160.6	10.6312	9.9047	3665.2	4160.4	9.8883	4.9519	3665.0	4160.2	9.5682
900	54.143	3856.9	4398.3	10.8429	10.8280	3856.8	4398.2	10.1000	5.4137	3856.7	4398.0	9.7800
1000	58.758	4055.3	4642.8	11.0429	11.7513	4055.2	4642.7	10.3000	5.8755	4055.0	4642.6	9.9800
1100	63.373	4260.0	4893.8	11.2326	12.6745	4259.9	4893.7	10.4897	6.3372	4259.8	4893.6	10.1698
1200	67.989	4470.9	5150.8	11.4132	13.5977	4470.8	5150.7	10.6704	6.7988	4470.7	5150.6	10.3504
1300	72.604	4687.4	5413.4	11.5857	14.5209	4687.3	5413.3	10.8429	7.2605	4687.2	5413.3	10.5229
	P = 0.20 MPa (120.21°C)				P = 0.30 MPa (133.52°C)				P = 0.40 MPa (143.61°C)			
Sat.	0.88578	2529.1	2706.3	7.1270	0.60582	2543.2	2724.9	6.9917	0.46242	2553.1	2738.1	6.8955
150	0.95986	2577.1	2769.1	7.2810	0.63402	2571.0	2761.2	7.0792	0.47088	2564.4	2752.8	6.9306
200	1.08049	2654.6	2870.7	7.5081	0.71643	2651.0	2865.9	7.3132	0.53434	2647.2	2860.9	7.1723
250	1.19890	2731.4	2971.2	7.7100	0.79645	2728.9	2967.9	7.5180	0.59520	2726.4	2964.5	7.3804
300	1.31623	2808.8	3072.1	7.8941	0.87535	2807.0	3069.6	7.7037	0.65489	2805.1	3067.1	7.5677
400	1.54934	2967.2	3277.0	8.2236	1.03155	2966.0	3275.5	8.0347	0.77265	2964.9	3273.9	7.9003

And you look at it and then you will find out somewhere for the case of P equal to 0.5 mega Pascal. So, now you look at again, so this table very carefully for each of them we have the saturation temperature and the other variables okay. So, let me again go back there variables are v, u, h and s. So, this is your basically h here okay.

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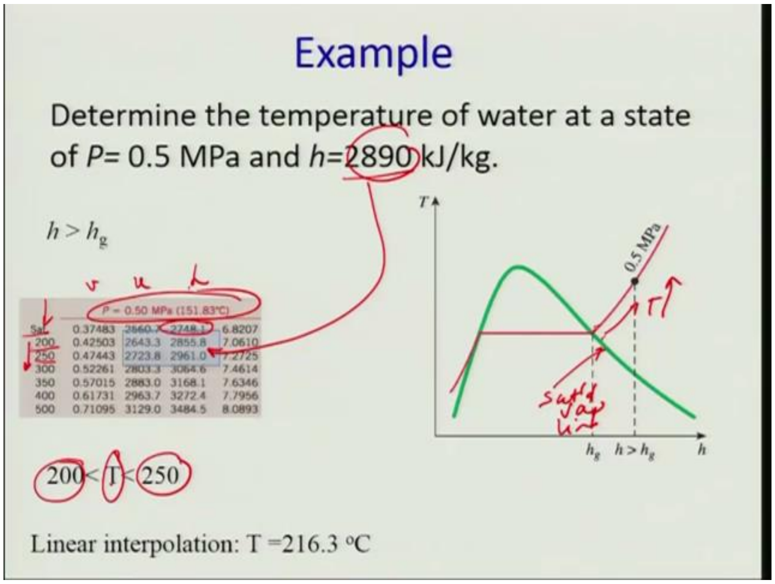

Example

Determine the temperature of water at a state of P= 0.5 MPa and h=2890 kJ/kg.

$h > h_g$

	v	u	h	
	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

200 < T < 250

Linear interpolation: T =216.3 °C

Now you look at saturation temperature this is value less than 2890 and it is done we have to of course this means as you go away from the saturated vapor line okay. This temperature is increasing. So, along this your temperature increases, so this is where the temperature is increasing here and here you should see where this value falls.

So, it falls somewhere in between, this is h. So, this is more than 2855.8, but less than 2961.0 and it essentially mean that temperature the system okay is somewhere between 200 to 250. Then you can use it linear interpretation to find out the temperature okay, based on your enthalpy values okay.

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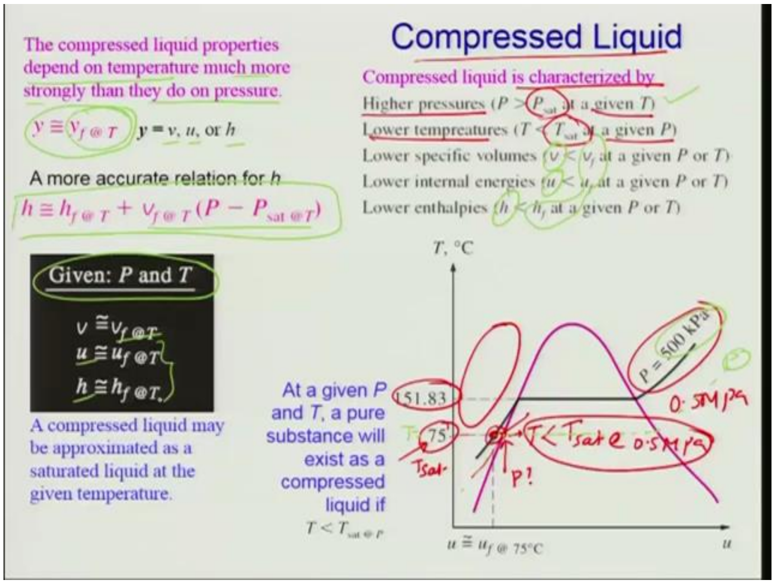

Compressed Liquid

Compressed liquid is characterized by

Higher pressures ($P > P_{sat}$ at a given T)

Lower tempreatures ($T < T_{sat}$ at a given P)

Lower specific volumes ($v < v_f$ at a given P or T)

Lower internal energies ($u < u_f$ at a given P or T)

Lower enthalpies ($h < h_f$ at a given P or T)

The compressed liquid properties depend on temperature much more strongly than they do on pressure.

$y \cong y_{f @ T}$ $y = v, u,$ or h

A more accurate relation for h

$$h \cong h_{f @ T} + v_{f @ T}(P - P_{sat @ T})$$

Given: P and T

$v \cong v_{f @ T}$

$u \cong u_{f @ T}$

$h \cong h_{f @ T}$

A compressed liquid may be approximated as a saturated liquid at the given temperature.

At a given P and T, a pure substance will exist as a compressed liquid if $T < T_{sat @ P}$

So, next we going to discuss is the compressed liquid, compressed liquid is of course this region which is left side of the saturated liquid line. Now this is something which you can be characterized by higher pressure then the saturation pressure at a given temperature or lower temperature for low temperature means less than the saturation temperature at a given pressure.

So, let us take a look of this pressure which is already given. So, this is the pressure 500kilopascal and it is saturation temperature is this. So, this is 0.5 mega Pascal, right. Its saturation temperature is this and our system lies here. So, this is our system, at this system there temperature is 75 but this is at the same pressure and thus the T here is less than T sat at 0.5 mega Pascal. So, which is the condition of your compressed liquid, so let us again look at this point here okay. So, if you take this T okay. This is our T and if you want this to be T sat then what would be the corresponding pressure.

So, somewhere this would be like this. So, this would be the pressure which we will give you the specific temperature T here. So, this would be the temperature and the corresponding pressure for this particular temperature would be P which would be less than this value.

So, that what it says as a P higher the pressure here is greater in the P sat, because this would be the T sat for this particular okay because this is the point which we are talking about. So this will be the P sat or this will be the condition for a compressed liquid that a pressure of the system in the compressed liquid should be greater than P sat any a given temperature and the temperature should be less than the T sat at any given pressure, okay.

The other important thing which is much easier to understand is that all other properties whether is specific volume, specific energy or enthalpy they are going to be less than the liquid properties because there compressed liquid is on left side if the saturated liquid line so all other properties are going to be less than the fluid property.

Now the compressed liquid it depends on temperature much more than they do on pressure and typically what we approximate compressed liquid is all other properties are approximated by their corresponding values of the saturated liquid. So, that is what we do is y or is, is any property specific volume, internal energy or enthalpy.

This gives approximated by y of saturated liquid at that particular temperature. But low accurate relation includes this term as well. So, this is what we similar that for given pressure and temperature volume is approximated by the saturated heat value in similarly for internal energy, similarly for h corresponding saturated properties.

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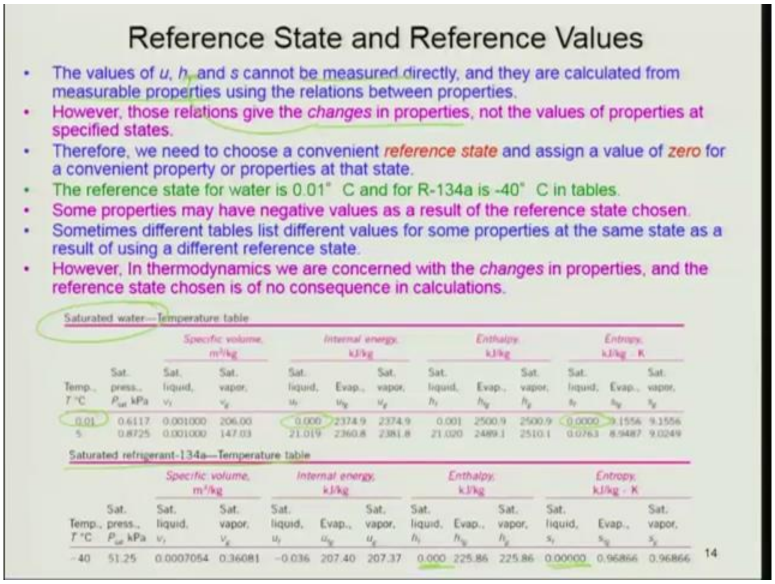

Reference State and Reference Values

- The values of u, h, and s cannot be measured directly, and they are calculated from measurable properties using the relations between properties.
- However, those relations give the *changes* in properties, not the values of properties at specified states.
- Therefore, we need to choose a convenient *reference state* and assign a value of *zero* for a convenient property or properties at that state.
- The reference state for water is 0.01° C and for R-134a is -40° C in tables.
- Some properties may have negative values as a result of the reference state chosen.
- Sometimes different tables list different values for some properties at the same state as a result of using a different reference state.
- However, In thermodynamics we are concerned with the *changes* in properties, and the reference state chosen is of no consequence in calculations.

Saturated water—Temperature table

		Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg · K		
Temp., T °C	Sat. press., P_{sat} kPa	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	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9	0.0000	9.1556	9.1556
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487	9.0249

Saturated refrigerant-134a—Temperature table

		Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg · K		
Temp., T °C	Sat. press., P_{sat} kPa	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	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
-40	51.25	0.0007054	0.36081	-0.036	207.40	207.37	0.000	225.86	225.86	0.00000	0.96866	0.96866

So, let us end this a specific lecture by you just looking at the different state and difference values. Now typically all the properties which we have listed in table such as your particular specific volume pressure and temperature, these are will well measurable properties okay in experiment but internal energy enthalpy, entropy, they are not, they depend on these other properties which are measurable. Now this is defined by a relation, very sound thermodynamic relations which tells us that how to calculate the changes in such properties in terms of measurable properties.

So, what we can do is we can find out the changes in the properties using the measurable properties. So, changing the property which cannot be measured or can be calculated using other measuring properties. So, in order to do that we make use of some reference because you need some reference value to find out the change and that is what this tables use some kind of references.

So, for example you can look at the saturated water temperature table, the reference value is triple point, where we assuming the saturated liquid internal energy to be zero and as well as entropy is to be zero okay.

And similarly for refrigerant you will refers where temperature is minus 40 and you can see here the values are considered to be zero. Now as long as use the same table to calculate the properties and analysis the reference value will get canceled. So, essentially in other there will be no effect on the on the reference value okay.

So, that is how we make use of the table. So, in (())(11:55) thermodynamics we are concerned with the changes in the property and the reference state chosen is of no consequence in calculation okay.

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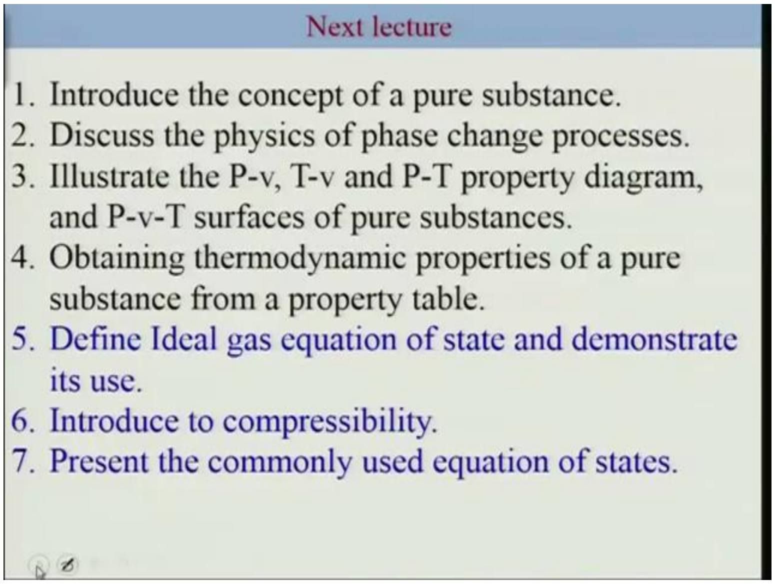

Next lecture

1. Introduce the concept of a pure substance.
2. Discuss the physics of phase change processes.
3. Illustrate the P-v, T-v and P-T property diagram, and P-v-T surfaces of pure substances.
4. Obtaining thermodynamic properties of a pure substance from a property table.
5. Define Ideal gas equation of state and demonstrate its use.
6. Introduce to compressibility.
7. Present the commonly used equation of states.

In the next lecture we going to discuss commonly used equation of state.