ENGR 292 Fluids and Thermodynamics

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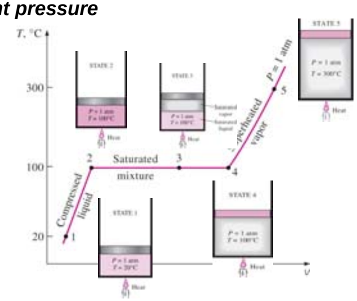
Review of Last Class

- ***Pure Substances***
- ***Phase-Change Process of Pure Substances***
- ***Specific Volume***
- ***Saturation Temperature (T_{sat})***
- ***Saturation Pressure (P_{sat})***
- ***Vapor Pressure***
- ***Property Tables***

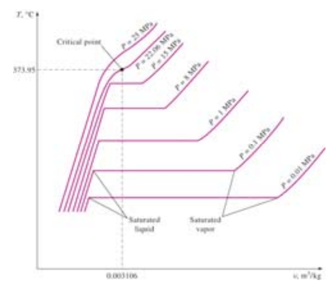
Review of Last Class

- ***T-v diagram for the heating process of water at constant pressure***



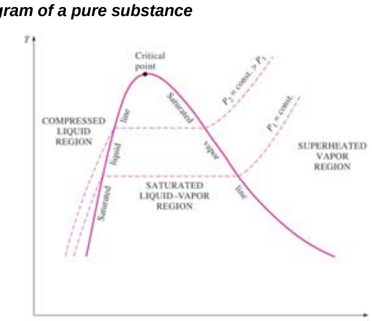
Review of Last Class

- ***T-v diagram of constant pressure phase-change process of water at various pressures***



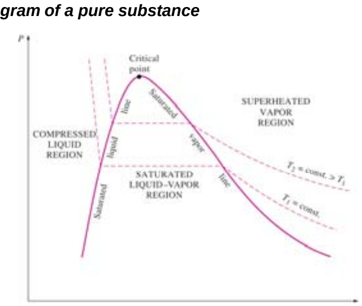
Review of Last Class

- ***T-v diagram of a pure substance***



Review of Last Class

- ***P-v diagram of a pure substance***



Review of Last Class

- **_Finding the Temperature of Saturated Vapor_**
- **_A piston-cylinder contains 3 m^3 of saturated water vapor at 50 kPa pressure. Determine the temperature of the vapor and the mass of the vapor inside the cylinder_**

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Review of Last Class

- **_Solution:_**

The state of the saturated water vapor is shown on a P-v diagram in the Fig below. Since the cylinder contains saturated vapor at 50 kPa, the temperature inside must be the saturation temperature at this pressure:

$T = T_{sat@50\ kPa} = 81.32\ ℃$ **_(Table A-5)_**

The specific volume of the saturation vapor at 50 psig is:

$v = v_{g@50psig} = 3.2403\ m^3/kg$ **_(Table A-5)_**

Then the mass of water vapor inside the cylinder is determined to be:

$$m = \frac{V}{v} = \frac{3\ m^3}{3.2403\ m^3/kg} = 0.9258\ kg$$

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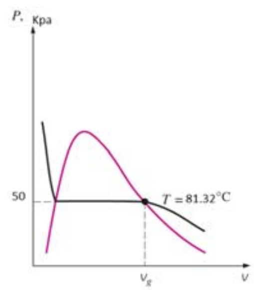
Review of Last Class



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Review of Last Class

- **_A partial list of Table A-5_**

TABLE A–5
Saturated water—Pressure table

		Specific volume, m^3/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
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765
4.0	28.96	0.001004	34.791	121.39	2293.1	2414.5	121.39	2432.3	2553.7	0.4224	8.0510	8.4734
5.0	32.87	0.001005	28.185	137.75	2282.1	2419.8	137.75	2423.0	2560.7	0.4762	7.9176	8.3938
7.5	40.29	0.001008	19.233	168.74	2261.1	2429.8	168.75	2405.3	2574.0	0.5763	7.6738	8.2501
10	45.81	0.001010	14.670	191.79	2245.4	2437.2	191.81	2392.1	2583.9	0.6492	7.4996	8.1488
15	53.97	0.001014	10.020	225.93	2222.1	2448.0	225.94	2372.3	2598.3	0.7549	7.2522	8.0071
20	60.06	0.001017	7.6481	251.40	2204.6	2456.0	251.42	2357.5	2608.9	0.8320	7.0752	7.9073
25	64.96	0.001020	6.2034	271.93	2190.4	2462.4	271.96	2345.5	2617.5	0.8932	6.9370	7.8302
30	69.09	0.001022	5.2287	289.24	2178.5	2467.7	289.27	2335.3	2624.6	0.9441	6.8234	7.7675
40	75.86	0.001026	3.9933	317.58	2158.8	2476.3	317.62	2318.4	2636.1	1.0261	6.6430	7.6691
50	81.32	0.001030	3.2403	340.49	2142.7	2483.2	340.54	2304.7	2645.2	1.0912	6.5019	7.5931
75	91.76	0.001037	2.2172	384.36	2111.8	2496.1	384.44	2278.0	2662.4	1.2132	6.2426	7.4558
100	99.61	0.001043	1.6941	417.40	2088.2	2505.6	417.51	2257.5	2675.0	1.3028	6.0562	7.3589

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Review of Last Class

- **_Enthalpy – A Combination Property_**

Total Enthalpy

$$H = U + PV$$

Specific Enthalpy (per unit mass):

$$h = u + Pv$$

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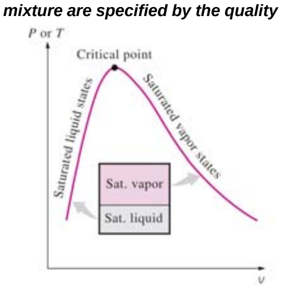
Saturated Liquid-Vapor Mixture

- **_The relative amounts of liquid and vapor phases in a saturated mixture are specified by the quality x_**



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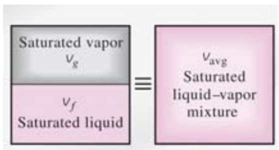
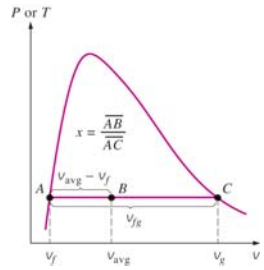
Saturated Liquid-Vapor Mixture

- A two-phase system can be treated as a homogenous mixture for convenience



Saturated Liquid-Vapor Mixture

- Quality is related to the horizontal distances on P-v and T-v diagrams.



Saturated Liquid-Vapor Mixture

- Consider a tank that contains a saturated liquid-vapor mixture. The volume occupied by saturated liquid is V_f, and the volume occupied by saturated vapor is V_g. The total volume V is the sum of these two:

$$V = V_f + V_g$$

$$V = mv \rightarrow m_t v_{av} = m_f V_f + m_g V_g$$

$$m_f = m_t - m_g \rightarrow m_t v_{ave} = (m_t - m_g) v_f + m_g v_g$$

Dividing by m_t, yields:

$$v_{av} = (1 - x) v_f + x v_g \text{ where } x = m_g / m_t$$

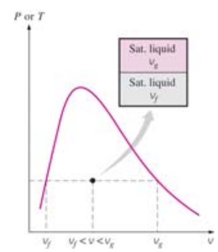
$$v_{av} = v_f + x v_{fg} \text{ where } v_{fg} = v_g - v_f$$

Then:

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

Saturated Liquid-Vapor Mixture

- The v value of a saturated liquid-vapor mixture lies between the v_f and v_g values at the specific T or P



Example 1

- **The Pressure and Volume of a Saturated Mixture**

A rigid tank contain 10 kg of water of 90℃. If 8 kg of the water is in the liquid form and the rest is in the vapor form, determine

(a) the pressure in the tank;

(b) the volume of the tank .

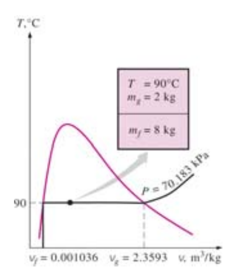
Example 1

- **Solution:**

A rigid tank contains a saturated mixture of water. The pressure and the volume of the tank are to be determined.

(a) The state of the saturated liquid-vapor mixture is shown in Fig. on the right side. Since the two phases coexist in equilibrium, we have a saturated mixture, and the pressure must be the saturation pressure at the given temperature.

$P_{sat@90℃} = 70.183$ kPa (Table A-4)



Example 1

(b) At 90℃, we have $v_f = 0.001036 m^3/kg$ and $v_g = 2.3593 m^3/kg$ (Table A-4)

Method 1:

One way of finding the volume of the tank is to determine the volume occupied by each phase and then add them:

$$V = V_f + V_g = m_f v_f + m_g v_g$$
$$= (8kg)(0.001036 m^3/kg) + (2kg)(2.3593 m^3/kg)$$
$$= 4.73 m^3$$

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Example 1

(b) At 90℃, we have $v_f = 0.001036 m^3/kg$ and $v_g = 2.3593 m^3/kg$ (Table A-4)

Method 2:

Another way is to first determine the quality x, then the average specific volume v, and finally the total volume:

$$x = \frac{m_g}{m_t} = \frac{2kg}{10kg} = 0.2$$
$$v = v_f + x v_g$$
$$= 0.001036 m^3/kg + (0.2)(2.3593 m^3/kg)$$
$$= 0.00473 m^3/kg$$
$$V = mv = (10kg)(0.00473 m^3/kg) = 4.73 m^3$$

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Example 1

Discussion:

The first method appears to be easier in this case since the masses of each phase are given. In most cases, the masses of each phase not available, and the second method becomes more convenient. Also note that we have dropped the "avg" subscript for convenience.

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Example 1

- ***A partial list of Table A-4***

TABLE A–4

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
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2	0.1511	8.7488	8.8999
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559	8.7803
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4	0.2965	8.3696	8.6661
25	3.1698	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5	0.3672	8.1895	8.5567
30	4.2469	0.001004	32.879	125.73	2290.2	2415.9	125.74	2429.8	2555.6	0.4368	8.0152	8.4520
35	5.6291	0.001006	25.205	146.63	2276.0	2422.7	146.64	2417.9	2564.6	0.5051	7.8466	8.3517
40	7.3851	0.001008	19.515	167.53	2261.9	2429.4	167.53	2406.0	2573.5	0.5724	7.6832	8.2556
45	9.5953	0.001010	15.251	188.43	2247.7	2436.1	188.44	2394.0	2582.4	0.6386	7.5247	8.1633
50	12.352	0.001012	12.026	209.33	2233.4	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748
55	15.763	0.001015	9.5639	230.24	2219.1	2449.3	230.26	2369.8	2600.1	0.7680	7.2218	7.9898
60	19.947	0.001017	7.6670	251.16	2204.7	2455.9	251.18	2357.7	2608.8	0.8313	7.0769	7.9082
65	25.043	0.001020	6.1935	272.09	2190.3	2462.4	272.12	2345.4	2617.5	0.8937	6.9360	7.8296
70	31.202	0.001023	5.0396	293.04	2175.8	2468.9	293.07	2333.0	2626.1	0.9551	6.7989	7.7540
75	38.597	0.001026	4.1291	313.99	2161.3	2475.3	314.03	2320.6	2634.6	1.0158	6.6655	7.6812
80	47.416	0.001029	3.4053	334.97	2146.6	2481.6	335.02	2308.0	2643.0	1.0756	6.5355	7.6111
85	57.868	0.001032	2.8261	355.96	2131.9	2487.8	356.02	2295.3	2651.4	1.1346	6.4089	7.5435
90	70.183	0.001036	2.3593	376.97	2117.0	2494.0	377.04	2282.5	2659.6	1.1929	6.2853	7.4782
95	84.609	0.001040	1.9808	398.00	2102.0	2500.1	398.09	2269.6	2667.6	1.2504	6.1647	7.4151

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Example 2

- ***An 80-L vessel contains 4 kg of refrigenat-134a at a pressure 160 kPa.***
- ***Determine***

(a) the temperature

(b) the quality

(c) the enthalpy of the refrigerant

(d) the volume occupied by the vapor phase.

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Example 2

- ***Solution:***
- ***A vessel is filled with refrigerant-134a at a pressure of 160 kPa.***

$$V = 80\ L = 0.080\ m^3$$
$$m = 4\ kg$$

- ***Some properties of the refrigerant are to be determined.***

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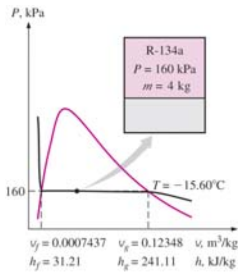
Example 2

(a) The state of the saturated liquid-vapor mixture is shown in Figure below:



Example 2

- ***A partial list of Table A-15 b***

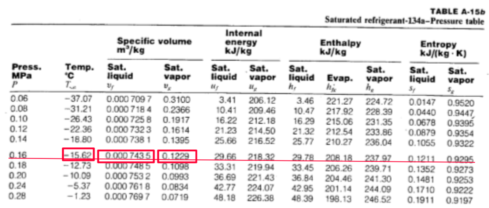


TABLE A-15b
Saturated refrigerant-134a–Pressure table

		Specific volume m³/kg		Internal energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/(kg·K)	
Press. MPa P	Temp. °C T_{sat}	Sat. liquid v_f	Sat. vapor v_g	Sat. liquid u_f	Sat. vapor u_g	Sat. liquid h_f	Evap. h_{fg}	Sat. vapor h_g	Sat. liquid s_f	Sat. vapor s_g
0.06	−37.07	0.000 709 7	0.3100	3.41	206.12	3.46	221.27	224.72	0.0147	0.9520
0.08	−31.21	0.000 718 4	0.2366	10.41	209.46	10.47	217.92	228.39	0.0440	0.9447
0.10	−26.43	0.000 725 8	0.1917	16.22	212.18	16.29	215.06	231.35	0.0678	0.9395
0.12	−22.36	0.000 732 3	0.1614	21.23	214.50	21.32	212.54	233.86	0.0879	0.9354
0.14	−18.80	0.000 738 1	0.1395	25.66	216.52	25.77	210.27	236.04	0.1055	0.9322
0.16	−15.62	0.000 743 5	0.1229	29.66	218.32	29.78	208.18	237.97	0.1211	0.9295
0.18	−12.73	0.000 748 5	0.1098	33.31	219.94	33.45	206.26	239.71	0.1352	0.9273
0.20	−10.09	0.000 753 2	0.0993	36.69	221.43	36.84	204.46	241.30	0.1481	0.9253
0.24	−5.37	0.000 761 8	0.0834	42.77	224.07	42.95	201.14	244.09	0.1710	0.9222
0.28	−1.23	0.000 769 7	0.0719	48.18	226.38	48.39	198.13	246.52	0.1911	0.9197

Example 2

At this point, we do not know whether the refrigerant is in the compressed liquid, Superheated vapor, or saturated mixture region. This can be determined by comparing a suitable property to the saturated liquid and saturated vapor values.

From the information given, we determine the specific volume:

$$v = \frac{V}{m} = \frac{0.080\ m^3}{4\ kg} = 0.02 m^3/kg$$

At pressure 160 kPa, we read from Table A-15 b

$$v_f = 0.0007435 m^3/kg$$

$$v_g = 0.1229 m^3/kg$$

Example 2

Obviously $v_f < v < v_g$, and therefore, the refrigerant is in the saturated mixture region. Thus, the temperature must be the saturation temperature at the specific pressure.

$$T = T_{sat@160\ kPa} = -15.62\ ℃$$

(b) Quality can be determined from following equation we talked about above:

$$x = \frac{v_{av} - v_f}{v_{fg}} = \frac{0.02 - 0.0007435}{0.1229 - 0.0007435} = 0.158$$

Example 2

(c) At pressure 160 kPa, we also read from Table A-15b that

$h_f = 29.78\ kJ/kg;\ h_{fg} = 208.18\ kJ/kg$

Then:

$$h = h_f + xh_{fg} = (29.78\ kJ/kg\ ) + (0.158)(208.18\ kJ/kg)$$
$$= 62.7\ kJ/kg$$

(d) The mass of the vapor can be determined by

$$m_g = xm_t = (0.158)(4kg) = 0.632\ kg$$

and the volume occupied by the vapor phase is :

$$V_g = m_g v_g = (0.632\ kg)(0.1229 m^3/kg\ ) = 0.0777 m^3$$
$$= 77.7\ L$$

The rest of the volume $80L - 77.7\ L = 2.3L$ is occupied by the liquid.

Superheated Vapor

- ***In the region to the right of the saturated vapor line and at temperatures above the critical point temperature, a substance exists as superheated vapor.***
- ***Since the superheated region is a single-phase region, temperature and pressure are no longer dependent properties and they can conveniently be used as the two independent properties in the tables.***

Superheated Vapor

- ***A partial list of Table A-6***

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

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Example 3

- ***Finding the Internal Energy of Superheated Vapor***

Determine the internal energy of water at 1 Mpa, and 400℃

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Example 3

- ***A partial list of Table A-6***

TABLE A–6

Superheated water (*Concluded*)

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 = 1.00 MPa (179.88°C)				P = 1.20 MPa (187.96°C)				P = 1.40 MPa (195.04°C)			
Sat.	0.19437	2582.8	2777.1	6.5850	0.16326	2587.8	2783.8	6.5217	0.14078	2591.8	2788.9	6.4675
200	0.20602	2622.3	2828.3	6.6956	0.16934	2612.9	2816.1	6.5909	0.14303	2602.7	2803.0	6.4975
250	0.23275	2710.4	2943.1	6.9265	0.19241	2704.7	2935.6	6.8313	0.16356	2698.9	2927.9	6.7488
300	0.25799	2793.7	3051.6	7.1246	0.21386	2789.7	3046.3	7.0335	0.18233	2785.7	3040.9	6.9553
350	0.28250	2875.7	3158.2	7.3029	0.23455	2872.7	3154.2	7.2139	0.20029	2869.7	3150.1	7.1379
400	0.30661	2957.9	3264.5	7.4670	0.25482	2955.5	3261.3	7.3793	0.21782	2953.1	3258.1	7.3046
500	0.35411	3125.0	3479.1	7.7642	0.29464	3123.4	3477.0	7.6779	0.25216	3121.8	3474.8	7.6047
600	0.40111	3297.5	3698.6	8.0311	0.33395	3296.3	3697.0	7.9456	0.28597	3295.1	3695.5	7.8730
700	0.44783	3476.3	3924.1	8.2755	0.37297	3475.3	3922.9	8.1904	0.31951	3474.4	3921.7	8.1183
800	0.49438	3661.7	4156.1	8.5024	0.41184	3661.0	4155.2	8.4176	0.35288	3660.3	4154.3	8.3458
900	0.54083	3853.9	4394.8	8.7150	0.45059	3853.3	4394.0	8.6303	0.38614	3852.7	4393.3	8.5587
1000	0.58721	4052.7	4640.0	8.9155	0.48928	4052.2	4639.4	8.8310	0.41933	4051.7	4638.8	8.7595
1100	0.63354	4257.9	4891.4	9.1057	0.52792	4257.5	4891.0	9.0212	0.45247	4257.0	4890.5	8.9497
1200	0.67983	4469.0	5148.9	9.2866	0.56652	4468.7	5148.5	9.2022	0.48558	4468.3	5148.1	9.1308
1300	0.72610	4685.8	5411.9	9.4593	0.60509	4685.5	5411.6	9.3750	0.51866	4685.1	5411.3	9.3036

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Example 3

- ***Solution:***

At 1 Mpa, the saturation temperature $T_{sat@1Mpa}$ ***is*** 179.88℃. ***Since*** $T = 400℃ > T_{sat@1Mpa}$, ***the water is in the superheated vapor region. Then the internal energy is determined from the superheated vapor table (Table A-6) to be:***

$u = 2957.9 kJ/kg$ ***At the given temperature and pressure.***

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
	P = 1.00 MPa (179.88°C)			
Sat.	0.19437	2582.8	2777.1	6.5850
200	0.20602	2622.3	2828.3	6.6956
250	0.23275	2710.4	2943.1	6.9265
300	0.25799	2793.7	3051.6	7.1246
350	0.28250	2875.7	3158.2	7.3029
400	0.30661	2957.9	3264.5	7.4670
500	0.35411	3125.0	3479.1	7.7642

34

Example 4

Finding the temperature of Superheated Vapor

- ***Determine the temperature of water at a state of P=0.5 Mpa, and h=2890 kJ/kg***

35

Example 4

- ***Solution:***

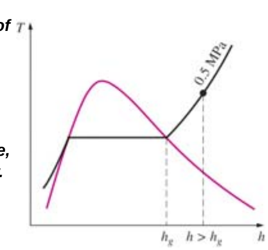
At 0.5 Mpa, the enthalpy of saturated water vapor is

$$h_g = 2748.7\ kJ/kg$$

Since

$$h = 2890\ kJ/kg > h_g$$

As shown in Fig on the right side, we again have superheated vapor.



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Example 4

- Under 0.5 Mpa in Table A-6

We read:

$$h_{@200℃} = 2855.4\ kJ/kg$$
$$h_{@250℃} = 2961.0\ kJ/kg$$

Obviously, the temperature is between 200℃ *and* 250℃. *By linear interpolation it is determined to be:*

$$T = 200 + (2890 - 2855.8)(\frac{250 - 200}{2961.0 - 2855.8})$$
$$= 216.4℃$$

- A partial list of Table A-6

T °C	v m³/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
800	0.98966	3663.6	4158.4	8.8240
900	1.08227	3855.4	4396.6	9.0362
1000	1.17480	4054.0	4641.4	9.2364
1100	1.26728	4259.0	4892.6	9.4263
1200	1.35972	4470.0	5149.8	9.6071
1300	1.45214	4686.6	5412.6	9.7797

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Example 5

- ***Determine the internal energy of compressed liquid water at T=80℃ and P=5 Mpa.***
- ***Using***
- ***(a) data from the compressed liquid table***
- ***(b) using saturated liquid data***

What is the error involved in the second case?

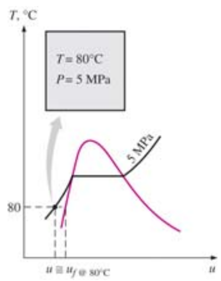
38

Example 5

- ***Solution:***

At 80 ℃, the saturation pressure of water is $P_{sat@80℃}$ ***=47.416 kPa.***

Since P=5 Mpa > $P_{sat@80℃}$***, We obviously have compressed liquid, as shown in Fig on the right side.***



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Example 5

- ***(a) From the Compressed Liquid Table (Table A-7)***

$$u_{@5Mpa\ \&\ 80℃} = 333.82\ kJ/kg$$

TABLE A–7

Compressed liquid water

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
	P = 5 MPa (263.94°C)			
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
160	0.0010988	672.55	678.04	1.9374
180	0.0011240	759.47	765.09	2.1338
200	0.0011531	847.92	853.68	2.3251
220	0.0011868	938.39	944.32	2.5127
240	0.0012268	1031.6	1037.7	2.6983
260	0.0012755	1128.5	1134.9	2.8841

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Example 5

- ***(b) From the Saturation Table (Table A-4)***

$$u_{f@\ 80℃} = 334.97\ kJ/kg$$

TABLE A–4

Saturated water—Temperature table

		Specific volume, m³/kg		Internal energy, kJ/kg		
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
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3
25	3.1698	0.001003	43.340	104.83	2304.3	2409.1
30	4.2469	0.001004	32.879	125.73	2290.2	2415.9
35	5.6291	0.001006	25.205	146.63	2276.0	2422.7
40	7.3851	0.001008	19.515	167.53	2261.9	2429.4
45	9.5953	0.001010	15.251	188.43	2247.7	2436.1
50	12.352	0.001012	12.026	209.33	2233.4	2442.7
55	15.763	0.001015	9.5639	230.24	2219.1	2449.3
60	19.947	0.001017	7.6670	251.16	2204.7	2455.9
65	25.043	0.001020	6.1935	272.09	2190.3	2462.4
70	31.202	0.001023	5.0396	293.04	2175.8	2468.9
75	38.597	0.001026	4.1291	313.99	2161.3	2475.3
80	47.416	0.001029	3.4053	334.97	2146.6	2481.6
85	57.868	0.001032	2.8261	355.96	2131.9	2487.8

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Example 5

- ***From Above, we have:***

$$u_{@5Mpa\ \&\ 80℃} \cong u_{f@\ 80℃}$$

The error involved is:

$$\frac{334.92 - 333.82}{333.72} = 0.34\%$$

which is less than 1 %

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Example 6

Determine the missing properties and the phase descriptions in the following table for water:

	T(℃)	P(kPa)	u (kJ/kg)	x	Phase decription
(a)		200		0.6	
(b)	125		1600		
(c)		1000	2950		
(d)	75	500			
(e)		850		0	

Example 6

Solution:

(a) The quality is given to be $x = 0.6$, which implies that 60% of mass is in the vapor phase and the remain 40 percent is in the liquid phase. Therefore, we have saturated liquid-vapor mixture at a pressure of 200 kPa. Then the temperature must be the saturation temperature at the given pressure:

$$T = T_{sat@200kPa} = 120.21℃ \text{ (Table A-5)}$$

At 200 kPa, we also read from Table A-5

$$u_f = 504.5\ kJ/Jg$$

$$u_g = 2024.6 kJ/Jg$$

$$u = u_f + xu_g = 504.5\ kJ/Jg + (0.6)(2024.6 kJ/Jg)$$
$$= 1719.26 kJ/Jg$$

Example 6

- ***A partial list of Table A-5***

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	Entropy, kJ/kg·K: Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765
175	116.04	0.001057	1.0037	486.82	2037.7	2524.5	487.01	2213.1	2700.2	1.4850	5.6865	7.1716
200	120.21	0.001061	0.88578	504.50	2024.6	2529.1	504.71	2201.6	2706.3	1.5302	5.5968	7.1270
225	123.97	0.001064	0.79329	520.47	2012.7	2533.2	520.71	2191.0	2711.7	1.5706	5.5171	7.0877
250	127.41	0.001067	0.71873	535.08	2001.8	2536.8	535.35	2181.2	2716.5	1.6072	5.4453	7.0525
275	130.58	0.001070	0.65732	548.57	1991.6	2540.1	548.86	2172.0	2720.9	1.6408	5.3800	7.0207

Example 6

Solution:

(b) This time the temperature and the internal energy are given, but we do not know which table to use to determine the missing properties because we have no clue as to whether we have a saturated mixture, compressed liquid, or superheated vapor. To determine the region we are in, we first go to the saturation table (Table A-4) and determine the u_f and u_g at given temperature.

At 125 ℃, we read $u_f = 524.83\ kJ/Jg$; $u_g = 2534.3kJ/kg$; since $u = 1600\ kJ/kg$; which is falls between u_f and u_g values at 125 ℃. Therefore, we have a saturated liquid-vapor mixture, then the pressure must be the saturated pressure at the given temperature

$P = P_{sat@150℃} = 232.23\ kPa$ (Table A-4)

Example 6

- ***A partial list of Table A-4***

TABLE A–4

Saturated water—Temperature table

Temp., T °C	Sat. press., P_{sat} kPa	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	Entropy, kJ/kg·K: 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
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2	0.1511	8.7488	8.8999
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559	8.7803
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4	0.2965	8.3696	8.6661
125	232.23	0.001065	0.77012	524.83	2009.5	2534.3	525.07	2188.1	2713.1	1.5816	5.4956	7.0771
130	270.28	0.001070	0.66808	546.10	1993.4	2539.5	546.38	2173.7	2720.1	1.6346	5.3919	7.0265
135	313.22	0.001075	0.58179	567.41	1977.3	2544.7	567.75	2159.1	2726.9	1.6872	5.2901	6.9773
140	361.53	0.001080	0.50850	588.77	1960.9	2549.6	589.16	2144.3	2733.5	1.7392	5.1901	6.9294
145	415.68	0.001085	0.44600	610.19	1944.2	2554.4	610.64	2129.2	2739.8	1.7908	5.0919	6.8827

Example 6

Solution:

(b) The quality is determined from

$$x = \frac{u - u_f}{u_{fg}} = \frac{1600 - 524.38}{2009.5} = 0.535$$

Example 6

Solution:

(c) This is similar to case (b), except pressure is given instead of temperature. Following the argument given above we read the u_f and u_g at given pressure (1Mpa). At 1 Mpa, we have $u_f = 761.39 kJ/Jg$; $u_g = 2528.8 kJ/kg$; The given $u = 2950 kJ/kg$, which is greater than u_g at 1 Mpa. Therefore, we have a superheated vapor, and the temperature at, this state is determined from the superheated vapor table by interpolation to be:

$$T = 350 + (2950 - 2875.7)(\frac{400 - 350}{2957.9 - 2875.7}) = 395.2℃$$

Example 6

- *A partial list of Table A-5*

TABLE A–5

Saturated water—Pressure table (*Concluded*)

		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
800	170.41	0.001115	0.24035	719.97	1856.1	2576.0	720.87	2047.5	2768.3	2.0457	4.6160	6.6616
850	172.94	0.001118	0.22690	731.00	1846.9	2577.9	731.95	2038.8	2770.8	2.0705	4.5705	6.6409
900	175.35	0.001121	0.21489	741.55	1838.1	2579.6	742.56	2030.5	2773.0	2.0941	4.5273	6.6213
950	177.66	0.001124	0.20411	751.67	1829.6	2581.3	752.74	2022.4	2775.2	2.1166	4.4862	6.6027
1000	179.88	0.001127	0.19436	761.39	1821.4	2582.8	762.51	2014.6	2777.1	2.1381	4.4470	6.5850
1100	184.06	0.001133	0.17745	779.78	1805.7	2585.5	781.03	1999.6	2780.7	2.1785	4.3735	6.5520

Example 6

- *A partial list of Table A-6*

TABLE A–6

Superheated water (*Concluded*)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
	P = 1.00 MPa (179.88°C)			
Sat.	0.19437	2582.8	2777.1	6.5850
200	0.20602	2622.3	2828.3	6.6956
250	0.23275	2710.4	2943.1	6.9265
300	0.25799	2793.7	3051.6	7.1246
350	0.28250	2875.7	3158.2	7.3029
400	0.30661	2957.9	3264.5	7.4670
500	0.35411	3125.0	3479.1	7.7642
600	0.40111	3297.5	3698.6	8.0311
700	0.44783	3476.3	3924.1	8.2755
800	0.49438	3661.7	4156.1	8.5024
900	0.54083	3853.9	4394.8	8.7150
1000	0.58721	4052.7	4640.0	8.9155
1100	0.63354	4257.9	4891.4	9.1057
1200	0.67983	4469.0	5148.9	9.2866
1300	0.72610	4685.8	5411.9	9.4593

Example 6

Solution:

(d) In this case the temperature and pressure is given, but again, we can not tell which table to use to determine the missing properties because we do not know whether

This is similar to case (b), except pressure is given instead of temperature. Following the argument given above we read the u_f and u_g at given pressure (1Mpa). At 1 Mpa, we have $u_f = 761.39 kJ/Jg$; $u_g = 2528.8 kJ/kg$; The given $u = 2950 kJ/kg$, which is greater than u_g at 1 Mpa. Therefore, we have a superheated vapor, and the temperature at, this state is determined from the superheated vapor table by interpolation to be:

$$T = 350 + (2950 - 2875.7)(\frac{400 - 350}{2957.9 - 2875.7}) = 395.2℃$$

Example 6

Solution:

(d) In this case the temperature and pressure is given, but again, we can not tell which table to use to determine the missing properties because we do not know whether we have a saturated mixture, compressed liquid, or superheated vapor.

To determine the region we are in, we go to the saturation table (Table A-5) and determine the saturation temperature value at the given pressure. At 500 kPa, we have $T_{sat@500kPa} = 151.83℃$; then we compare the given T value to this $T_{sat@500kPa}$;

In our case, the given T = 75℃; $T < T_{sat@500kPa}$; Therefore

Example 6

- *A partial list of Table A-5*

TABLE A–5

Saturated water—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
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765
450	147.90	0.001088	0.41392	622.65	1934.5	2557.1	623.14	2120.3	2743.4	1.8205	5.0356	6.8561
500	151.83	0.001093	0.37483	639.54	1921.2	2560.7	640.09	2108.0	2748.1	1.8604	4.9603	6.8207
550	155.46	0.001097	0.34261	655.16	1908.8	2563.9	655.77	2096.6	2752.4	1.8970	4.8916	6.7886
600	158.83	0.001101	0.31560	669.72	1897.1	2566.8	670.38	2085.8	2756.2	1.9308	4.8285	6.7593
650	161.98	0.001104	0.29260	683.37	1886.1	2569.4	684.08	2075.5	2759.6	1.9623	4.7699	6.7322
700	164.95	0.001108	0.27278	696.23	1875.6	2571.8	697.00	2065.8	2762.8	1.9918	4.7153	6.7071
750	167.75	0.001111	0.25552	708.40	1865.6	2574.0	709.24	2056.4	2765.7	2.0195	4.6642	6.6837

Example 6

Solution:

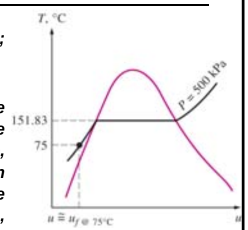
(d) In our case, the given T = 75℃; $T < T_{sat@500kPa}$; Therefore

We have a compressed liquid.

And normally, we would determine the internal energy value from the compressed liquid table. But in this case, the given pressure is much lower than the lowest pressure value in the compressed liquid table (which is 5 Mpa), and therefore, we are justified to treat the compressed liquid as saturated liquid at the given temperature (not pressure):

$u_{@500kPa\ \&\ 75℃} \cong u_{f@\ 75℃} = 313.99 kJ/kg$

(Table A-4)



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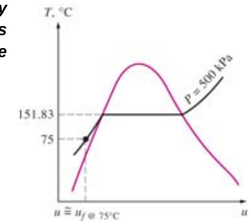
Example 6

Solution:

(d) We would leave the quality column blank or write "NA" in this case since quality has meaning in the compressed liquid region



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Example 6

Solution:

(e) The quality is given to be x = 0, thus we have saturated liquid at the specified pressure of 850 kPa. Then the temperature must be the saturation temperature at the given pressure, and the internal energy have the saturated liquid value:

$$T = T_{sat@850kPa} = 179.94℃$$
$$u = u_{f@850kPa} = 731.00 kJ/kg$$

(Table A-5)

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Example 6

- ***A partial list of Table A-5***

TABLE A–5

Saturated water—Pressure table (*Concluded*)

		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
800	170.41	0.001115	0.24035	719.97	1856.1	2576.0	720.87	2047.5	2768.3	2.0457	4.6160	6.6616
850	172.94	0.001118	0.22690	731.00	1846.9	2577.9	731.95	2038.8	2770.8	2.0705	4.5705	6.6409
900	175.35	0.001121	0.21489	741.55	1838.1	2579.6	742.56	2030.5	2773.0	2.0941	4.5273	6.6213
950	177.66	0.001124	0.20411	751.67	1829.6	2581.3	752.74	2022.4	2775.2	2.1166	4.4862	6.6027
1000	179.88	0.001127	0.19436	761.39	1821.4	2582.8	762.51	2014.6	2777.1	2.1381	4.4470	6.5850

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What is next?

- ***Any Questions?***
- ***Assignment 3 will be posted soon***
- ***Continue on with Thermodynamics***

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