Al-Mustaqbal University
Department of Biomedical Engineering
Third Stage / 2nd Course
"Thermodynamics"
Assist. Lec. Samara Bashar Saeed

Lec.4: Steam Tables

By

Assist. Lec. Samara Bashar

Saturated Liquid and Saturated Vapor States

- The properties of saturated liquid and saturated vapor for water are listed in Tables A–4 and A–5. Both tables give the same information.
- The only difference is that in Table A–4 properties are listed under temperature and in Table A–5 under pressure.
- Therefore, it is more convenient to use Table A–4 when *temperature is given and Table A–5 when pressure is given.*
- The subscript *f is used to denote properties of a saturated liquid, and the* subscript *g to denote the properties of saturated vapor.*
- Another subscript commonly used is *fg, which denotes the difference between* the saturated vapor and saturated liquid values of the same property. For example,

- v_f = *specific volume of saturated liquid*
- v_g = *specific volume of saturated vapor*
- v_{fg} = *difference between* v_g *and* v_f *(that is* $v_{fg} = v_g - v_f$*)*
- The quantity h_{fg} *is called the* ***enthalpy of vaporization (or latent heat*** of vaporization).

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

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

Example (1)
A rigid tank contains 50 kg of saturated liquid water at 90 C. Determine the pressure in the tank and the volume of the tank.

Example (2)
A piston–cylinder device contains 2 ft^3 of saturated water vapor at 50-psia pressure. Determine the temperature and the mass of the vapor inside the cylinder.

Example (3)
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.

Saturated Liquid-Vapor Mixture

To analyze this mixture properly, we need to know the proportions of the liquid and vapor phases in the mixture. This is done by defining a new property called the **quality** ***x as the ratio of the mass of vapor to the*** total mass of the mixture:

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

Where

$$m_{\text{total}} = m_{\text{liquid}} + m_{\text{vapor}} = m_f + m_g$$

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 the two:*

$$V = V_f + V_g$$

$$V = mv \longrightarrow m_t v_{\text{avg}} = m_f v_f + m_g v_g$$

$$m_f = m_t - m_g \longrightarrow m_t v_{\text{avg}} = (m_t - m_g) v_f + m_g v_g$$

Dividing by m_t yields

$$v_{avg} = (1 - x)v_f + xv_g$$

since $x = m_g/m_t$. This relation can also be expressed as

$$v_{avg} = v_f + xv_{fg} \quad (\text{m}^3/\text{kg})$$

where $v_{fg} = v_g - v_f$. Solving for quality, we obtain

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

The analysis given above can be repeated for internal energy and enthalpy with the following results:

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

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

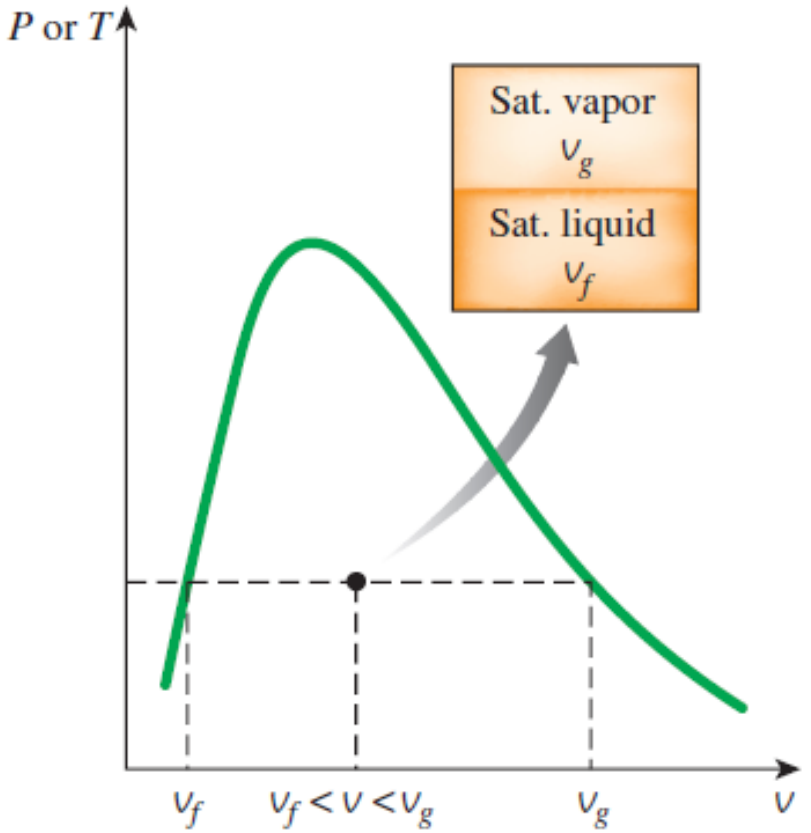
All the results are of the same format, and they can be summarized in a single equation as

$$y_{\text{avg}} = y_f + xy_{fg}$$

where *y is v, u, or h.*

The values of the average properties of the mixtures are always *between the values of the saturated liquid and the saturated vapor* properties. That is,

$$y_f \leq y_{\text{avg}} \leq y_g$$



Example (4)

A rigid tank contains 10 kg of water at 90 °C . 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 and (*b) the volume of the tank*.

Superheated Vapor

Compared to saturated vapor, superheated vapor Table (A-6) is characterized by

Lower pressures ($P < P_{sat}$ at a given T)
Higher tempreatures ($T > T_{sat}$ at a given P)
Higher specific volumes ($v > v_g$ at a given P or T)
Higher internal energies ($u > u_g$ at a given P or T)
Higher enthalpies ($h > h_g$ at a given P or T)

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
	P = 0.01 MPa (45.81°C)*				P = 0.05 MPa (81.32°C)			
Sat.†	14.670	2437.2	2583.9	8.1488	3.2403	2483.2	2645.2	7.5931
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
150	19.513	2587.9	2783.0	8.6893	3.8897	2585.7	2780.2	7.9413
200	21.826	2661.4	2879.6	8.9049	4.3562	2660.0	2877.8	8.1592
250	24.136	2736.1	2977.5	9.1015	4.8206	2735.1	2976.2	8.3568
300	26.446	2812.3	3076.7	9.2827	5.2841	2811.6	3075.8	8.5387
400	31.063	2969.3	3280.0	9.6094	6.2094	2968.9	3279.3	8.8659
500	35.680	3132.9	3489.7	9.8998	7.1338	3132.6	3489.3	9.1566
600	40.296	3303.3	3706.3	10.1631	8.0577	3303.1	3706.0	9.4201
700	44.911	3480.8	3929.9	10.4056	8.9813	3480.6	3929.7	9.6626
800	49.527	3665.4	4160.6	10.6312	9.9047	3665.2	4160.4	9.8883
900	54.143	3856.9	4398.3	10.8429	10.8280	3856.8	4398.2	10.1000
1000	58.758	4055.3	4642.8	11.0429	11.7513	4055.2	4642.7	10.3000
1100	63.373	4260.0	4893.8	11.2326	12.6745	4259.9	4893.7	10.4897
1200	67.989	4470.9	5150.8	11.4132	13.5977	4470.8	5150.7	10.6704
1300	72.604	4687.4	5413.4	11.5857	14.5209	4687.3	5413.3	10.8429

Example (5)

Determine the internal energy of water at 200 kPa and 300 °C.

Example (6)

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

Compressed Liquid

Compressed liquid tables are not as commonly available, and Table A–7 is the only compressed liquid table in this text. The format of Table A–7 is very much like the format of the superheated vapor tables. One reason for the lack of compressed liquid data is the relative independence of compressed liquid properties from pressure. Variation of properties of compressed liquid with pressure is very mild. Increasing the pressure 100 times often causes properties to change less than 1 percent.

In the absence of compressed liquid data, a general approximation is *to treat compressed liquid as saturated liquid at the given temperature* . This is because the compressed liquid properties depend on temperature much more strongly than they do on pressure. Thus,

$$y \cong y_{f\,@\,T}$$

for compressed liquids, where *y is v, u , or h.* Of these three properties, the property whose value is most sensitive to variations in the pressure is the enthalpy *h. Although the above approximation results in negligible error in v and u, the error in h may reach undesirable levels. However, the error in h* at low to moderate pressures and temperatures can be reduced significantly by evaluating it from

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

In general, a 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)

Example (7)

Determine the internal energy of compressed liquid water at 80 C and 5 MPa, using (*a) data from the compressed liquid table and (b) saturated* liquid data. What is the error involved in the second case?

TABLE A–7

Compressed liquid 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
	P = 5 MPa (263.94°C)				P = 10 MPa (311.00°C)			
Sat.	0.0012862	1148.1	1154.5	2.9207	0.0014522	1393.3	1407.9	3.3603
0	0.0009977	0.04	5.03	0.0001	0.0009952	0.12	10.07	0.0003
20	0.0009996	83.61	88.61	0.2954	0.0009973	83.31	93.28	0.2943
40	0.0010057	166.92	171.95	0.5705	0.0010035	166.33	176.37	0.5685
60	0.0010149	250.29	255.36	0.8287	0.0010127	249.43	259.55	0.8260
80	0.0010267	333.82	338.96	1.0723	0.0010244	332.69	342.94	1.0691
100	0.0010410	417.65	422.85	1.3034	0.0010385	416.23	426.62	1.2996
120	0.0010576	501.91	507.19	1.5236	0.0010549	500.18	510.73	1.5191
140	0.0010769	586.80	592.18	1.7344	0.0010738	584.72	595.45	1.7293
160	0.0010988	672.55	678.04	1.9374	0.0010954	670.06	681.01	1.9316
180	0.0011240	759.47	765.09	2.1338	0.0011200	756.48	767.68	2.1271
200	0.0011531	847.92	853.68	2.3251	0.0011482	844.32	855.80	2.3174
220	0.0011868	938.39	944.32	2.5127	0.0011809	934.01	945.82	2.5037
240	0.0012268	1031.6	1037.7	2.6983	0.0012192	1026.2	1038.3	2.6876
260	0.0012755	1128.5	1134.9	2.8841	0.0012653	1121.6	1134.3	2.8710
280					0.0013226	1221.8	1235.0	3.0565
300					0.0013980	1329.4	1343.3	3.2488
320								