ME 266 THERMODYNAMICS 1

3. Properties of Pure Substances

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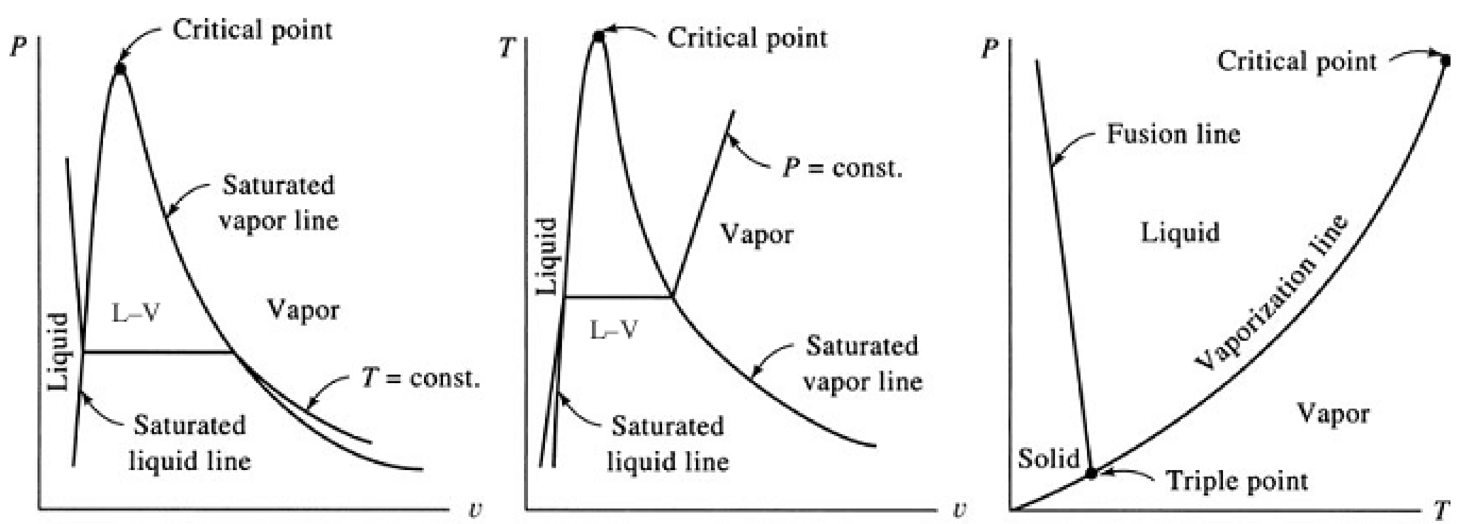
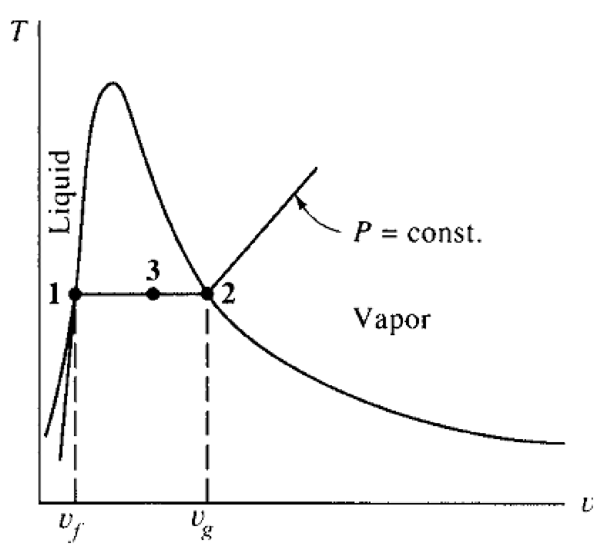
PROPERTIES OF PURE SUBSTANCES

- ✓ A pure substance is homogeneous, but may exist in more than one phase, with each phase having the same chemical composition.
- ✓ Water is a pure substance – the various combinations of its three phases (vapor, liquid, ice) have the same chemical composition.



(a) (b) (c)

PROPERTIES OF PURE SUBSTANCES

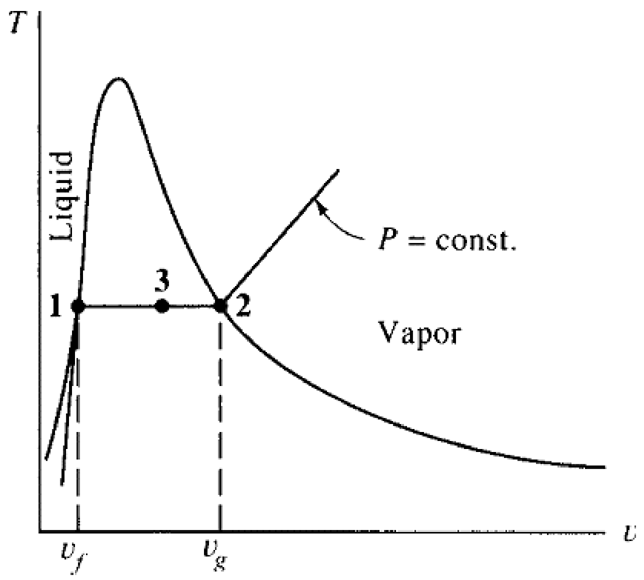


- ✓ Let **m** be the total mass of a system,
- ✓ **m_f** the amount of mass in the liquid phase
- ✓ **m_g** the amount of mass in the vapor phase.
- ✓ Then, for a state of the system, such as state 3,
- ✓ the total volume ***(V)*** of the mixture is the sum of the volume occupied by the liquid and that occupied by the vapour:

$$V = V_f + V_g \quad \Rightarrow \quad mv = m_f v_f + m_g v_g$$

- *v_f- Specific volume at state 1 (saturated liquid) (m^3/kg)*
- *v_g- specific volume at state 2 (saturated vapour) (m^3/kg)*
- *v- specific volume (average) of vapour-liquid mixture (m^3/kg)*
- *m is mass (kg)*

PROPERTIES OF PURE SUBSTANCES



- ✓ The ratio of the mass of saturated vapor to the total mass is called the **quality** of the mixture, designated by the symbol x.

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

Recognizing that: $m = m_f + m_g$; and total volume **V** is:

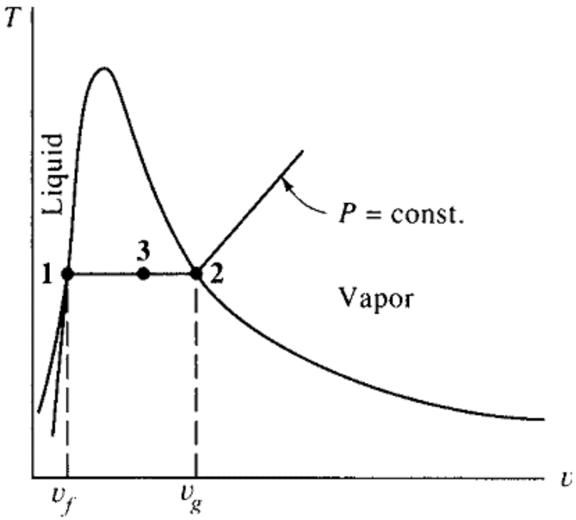
- *v=(m³/kg)*

$$mv = m_f v_f + m_g v_g$$

We may write the average specific volume as:

$$v = v_f + x(v_g - v_f)$$

PROPERTIES OF PURE SUBSTANCES



- ✓ Because the difference in saturated vapour and saturated liquid properties frequently appears in calculations, it often denoted by the subscript *"fg"*:

$$v_{fg} = v_g - v_f$$

The average specific volume of the liquid-vapour mixture can the be written as:

$$v = v_f + x v_{fg}$$

- ✓ **This concept will be used extensively later in this course, in analyzing power cycles.**

PROPERTIES OF PURE SUBSTANCES

Equations of State

- ✓ When the vapour of a substance has relatively low density, the pressure, specific volume, and temperature are related by an **equation of state**.

$$Pv = RT$$

- ✓ For a particular gas, R is a constant. A gas for which this equation is valid is called an ideal or perfect gas.
- ✓ The gas constant R is related to a *universal gas constant* $\bar{R}$ which has the same value for all gases as:

$$R = \frac{\bar{R}}{M}$$

Where M is the molar mass

The value $\bar{R}$ = 8.314 kJ/kmol•K. For air M is 28.97 kg/kmol, so that for air R is 0.287 kJ/kg•K, or 287 J/kg•K, a value used extensively in calculations involving air.

PROPERTIES OF PURE SUBSTANCES

Equations of State

- ✓ Other forms of the ideal gas equation are also used:

$$PV = mRT \qquad P = \rho RT \qquad PV = n\bar{R}T$$

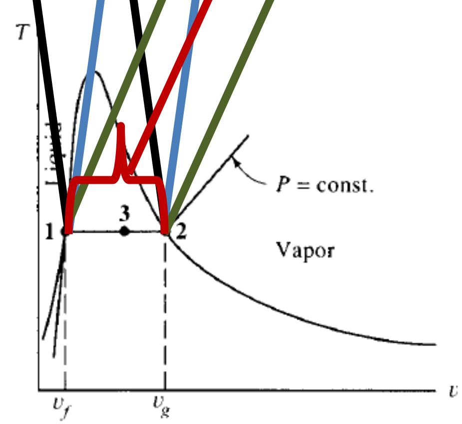
- ✓ For each form chosen, the proper form of the gas constant must be used, for dimensional consistency.

Steam Tables

STEAM TABLES

Saturated water table (Temperature table)

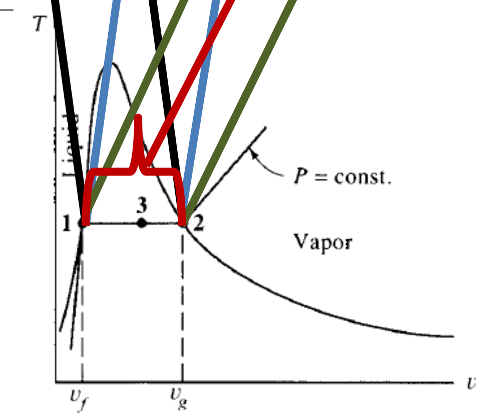
T, °C	P, MPa	v, m³/kg		u, kJ/kg		h, kJ/kg			s, kJ/kg·K		
		v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
0.01	0 0.000611	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0000	9.1571	9.1571
2	0.0007056	0.001000	179.9	8.4	2378.1	8.4	2496.6	2505.0	0.0305	9.0738	9.1043
5	0.0008721	0.001000	147.1	21.0	2382.2	21.0	2489.5	2510.5	0.0761	8.9505	9.0266
10	0.001228	0.001000	106.4	42.0	2389.2	42.0	2477.7	2519.7	0.1510	8.7506	8.9016
20	0.002338	0.001002	57.79	83.9	2402.9	83.9	2454.2	2538.1	0.2965	8.3715	8.6680
30	0.004246	0.001004	32.90	125.8	2416.6	125.8	2430.4	2556.2	0.4367	8.0174	8.4541
40	0.007383	0.001008	19.52	167.5	2430.1	167.5	2406.8	2574.3	0.5723	7.6855	8.2578
50	0.01235	0.001012	12.03	209.3	2443.5	209.3	2382.8	2592.1	0.7036	7.3735	8.0771
60	0.01994	0.001017	7.671	251.1	2456.6	251.1	2358.5	2609.6	0.8310	7.0794	7.9104
70	0.03119	0.001023	5.042	292.9	2469.5	293.0	2333.8	2626.8	0.9549	6.8012	7.7561
80	0.04739	0.001029	3.407	334.9	2482.2	334.9	2308.8	2643.7	1.0754	6.5376	7.6130



STEAM TABLES

Saturated water table (Pressure table)

P, MPa	T, °C	v, m³/kg		u, kJ/kg		h, kJ/kg			s, kJ/kg·K		
		v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
0.0006	0.01	0.001000	206.1	0.0	2375.3	0.0	2501.3	2501.3	0.0000	9.1571	9.1571
0.0008	3.8	0.001000	159.7	15.8	2380.5	15.8	2492.5	2508.3	0.0575	9.0007	9.0582
0.001	7.0	0.001000	129.2	29.3	2385.0	29.3	2484.9	2514.2	0.1059	8.8706	8.9765
0.0012	9.7	0.001000	108.7	40.6	2388.7	40.6	2478.5	2519.1	0.1460	8.7639	8.9099
0.0014	12.0	0.001001	93.92	50.3	2391.9	50.3	2473.1	2523.4	0.1802	8.6736	8.8538
0.0016	14.0	0.001001	82.76	58.9	2394.7	58.9	2468.2	2527.1	0.2101	8.5952	8.8053
0.002	17.5	0.001001	67.00	73.5	2399.5	73.5	2460.0	2533.5	0.2606	8.4639	8.7245
0.003	24.1	0.001003	45.67	101.0	2408.5	101.0	2444.5	2545.5	0.3544	8.2240	8.5784
0.004	29.0	0.001004	34.80	121.4	2415.2	121.4	2433.0	2554.4	0.4225	8.0529	8.4754
0.006	36.2	0.001006	23.74	151.5	2424.9	151.5	2415.9	2567.4	0.5208	7.8104	8.3312



STEAM TABLES

Superheated steam

Look for given pressure and align with the given temperature and then read the desired value. e.g. 2 MPa & max temp 400 °C

T	*v*	*u*	*h*	*s*	*v*	*u*	*h*	*s*	*v*	*u*	*h*	*s*
	P = 1.60 MPa (201.4°C)				*P* = 1.80 MPa (207.2°C)				*P* = 2.00 MPa (212.4°C)			
Sat.	.1238	2596	2794	6.422	.1104	2598	2797	6.3794	.099 6	2600	2800	6.341
250	.1418	2692	2919	6.673	.1250	2686	2911	6.6066	.1114	2680	2902	6.545
300	.1586	2781	3035	6.884	.1402	2777	3029	6.8226	.1255	2773	3024	6.766
350	.1746	2866	3145	7.069	.1546	2863	3141	7.0100	.1386	2860	3137	6.956
400	.1900	2950	3254	7.237	.1685	2948	3251	7.1794	.1512	2945	3248	7.128
500	.2203	3119	3472	7.539	.1955	3118	3470	7.4825	.1757	3116	3468	7.432
600	.2500	3293	3693	7.808	.2220	3292	3692	7.7523	.1996	3291	3690	7.702
700	.2794	3473	3920	8.054	.2482	3473	3918	7.9983	.2232	3471	3917	7.949
800	.3086	3658	4152	8.281	.2742	3658	4151	8.2258	.2467	3657	4150	8.176
900	.3377	3850	4391	8.494	.3001	3850	4390	8.4386	.2700	3849	4389	8.390

STEAM TABLES

P, MPa	T, °C	v, m³/kg		u, kJ/kg		h, kJ/kg			s, kJ/kg·K		
		v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
0.0006	0.01	0.001000	206.1	0.0	2375.3	0.0	2501.3	2501.3	0.0000	9.1571	9.1571
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0.004	29.0	0.001004	34.80	121.4	2415.2	121.4	2433.0	2554.4	0.4225	8.0529	8.4754
0.006	36.2	0.001006	23.74	151.5	2424.9	151.5	2415.9	2567.4	0.5208	7.8104	8.3312

Linear interpolation may be necessary in some instances.

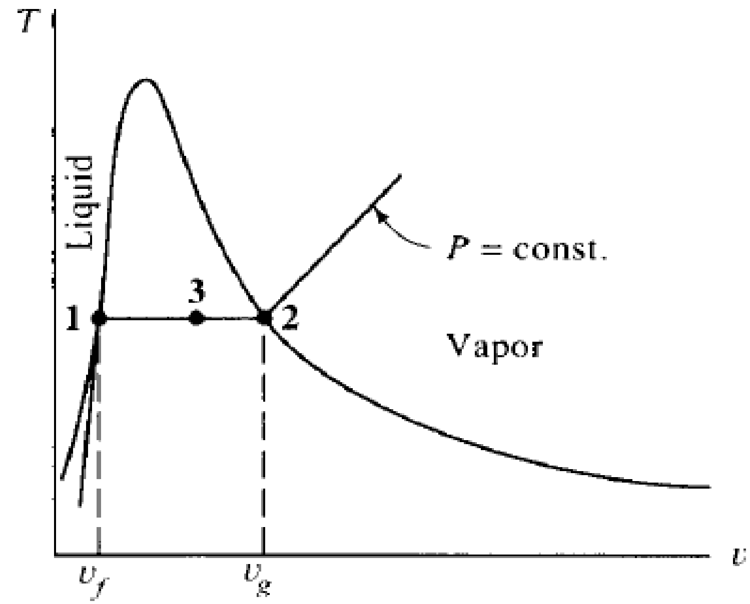
E.g. Enthalpy of saturated water (liquid) at 5 kPa (0.005 MPa):

h@4 kPa = 121.4 kJ/kg
h@5 kPa = ?
h@6 kPa = 151.5 kJ/kg

STEAM TABLES

Question

Determine the volume change when 10 kg of saturated water is completely vaporized at a pressure of:
(a) 1 kPa,
(b) 200 kPa, and
(c) 8 000 kPa.



SUGGESTED STEPS

1. Read from pressure tables (instead of Temperature tables).
2. Read specific volume (v_f and v_g) corresponding to the pressure.
3. Compute v_g-v_f and multiply result by the mass of saturated water (10 kg).

- **One kilogram of steam with a quality of 20 percent is heated at a contant pressure of 200 kPa until the temperature reaches 400 °C. Calculate the work done by the steam.**

$$W = \int_{V_1}^{V_2} P dV$$

$$W = P(V_2 - V_1)$$
$$= mP(v_2 - v_1)$$

$$v_1 = v_f + x(v_g - v_f)$$

$$\left.\begin{aligned} v_1 &= 0.178\ m^3/kg \\ v_2 &= 1.549\ m^3/kg \end{aligned}\right\}$$

Using data from steam tables

$$P = 200\ kPa, \mathrm{m} = 1\ \mathrm{kg}$$

$$W = 274.2\ \mathrm{kJ}$$