

Thermodynamics
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Lecture 46
Two Phase System: Water and Steam

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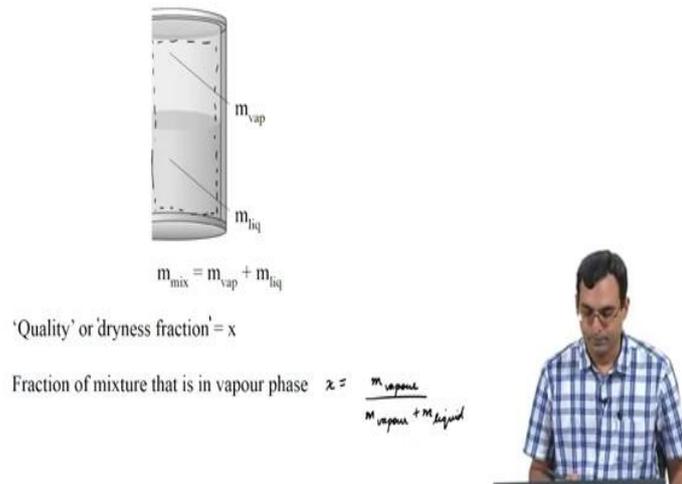


Figure 1.

Let's look at a mixture of liquid water and steam which is used in a lot of applications. Whatever we study for the mixture of water and steam will also be applicable for mixtures of other liquids and their vapour.

Consider a closed container as shown in Fig .1 which contains a mixture of liquid and vapour at equilibrium (half of the container is invisible because of some display issue). The mass of the vapour is m_{vap} and the mass of the liquid is m_{liq} . The mass of the mixture is $m_{mix} = m_{vap} + m_{liq}$. Our system is made of this liquid and vapour. For such a system, dryness fraction or quality x is defined as $x = \frac{m_{vap}}{m_{vap} + m_{liq}} = \frac{m_{vap}}{m_{mix}}$ = fraction of the mixture that is in vapour phase. We had used the alphabet x to represent mole fraction when we studied ideal gases. Be careful!

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- $m = m_f + m_g$
- $V = V_f + V_g$
- $mv = m_f v_f + m_g v_g = (m - m_g)v_f + m_g v_g$
- $v = (1 - m_g/m)v_f + m_g v_g/m$
- $v = (1-x)v_f + x(v_g)$ ✓
- $v = v_f - x v_f + x v_g \Rightarrow v = v_f + x(v_g - v_f)$ ✓
- $v = v_f + x v_{fg}$ ✓
- Saturated vapour / Dry saturated vapour

$x = \frac{m_g}{m_f + m_g} = \frac{m_g}{m}$

$x = \frac{m_g}{m_g + 0} = 1$

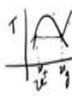




Figure 2.

In general, we use the alphabet f to represent liquid (fluid) and g to represent gas (these notations are used in all the books). Now, the mass of the mixture $m = m_f + m_g$ and the quality $x = \frac{m_g}{m}$. The volume of the mixture $V = V_f + V_g$. Hence, $mv = m_f v_f + m_g v_g = (m - m_g)v_f + m_g v_g$, where v represents specific volume of the mixture. Dividing by m throughout, $v = \left(1 - \frac{m_g}{m}\right)v_f + \frac{m_g v_g}{m}$. Hence, $v = (1 - x)v_f + x v_g = v_f + x(v_g - v_f) = v_f + x v_{fg}$, where $v_g - v_f$ is v_{fg} . When we have a mixture of a liquid and vapour in equilibrium, the liquid and vapour are called as saturated liquid and saturated vapour/dry saturated vapour, respectively. All the properties with subscripts f and g are properties of saturated liquid and saturated vapour, which are the states on a T-v diagram where an isobar (with pressure less than critical pressure) cuts the liquid-vapor dome. The intersection of such an isobar and the saturated liquid line represents the state where we have saturated liquid and the quality $x=0$ here. The intersection of that isobar with the saturated vapour line represents the state where we have saturated vapour/dry saturated vapour and the quality $x=1$ here. The quality/dryness fraction is associated with only the two-phase region and those two states where we have only liquid ($x=0$) and only vapour ($x=1$) at saturated conditions. It is not associated with the subcooled region or the superheated region.

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- Steam tables



Let's look at steam tables (these are for water). We can obtain properties of liquid water, steam and a mixture of water and steam from such tables. Similarly, we can have tables for other liquids such as refrigerants or for gases such as nitrogen, oxygen, argon, etc.

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Properties of Saturated Water - Temperature Table												
Temp	Pressure	volume (m ³ /kg)		energy (kJ/kg)		enthalpy (kJ/kg)			entropy (kJ/kg K)			
deg C	MPa	vf	vg	uf	ug	hf	hfg	hg	sf	sfg	sg	
0.01	0.0006117	0.001000	205.99	0.0	2374.9	0.00	2500.9	2500.9	0.0000	9.1555	9.1555	
5	0.0008726	0.001000	147.01	21.0	2381.8	21.02	2489.1	2510.1	0.0763	8.9485	9.0248	
10	0.001228	0.001000	106.30	42.0	2388.6	42.02	2477.2	2519.2	0.1511	8.7487	8.8998	
15	0.001706	0.001001	77.88	63.0	2395.5	62.98	2465.3	2528.3	0.2245	8.5558	8.7803	
20	0.002339	0.001002	57.76	83.9	2402.3	83.91	2453.5	2537.4	0.2965	8.3695	8.6660	
25	0.003170	0.001003	43.34	104.8	2409.1	104.83	2441.7	2546.5	0.3672	8.1894	8.5566	
30	0.004247	0.001004	32.88	125.7	2415.9	125.73	2429.8	2555.5	0.4368	8.0153	8.4520	
35	0.005629	0.001006	25.21	146.6	2422.7	146.63	2417.9	2564.3	0.5051	7.8466	8.3517	
40	0.007385	0.001008	19.52	167.5	2429.4	167.53	2406.0	2573.5	0.5724	7.6831	8.2555	
45	0.009595	0.001010	15.25	188.4	2436.1	188.43	2394.0	2582.4	0.6386	7.5247	8.1633	
50	0.01235	0.001012	12.03	209.3	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748	
55	0.01576	0.001015	9.564	230.2	2449.3	230.26	2369.8	2600.1	0.7680	7.2218	7.9898	
60	0.01995	0.001017	7.667	251.2	2455.9	251.18	2357.6	2608.8	0.8313	7.0768	7.9081	
65	0.02504	0.001020	6.194	272.1	2462.4	272.12	2345.4	2617.5	0.8937	6.9360	7.8296	
70	0.03120	0.001023	5.040	293.0	2468.9	293.07	2333.0	2626.1	0.9551	6.7989	7.7540	
75	0.03860	0.001026	4.129	314.0	2475.2	314.03	2320.6	2634.6	1.0158	6.6654	7.6812	
80	0.04741	0.001029	3.405	335.0	2481.6	335.01	2308.0	2643.0	1.0756	6.5355	7.6111	
85	0.05787	0.001032	2.826	356.0	2487.8	356.01	2295.3	2651.3	1.1346	6.4088	7.5434	
90	0.07018	0.001036	2.359	377.0	2494.0	377.04	2282.5	2659.5	1.1929	6.2852	7.4781	
95	0.08461	0.001040	1.981	398.0	2500.0	398.09	2269.5	2667.6	1.2504	6.1647	7.4151	
100	0.1014	0.001044	1.672	419.1	2506.0	419.17	2256.4	2675.6	1.3072	6.0469	7.3541	
110	0.1434	0.001052	1.209	461.3	2517.7	461.42	2229.7	2691.1	1.4188	5.8193	7.2381	
120	0.1987	0.001060	0.8912	503.6	2528.9	503.81	2202.1	2705.9	1.5279	5.6012	7.1291	
130	0.2703	0.001070	0.6680	546.1	2539.5	546.38	2173.7	2720.1	1.6346	5.3918	7.0264	
140	0.3615	0.001080	0.5085	588.8	2549.6	589.16	2144.2	2733.4	1.7392	5.1901	6.9293	



Figure 3.

Figure 3 shows a snippet of steam tables for saturated water listed by temperature. For saturated water (only water, no vapour), $x = 0$. For saturated vapour (only vapour, no water), $x=1$. For a mixture of saturated water and saturated vapour, $0 \leq x \leq 1$.

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Properties of Saturated Water - Pressure Table											
Pressure MPa	Temp deg C	volume (m ³ /kg)		energy (kJ/kg)		enthalpy (kJ/kg)			entropy (kJ/kg K)		
		vf	vg	uf	ug	hf	hfg	hg	sf	sg	
0.001	7.0	0.001000	129.2	29.3	2384.9	29.3	2484.4	2513.7	0.1059	8.8690	8.9749
0.0012	9.7	0.001000	108.7	40.6	2388.2	40.6	2478.0	2518.6	0.1460	8.7623	8.9082
0.0014	12.0	0.001001	93.90	50.3	2391.3	50.3	2472.5	2522.8	0.1802	8.6720	8.8521
0.0016	14.0	0.001001	82.74	58.8	2394.1	58.8	2467.7	2526.5	0.2100	8.5935	8.8035
0.0018	15.8	0.001001	74.01	66.5	2396.6	66.5	2463.4	2529.9	0.2366	8.5242	8.7608
0.002	17.5	0.001001	66.99	73.4	2398.9	73.4	2459.5	2532.9	0.2606	8.4620	8.7226
0.003	24.1	0.001003	45.65	101.0	2407.9	101.0	2443.8	2544.8	0.3543	8.2221	8.5764
0.004	29.0	0.001004	34.79	121.4	2414.5	121.4	2432.3	2553.7	0.4224	8.0510	8.4734
0.006	36.2	0.001007	23.73	151.5	2424.2	151.5	2415.1	2566.6	0.5208	7.8082	8.3290
0.008	41.5	0.001009	18.10	173.8	2431.4	173.8	2402.4	2576.2	0.5925	7.6348	8.2273
0.01	45.8	0.001010	14.67	191.8	2437.2	191.8	2392.1	2583.9	0.6492	7.4996	8.1488
0.012	49.4	0.001012	12.36	206.9	2442.0	206.9	2383.4	2590.3	0.6963	7.3886	8.0849
0.014	52.5	0.001013	10.49	220.0	2446.1	220.0	2375.8	2595.8	0.7366	7.2945	8.0211
0.016	55.3	0.001015	9.431	231.6	2449.8	231.6	2369.0	2600.6	0.7720	7.2126	7.9646
0.018	57.8	0.001016	8.443	242.0	2453.0	242.0	2363.0	2605.0	0.8036	7.1402	7.9137
0.02	60.1	0.001017	7.648	251.4	2456.0	251.4	2357.5	2608.9	0.8320	7.0752	7.8702
0.03	69.1	0.001022	5.228	289.2	2467.7	289.2	2335.2	2624.5	0.9441	6.8234	7.7675
0.04	75.9	0.001026	3.993	317.6	2476.3	317.6	2318.5	2636.1	1.0261	6.6429	7.6690
0.06	85.9	0.001033	2.732	359.8	2489.0	359.9	2293.0	2652.9	1.1454	6.3857	7.5311
0.08	93.5	0.001039	2.087	391.6	2498.2	391.7	2273.5	2665.2	1.2300	6.2009	7.4339
0.1	99.6	0.001043	1.694	417.4	2505.6	417.5	2257.4	2674.9	1.3028	6.0560	7.3588
0.12	104.8	0.001047	1.428	439.2	2511.7	439.4	2243.7	2683.1	1.3609	5.9368	7.2977
0.14	109.3	0.001051	1.237	458.3	2516.9	458.4	2231.6	2690.0	1.4110	5.8351	7.2461
0.16	113.3	0.001054	1.091	475.2	2521.4	475.4	2220.6	2696.0	1.4551	5.7463	7.2014
0.18	116.9	0.001058	0.9775	490.5	2525.5	490.7	2210.7	2701.4	1.4945	5.6676	7.1621
0.2	120.2	0.001061	0.8857	504.5	2529.1	504.7	2201.5	2706.3	1.5302	5.5947	7.1269
0.3	133.5	0.001073	0.6058	561.1	2543.2	561.4	2163.5	2724.9	1.6717	5.3199	6.9916



Figure 4.

Properties of Saturated Water - Temperature Table											
Temp deg C	Pressure MPa	volume (m ³ /kg)		energy (kJ/kg)		enthalpy (kJ/kg)			entropy (kJ/kg K)		
		vf	vg	uf	ug	hf	hfg	hg	sf	sg	
0.01	0.006117	0.001000	205.99	0.0	2374.9	0.00	2500.9	2500.9	0.0000	9.1555	9.1555
5	0.008726	0.001000	147.01	21.0	2381.8	21.02	2489.1	2510.1	0.0763	8.9485	9.0248
10	0.01228	0.001000	106.30	42.0	2388.6	42.02	2477.2	2519.2	0.1511	8.7487	8.8998
15	0.01706	0.001001	77.88	63.0	2395.5	62.98	2465.3	2528.3	0.2245	8.5558	8.7803
20	0.02339	0.001002	57.76	83.9	2402.3	83.91	2453.5	2537.4	0.2965	8.3695	8.6660
25	0.03170	0.001003	43.34	104.8	2409.1	104.83	2441.7	2546.5	0.3672	8.1894	8.5566
30	0.04247	0.001004	32.88	125.7	2415.9	125.73	2429.8	2555.5	0.4368	8.0153	8.4520
35	0.05629	0.001006	25.21	146.6	2422.7	146.63	2417.9	2564.5	0.5051	7.8466	8.3517
40	0.07385	0.001008	19.52	167.5	2429.4	167.53	2406.0	2573.5	0.5724	7.6831	8.2555
45	0.09595	0.001010	15.25	188.4	2436.1	188.43	2394.0	2582.4	0.6386	7.5247	8.1633
50	0.12235	0.001012	12.03	209.3	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748
55	0.1576	0.001015	9.564	230.2	2449.3	230.26	2369.8	2600.1	0.7680	7.2218	7.9898
60	0.21995	0.001017	7.667	251.2	2455.9	251.18	2357.6	2608.8	0.8313	7.0768	7.9081
65	0.22594	0.001020	6.194	272.1	2462.4	272.12	2345.4	2617.5	0.8937	6.9360	7.8296
70	0.03120	0.001023	5.040	293.0	2468.9	293.07	2333.0	2626.1	0.9551	6.7989	7.7540
75	0.03860	0.001026	4.129	314.0	2475.2	314.03	2320.6	2634.6	1.0158	6.6654	7.6812
80	0.04741	0.001029	3.405	335.0	2481.6	335.01	2308.0	2643.0	1.0756	6.5355	7.6111
85	0.05787	0.001032	2.826	356.0	2487.8	356.01	2295.3	2651.3	1.1346	6.4088	7.5434
90	0.07018	0.001036	2.359	377.0	2494.0	377.04	2282.5	2659.5	1.1929	6.2852	7.4781
95	0.08461	0.001040	1.981	398.0	2500.0	398.09	2269.5	2667.6	1.2504	6.1647	7.4151
100	0.1014	0.001044	1.672	419.1	2506.0	419.17	2256.4	2675.6	1.3072	6.0469	7.3541
110	0.1434	0.001052	1.209	461.3	2517.7	461.42	2229.7	2691.1	1.4188	5.8193	7.2381
120	0.1987	0.001060	0.8912	503.6	2528.9	503.81	2202.1	2705.9	1.5279	5.6012	7.1291
130	0.2703	0.001070	0.6680	546.1	2539.5	546.38	2173.7	2720.1	1.6346	5.3918	7.0264
140	0.3615	0.001080	0.5085	588.8	2549.6	589.16	2144.2	2733.4	1.7392	5.1901	6.9293



0.14	109.3	0.0010931	1.231	498.3	2516.9	458.4	2231.6	2690.0	1.4110	5.8201	7.2461
0.16	113.3	0.001054	1.091	475.2	2521.4	475.4	2220.6	2696.0	1.4551	5.7463	7.2014
0.18	116.9	0.001058	0.9775	490.5	2525.5	490.7	2210.7	2701.4	1.4945	5.6676	7.1621
0.2	120.2	0.001061	0.8857	504.5	2529.1	504.7	2201.5	2706.2	1.5302	5.5907	7.1269
0.3	133.5	0.001073	0.6058	561.1	2543.2	561.4	2163.5	2724.9	1.6717	5.3199	6.9916
0.4	143.6	0.001084	0.4624	604.2	2553.1	604.7	2133.5	2738.1	1.7765	5.1190	6.8955
0.6	158.8	0.001101	0.3156	669.7	2566.8	670.4	2085.7	2756.1	1.9308	4.8284	6.7592
0.8	170.4	0.001115	0.2403	720.0	2576.0	720.9	2047.4	2768.3	2.0457	4.6159	6.6616
1	179.9	0.001127	0.1944	761.4	2582.7	762.5	2014.6	2777.1	2.1381	4.4469	6.5850
1.2	188.0	0.001139	0.1633	797.0	2587.8	798.3	1985.4	2783.7	2.2159	4.3098	6.5217
1.4	195.0	0.001149	0.1408	828.4	2591.8	830.0	1958.8	2788.8	2.2835	4.1840	6.4675
1.6	201.4	0.001159	0.1237	856.6	2594.8	858.5	1934.3	2792.8	2.3435	4.0764	6.4199
1.8	207.1	0.001168	0.1104	882.4	2597.2	884.5	1911.4	2795.9	2.3975	3.9800	6.3775
2	212.4	0.001177	0.09959	906.1	2599.1	908.5	1889.8	2798.3	2.4468	3.8922	6.3390
3	233.9	0.001217	0.06666	1004.7	2603.2	1008.3	1794.9	2803.2	2.6455	3.5401	6.1856
4	250.4	0.001253	0.04978	1082.5	2601.7	1087.5	1713.3	2800.8	2.7968	3.2728	6.0696
6	275.6	0.001319	0.03245	1206.0	2589.9	1213.9	1570.7	2784.6	3.0278	2.8623	5.8901
8	295.0	0.001385	0.02353	1306.2	2570.5	1317.3	1441.4	2758.7	3.2081	2.5369	5.7450
10	311.0	0.001453	0.01803	1393.5	2545.2	1408.1	1317.4	2725.5	3.3606	2.2554	5.6160
12	324.7	0.001526	0.01426	1473.1	2514.3	1491.5	1193.9	2685.4	3.4967	1.9972	5.4939
14	336.7	0.001610	0.01149	1548.4	2477.1	1571.0	1066.9	2637.9	3.6232	1.7495	5.3727
16	347.4	0.001709	0.009309	1622.3	2431.8	1649.7	931.1	2580.8	3.7457	1.5006	5.2463
18	357.0	0.001840	0.007502	1699.0	2374.8	1732.1	777.7	2509.8	3.8718	1.2343	5.1061
20	365.8	0.002040	0.005865	1786.4	2295.0	1827.2	585.1	2412.3	4.0156	0.9158	4.9314
22.064	373.95	0.003106	0.003106	2015.7	2015.7	2084.3	0.0	2084.3	4.4070	0.0	4.4070

(Source of table data: NIST Chemistry WebBook Accessed: Jan 2008)



Figure 4 shows a snippet of steam tables for saturated water listed by pressure.

In the pressure table, the first column lists pressure (unit is megapascal). Other columns list properties such as temperature, specific volume, specific internal energy, specific enthalpy, and specific entropy. Temperature is in °C. v_f represents specific volume of saturated water, while v_g represents specific volume of saturated vapour (unit – m^3/kg). u_f represents specific internal energy of saturated water, while u_g represents specific internal energy of saturated vapour (unit – kJ/kg). h_f represents specific enthalpy of saturated water, while h_g represents specific enthalpy of saturated vapour (unit – kJ/kg), and $h_{fg} = h_g - h_f =$ latent heat of vaporization. Similarly, s_f represents specific entropy of saturated water, while s_g represents specific entropy of saturated vapour (unit – m^3/kg) and $s_{fg} = s_g - s_f$ (we will look at the concept of entropy when we look at the second law of thermodynamics). Let's read a row shown in the table shown in Fig.4.

For a pressure of 0.1 MPa, the saturation temperature is 99.6 °C. The specific volume of the saturated liquid ($x=0$) is $0.001043 \text{ m}^3/\text{kg}$ and the specific volume of saturated vapour ($x=1$) is $1.694 \text{ m}^3/\text{kg}$. Similarly, $u_f = 417.4 \text{ kJ}/\text{kg}$ and $u_g = 2505 \text{ kJ}/\text{kg}$, $h_f = 417 \text{ kJ}/\text{kg}$, $h_g = 2674.9 \text{ kJ}/\text{kg}$ and $h_{fg} = 2257.4 \text{ kJ}/\text{kg}$. Similarly, we can find property values at other pressures. For example, at 0.2 MPa, the saturation temperature is 120.2 °C. The specific volume of the saturated liquid ($x=0$) is $0.001061 \text{ m}^3/\text{kg}$ and the specific volume of saturated vapour ($x=1$) is $0.8857 \text{ m}^3/\text{kg}$. Similarly, $u_f = 504.5 \text{ kJ}/\text{kg}$ and $u_g = 2529.1 \text{ kJ}/\text{kg}$, $h_f = 504.7 \text{ kJ}/\text{kg}$, $h_g = 2706.5 \text{ kJ}/\text{kg}$ and $h_{fg} = 2201.5 \text{ kJ}/\text{kg}$. The latent heat of vaporization has reduced at higher pressure. The last value in the pressure column is that of critical pressure; $p_c = 22.064 \text{ MPa}$ and

$T_c=373.95$ °C. At the critical point, the specific volume of the liquid and the specific volume of the gas are the same. Similarly, the specific internal energy and specific enthalpy of the liquid and the vapor are the same.

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Properties of Saturated Water - Pressure Table									
Pressure MPa	Temp deg C	volume (m ³ /kg)		energy (kJ/kg)		enthalpy (kJ/kg)			
		vf	vg	uf	ug	hf	hfg	hg	
0.001	7.0	0.001000	129.2	29.3	2384.5	29.3	2484.4	2513.7	
0.0012	9.7	0.001000	108.7	40.6	2388.2	40.6	2478.0	2518.6	
0.0014	12.0	0.001001	93.90	50.3	2391.3	50.3	2472.5	2522.8	
0.0016	14.0	0.001001	82.74	58.8	2394.1	58.8	2467.7	2526.5	
0.0018	15.8	0.001001	74.01	66.5	2396.6	66.5	2463.4	2529.9	
0.002	17.5	0.001001	66.99	73.4	2398.9	73.4	2459.5	2532.9	
0.003	24.1	0.001003	45.65	101.0	2407.9	101.0	2443.8	2544.8	
0.004	29.0	0.001004	34.79	121.4	2414.5	121.4	2432.3	2553.7	
0.006	36.2	0.001007	23.73	151.5	2424.2	151.5	2415.1	2566.6	
0.008	41.5	0.001009	18.10	173.8	2431.4	173.8	2402.4	2576.2	
0.01	45.8	0.001010	14.67	191.8	2437.2	191.8	2392.1	2583.9	
0.012	49.4	0.001012	12.36	206.9	2442.0	206.9	2383.4	2590.3	
0.014	52.5	0.001013	10.69	220.0	2446.1	220.0	2375.8	2595.8	
0.016	55.3	0.001015	9.431	231.6	2449.8	231.6	2369.0	2600.6	
0.018	57.8	0.001016	8.443	242.0	2453.0	242.0	2363.0	2605.0	
0.02	60.1	0.001017	7.648	251.4	2456.0	251.4	2357.5	2608.9	
0.03	69.1	0.001022	5.228	289.2	2467.7	289.3	2335.2	2624.5	
0.04	75.9	0.001026	3.993	317.6	2476.3	317.6	2318.5	2636.1	
0.06	85.9	0.001033	2.732	359.8	2489.0	359.9	2293.0	2652.9	
0.08	93.5	0.001039	2.087	391.6	2498.2	391.7	2273.5	2665.2	
0.1	99.6	0.001043	1.694	417.4	2505.6	417.5	2257.4	2674.9	
0.12	104.8	0.001047	1.428	439.2	2511.7	439.4	2243.7	2683.1	
0.14	109.3	0.001051	1.237	458.3	2516.9	458.4	2231.6	2690.0	
0.16	113.3	0.001054	1.091	475.2	2521.4	475.4	2220.6	2696.0	
0.18	116.9	0.001058	0.9775	490.5	2525.5	490.7	2210.7	2701.4	



Pressure MPa	Temp deg C	volume (m ³ /kg)		energy (kJ/kg)		enthalpy (kJ/kg)		
		vf	vg	uf	ug	hf	hfg	hg
0.001	7.0	0.001000	129.2	29.3	2384.5	29.3	2484.4	2513.7
0.0012	9.7	0.001000	108.7	40.6	2388.2	40.6	2478.0	2518.6
0.0014	12.0	0.001001	93.90	50.3	2391.3	50.3	2472.5	2522.8
0.0016	14.0	0.001001	82.74	58.8	2394.1	58.8	2467.7	2526.5
0.0018	15.8	0.001001	74.01	66.5	2396.6	66.5	2463.4	2529.9
0.002	17.5	0.001001	66.99	73.4	2398.9	73.4	2459.5	2532.9
0.003	24.1	0.001003	45.65	101.0	2407.9	101.0	2443.8	2544.8
0.004	29.0	0.001004	34.79	121.4	2414.5	121.4	2432.3	2553.7
0.006	36.2	0.001007	23.73	151.5	2424.2	151.5	2415.1	2566.6
0.008	41.5	0.001009	18.10	173.8	2431.4	173.8	2402.4	2576.2
0.01	45.8	0.001010	14.67	191.8	2437.2	191.8	2392.1	2583.9
0.012	49.4	0.001012	12.36	206.9	2442.0	206.9	2383.4	2590.3
0.014	52.5	0.001013	10.69	220.0	2446.1	220.0	2375.8	2595.8
0.016	55.3	0.001015	9.431	231.6	2449.8	231.6	2369.0	2600.6
0.018	57.8	0.001016	8.443	242.0	2453.0	242.0	2363.0	2605.0
0.02	60.1	0.001017	7.648	251.4	2456.0	251.4	2357.5	2608.9
0.03	69.1	0.001022	5.228	289.2	2467.7	289.3	2335.2	2624.5
0.04	75.9	0.001026	3.993	317.6	2476.3	317.6	2318.5	2636.1
0.06	85.9	0.001033	2.732	359.8	2489.0	359.9	2293.0	2652.9
0.08	93.5	0.001039	2.087	391.6	2498.2	391.7	2273.5	2665.2
0.1	99.6	0.001043	1.694	417.4	2505.6	417.5	2257.4	2674.9
0.12	104.8	0.001047	1.428	439.2	2511.7	439.4	2243.7	2683.1
0.14	109.3	0.001051	1.237	458.3	2516.9	458.4	2231.6	2690.0
0.16	113.3	0.001054	1.091	475.2	2521.4	475.4	2220.6	2696.0
0.18	116.9	0.001058	0.9775	490.5	2525.5	490.7	2210.7	2701.4
0.2	120.2	0.001061	0.8857	504.5	2529.1	504.7	2201.5	2706.2
0.3	133.5	0.001073	0.6088	641.1	2549.9	641.4	2162.8	2734.6



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Properties of Saturated Water - Temperature Table											
Temp deg C	Pressure MPa	volume (m ³ /kg)		energy (kJ/kg)		enthalpy (kJ/kg)			entropy (kJ/kg.K)		
		vf	vg	uf	ug	hf	hfg	hg	sf	sfg	sg
0.01	0.0006117	0.001000	205.99	0.0	2374.9	0.00	2500.9	2500.9	0.0000	9.1555	9.1555
5	0.0008726	0.001000	147.01	21.0	2381.8	21.02	2489.1	2510.1	0.0763	8.9485	9.0248
10	0.001228	0.001000	106.30	42.0	2388.6	42.02	2477.2	2519.2	0.1511	8.7487	8.8998
15	0.001706	0.001001	77.88	63.0	2395.5	62.98	2465.3	2528.3	0.2245	8.5558	8.7803
20	0.002339	0.001002	57.76	83.9	2402.3	83.91	2453.3	2537.4	0.2965	8.3695	8.6660
25	0.003170	0.001003	43.34	104.8	2409.1	104.83	2441.7	2546.5	0.3672	8.1894	8.5566
30	0.004247	0.001004	32.88	125.7	2415.9	125.73	2429.8	2555.5	0.4368	8.0153	8.4520
35	0.005629	0.001006	25.21	146.6	2422.7	146.63	2417.9	2564.5	0.5051	7.8466	8.3517
40	0.007385	0.001008	19.52	167.5	2429.4	167.53	2406.0	2573.5	0.5724	7.6831	8.2555
45	0.009595	0.001010	15.25	188.4	2436.1	188.43	2394.0	2582.4	0.6386	7.5247	8.1633
50	0.01235	0.001012	12.03	209.3	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748
55	0.01576	0.001015	9.564	230.2	2449.3	230.26	2369.8	2600.1	0.7680	7.2218	7.9898
60	0.01995	0.001017	7.667	251.2	2455.9	251.18	2357.6	2608.8	0.8313	7.0768	7.9081
65	0.02504	0.001020	6.194	272.1	2462.4	272.12	2345.4	2617.5	0.8937	6.9360	7.8296
70	0.03120	0.001023	5.040	293.0	2468.9	293.07	2333.0	2626.1	0.9551	6.7989	7.7540
75	0.03860	0.001026	4.129	314.0	2475.2	314.03	2320.6	2634.6	1.0158	6.6654	7.6812
80	0.04741	0.001029	3.405	335.0	2481.4	335.01	2308.0	2643.0	1.0756	6.5355	7.6111
85	0.05787	0.001032	2.826	356.0	2487.8	356.01	2295.3	2651.3	1.1346	6.4088	7.5434
90	0.07018	0.001036	2.359	377.0	2494.0	377.04	2282.5	2659.5	1.1929	6.2852	7.4781
95	0.08461	0.001040	1.981	398.0	2500.0	398.09	2269.5	2667.6	1.2504	6.1647	7.4151
100	0.1014	0.001044	1.672	419.1	2506.0	419.17	2256.4	2675.6	1.3072	6.0469	7.3541
110	0.1434	0.001052	1.209	461.3	2517.7	461.42	2229.7	2691.1	1.4188	5.8193	7.2381
120	0.1987	0.001060	0.8912	503.6	2528.9	503.81	2202.1	2705.9	1.5279	5.6012	7.1291
130	0.2703	0.001070	0.6680	546.1	2539.5	546.38	2173.7	2720.1	1.6346	5.3918	7.0264
140	0.3615	0.001080	0.5085	588.8	2549.6	589.16	2144.2	2733.4	1.7392	5.1901	6.9293

Figure 5.

150	0.4782	0.001091	0.3925	631.7	2558.1	632.18	2113.7	2745.9	1.8418	4.9953	6.8371
160	0.6182	0.001102	0.3068	674.8	2567.8	675.47	2081.9	2757.4	1.9426	4.8065	6.7491
170	0.7922	0.001114	0.2426	718.2	2575.7	719.08	2048.8	2767.9	2.0417	4.6233	6.6650
180	1.0028	0.001127	0.1938	761.9	2582.8	763.05	2014.2	2777.2	2.1392	4.4448	6.5840
190	1.2552	0.001142	0.1564	806.0	2589.0	807.43	1977.9	2785.3	2.2355	4.2704	6.5059
200	1.5549	0.001157	0.1272	850.5	2594.2	852.27	1939.7	2792.0	2.3309	4.0997	6.4302
210	1.9077	0.001173	0.1043	895.4	2598.3	897.63	1899.7	2797.3	2.4245	3.9318	6.3563
220	2.3196	0.001190	0.08609	940.8	2601.2	943.58	1857.3	2800.9	2.5177	3.7663	6.2840
230	2.7971	0.001209	0.07150	986.8	2602.9	990.19	1812.7	2802.9	2.6101	3.6027	6.2128
240	3.3469	0.001230	0.05971	1033.4	2603.1	1037.60	1765.4	2803.0	2.7020	3.4403	6.1423
250	3.9762	0.001252	0.05008	1080.8	2601.8	1085.80	1715.1	2800.9	2.7935	3.2786	6.0721
260	4.6923	0.001276	0.04217	1129.0	2598.7	1135.00	1661.6	2796.6	2.8849	3.1167	6.0016
270	5.5030	0.001303	0.03562	1178.1	2593.7	1185.30	1604.4	2789.7	2.9765	2.9539	5.9304
280	6.4166	0.001333	0.03015	1228.3	2586.4	1236.90	1543.0	2779.9	3.0685	2.7894	5.8579
290	7.4418	0.001366	0.02556	1279.9	2576.5	1290.00	1476.7	2766.7	3.1612	2.6222	5.7834
300	8.5879	0.001404	0.02166	1332.9	2563.6	1345.00	1404.6	2749.4	3.2552	2.4507	5.7099
310	9.8651	0.001448	0.01834	1387.9	2547.1	1402.20	1325.7	2727.9	3.3510	2.2734	5.6344
320	11.284	0.001499	0.01547	1445.3	2528.0	1462.20	1238.4	2700.4	3.4494	2.0878	5.5572
330	12.858	0.001561	0.01298	1505.8	2499.2	1525.90	1140.1	2666.0	3.5518	1.8904	5.4422
340	14.601	0.001638	0.01078	1570.6	2464.4	1594.50	1027.3	2621.8	3.6601	1.6755	5.3356
350	16.529	0.001740	0.008802	1642.1	2418.1	1670.90	892.7	2563.6	3.7784	1.4326	5.2110
360	18.666	0.001895	0.006949	1726.3	2351.8	1761.70	719.8	2481.5	3.9167	1.1369	5.0536
370	21.044	0.002215	0.004954	1844.1	2230.3	1890.70	443.8	2334.5	4.1112	0.6900	4.8012
373.95	22.064	0.003106	0.003106	2015.7	2015.7	2084.30	0.0	2084.3	4.4070	0.0	4.4070

Figure 5 shows the snippet of the steam tables listed by temperature. Here, the first column is of temperature. The properties can be read in a similar way we discussed in the case of the tables listed by pressure. The choice of the tables listed by pressure or temperature depends on convenience. If the properties at temperature and pressure we are looking for are not listed, then we can use linear interpolation to find properties at the required temperature and pressure. The last entry in the tables listed by temperature is the critical point.

Using these tables, we can find properties of liquid water and vapour at saturation, and using these properties we can also find properties of a mixture of liquid water and vapour.

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Program of Operations - 2018														
2018-19			2017-18			2016-17			2015-16			2014-15		
Sl. No.	Particulars	Amount	Sl. No.	Particulars	Amount	Sl. No.	Particulars	Amount	Sl. No.	Particulars	Amount	Sl. No.	Particulars	Amount
1	Salaries	1000000	1	Salaries	950000	1	Salaries	900000	1	Salaries	850000	1	Salaries	800000
2	Grants	500000	2	Grants	480000	2	Grants	460000	2	Grants	440000	2	Grants	420000
3	Expenses	300000	3	Expenses	280000	3	Expenses	260000	3	Expenses	240000	3	Expenses	220000
4	Income	200000	4	Income	190000	4	Income	180000	4	Income	170000	4	Income	160000
5	Reserves	100000	5	Reserves	95000	5	Reserves	90000	5	Reserves	85000	5	Reserves	80000
6	Other	50000	6	Other	48000	6	Other	46000	6	Other	44000	6	Other	42000
7	Total	2000000	7	Total	1900000	7	Total	1800000	7	Total	1700000	7	Total	1600000



Program of Operations - 2018														
2018-19			2017-18			2016-17			2015-16			2014-15		
Sl. No.	Particulars	Amount	Sl. No.	Particulars	Amount	Sl. No.	Particulars	Amount	Sl. No.	Particulars	Amount	Sl. No.	Particulars	Amount
1	Salaries	1000000	1	Salaries	950000	1	Salaries	900000	1	Salaries	850000	1	Salaries	800000
2	Grants	500000	2	Grants	480000	2	Grants	460000	2	Grants	440000	2	Grants	420000
3	Expenses	300000	3	Expenses	280000	3	Expenses	260000	3	Expenses	240000	3	Expenses	220000
4	Income	200000	4	Income	190000	4	Income	180000	4	Income	170000	4	Income	160000
5	Reserves	100000	5	Reserves	95000	5	Reserves	90000	5	Reserves	85000	5	Reserves	80000
6	Other	50000	6	Other	48000	6	Other	46000	6	Other	44000	6	Other	42000
7	Total	2000000	7	Total	1900000	7	Total	1800000	7	Total	1700000	7	Total	1600000



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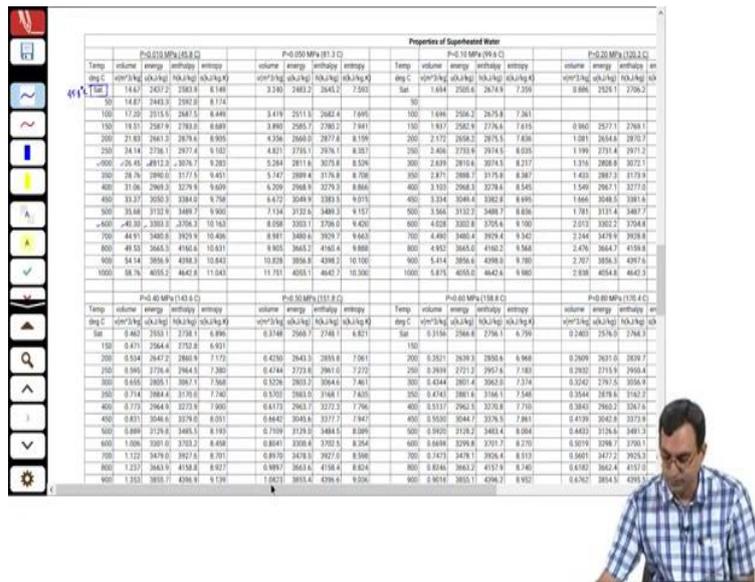
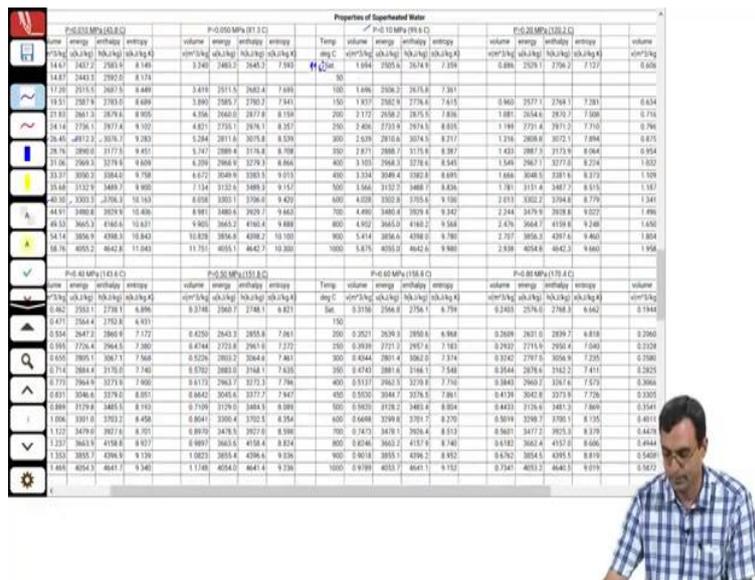


Figure 6.



There are tables to find properties of superheated vapour. Figure 6 shows tables for superheated steam. Let's look at the table in the top left corner of Fig .6. The first row reads the pressure and the corresponding saturation temperature; $p=0.01$ MPa and $T = 45.8$ °C. This table is for a pressure of 0.01 MPa and temperatures larger than the saturation temperature corresponding to $p=0.01$ MPa which is 45.8 °C. At $T > 45.8$ °C, we will have only the superheated vapour. Hence, we can't see properties of liquid in this table. The table mentions the volume, internal energy, enthalpy and entropy of vapour only. So, this table is for $p=0.01$ MPa and $T > 45.8$ °C ($T=45.8$ °C is the saturation temperature for $p=0.01$ MPa). Similarly, we

have tables for different pressures and the properties are mentioned only for temperatures greater than the corresponding saturation temperatures.

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P=0.01 MPa (0.1 bar)										P=0.1 MPa (1 bar)										P=1 MPa (10 bar)										P=10 MPa (100 bar)									
Temp	Volume	Energy	Enthalpy	Entropy	Temp	Volume	Energy	Enthalpy	Entropy	Temp	Volume	Energy	Enthalpy	Entropy	Temp	Volume	Energy	Enthalpy	Entropy	Temp	Volume	Energy	Enthalpy	Entropy															
deg C	m³/kg	kJ/kg	kJ/kg	kJ/kg.K	deg C	m³/kg	kJ/kg	kJ/kg	kJ/kg.K	deg C	m³/kg	kJ/kg	kJ/kg	kJ/kg.K	deg C	m³/kg	kJ/kg	kJ/kg	kJ/kg.K	deg C	m³/kg	kJ/kg	kJ/kg	kJ/kg.K															
0	0.0001	0	0	0	0	0.0001	0	0	0	0	0.0001	0	0	0	0	0.0001	0	0	0	0	0.0001	0	0	0															
100	0.0001	0.0001	0.0001	0.0001	100	0.0001	0.0001	0.0001	0.0001	100	0.0001	0.0001	0.0001	0.0001	100	0.0001	0.0001	0.0001	0.0001	100	0.0001	0.0001	0.0001	0.0001															
200	0.0001	0.0002	0.0002	0.0002	200	0.0001	0.0002	0.0002	0.0002	200	0.0001	0.0002	0.0002	0.0002	200	0.0001	0.0002	0.0002	0.0002	200	0.0001	0.0002	0.0002	0.0002															
300	0.0001	0.0003	0.0003	0.0003	300	0.0001	0.0003	0.0003	0.0003	300	0.0001	0.0003	0.0003	0.0003	300	0.0001	0.0003	0.0003	0.0003	300	0.0001	0.0003	0.0003	0.0003															
400	0.0001	0.0004	0.0004	0.0004	400	0.0001	0.0004	0.0004	0.0004	400	0.0001	0.0004	0.0004	0.0004	400	0.0001	0.0004	0.0004	0.0004	400	0.0001	0.0004	0.0004	0.0004															
500	0.0001	0.0005	0.0005	0.0005	500	0.0001	0.0005	0.0005	0.0005	500	0.0001	0.0005	0.0005	0.0005	500	0.0001	0.0005	0.0005	0.0005	500	0.0001	0.0005	0.0005	0.0005															
600	0.0001	0.0006	0.0006	0.0006	600	0.0001	0.0006	0.0006	0.0006	600	0.0001	0.0006	0.0006	0.0006	600	0.0001	0.0006	0.0006	0.0006	600	0.0001	0.0006	0.0006	0.0006															
700	0.0001	0.0007	0.0007	0.0007	700	0.0001	0.0007	0.0007	0.0007	700	0.0001	0.0007	0.0007	0.0007	700	0.0001	0.0007	0.0007	0.0007	700	0.0001	0.0007	0.0007	0.0007															
800	0.0001	0.0008	0.0008	0.0008	800	0.0001	0.0008	0.0008	0.0008	800	0.0001	0.0008	0.0008	0.0008	800	0.0001	0.0008	0.0008	0.0008	800	0.0001	0.0008	0.0008	0.0008															
900	0.0001	0.0009	0.0009	0.0009	900	0.0001	0.0009	0.0009	0.0009	900	0.0001	0.0009	0.0009	0.0009	900	0.0001	0.0009	0.0009	0.0009	900	0.0001	0.0009	0.0009	0.0009															
1000	0.0001	0.001	0.001	0.001	1000	0.0001	0.001	0.001	0.001	1000	0.0001	0.001	0.001	0.001	1000	0.0001	0.001	0.001	0.001	1000	0.0001	0.001	0.001	0.001															

