Properties of Pure Substances
(*Contd…*)

Property Table

❖ For example if the pressure and specific volume are specified, three questions are asked: For the given pressure,

❖ If the answer to the first question is yes, the state is in the compressed liquid region, and the compressed liquid table is used to find the properties. (or using *saturation temperature table*)
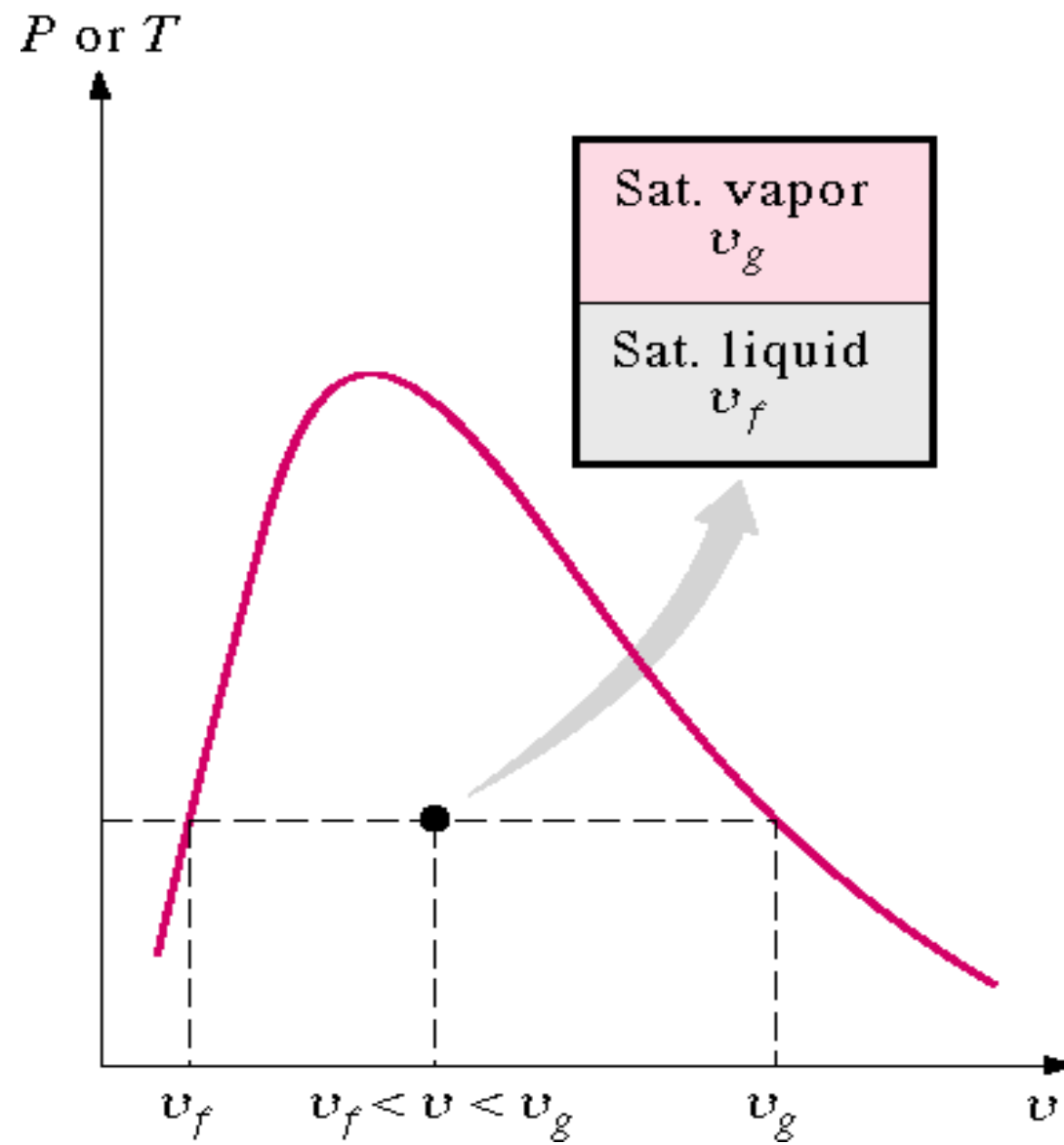
$$v < v_f$$

❖ If the answer to the second question is yes, the state is in the saturation region, and either the saturation temperature table or the saturation pressure table is used.

$$v_f < v < v_g$$

❖ If the answer to the third question is yes, the state is in the superheated region and the superheated table is used.

$$v_g < v$$

Property Table

Example 3.3

Determine the enthalpy of 1.5 kg of water contained in a volume of 1.2 m³ at 200 kPa.

Solution:

❑ Specific volume for water

$$v = \frac{Volume}{mass} = \frac{1.2\,m^3}{1.5\,kg} = 0.8\,\frac{m^3}{kg}$$

❑ From saturated water-pressure table:

$$v_f = 0.001061\,^{m^3}\!/_{kg}$$

$$v_g = 0.8858\,^{m^3}\!/_{kg}$$

Is $v < v_f$? No

Is $v_f < v < v_g$? Yes

Is $v_g < v$? No

❑ Find the quality

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

$$x = \frac{v - v_f}{v_g - v_f}$$

$$= \frac{0.8 - 0.001061}{0.8858 - 0.001061}$$

$$= 0.903 \quad \text{(What does this mean?)}$$

❑ The enthalpy

$$h = h_f + x\,h_{fg}$$

$$= 504.7 + (0.903)(2201.6)$$

$$= 2492.7\,\frac{kJ}{kg}$$

Example 3.4

Determine the internal energy of refrigerant-134a at a temperature of 0°C and a quality of 60%.
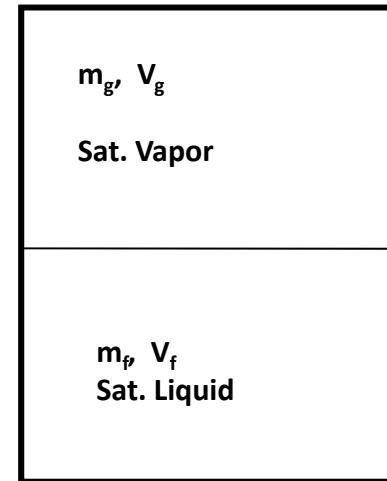
Solution:

❖ From table:

$$u_f = 51.63 \frac{kJ}{kg}$$

$$u_g = 230.16 \frac{kJ}{kg}$$

❖ The internal energy of R 134a at given condition:

$$u = u_f + x(u_g - u_f)$$

$$= 51.63 + (0.6)(230.16 - 51.63)$$

$$= 158.75 \frac{kJ}{kg}$$

Example 3.5

Consider the closed, rigid container of water as shown. The pressure is 700 kPa, the mass of the saturated liquid is 1.78 kg, and the mass of the saturated vapor is 0.22 kg. Heat is added to the water until the pressure increases to 8 MPa. Find the final temperature, enthalpy, and internal energy of the water

Solution:

❖ Theoretically:

$$v_2 = v_1$$

❖ The quality before pressure increased (*state 1*).

$$x_1 = \frac{m_{g1}}{m_{f1} + m_{g1}}$$

$$= \frac{0.22\,kg}{(1.78 + 0.22)\,kg} = 0.11$$

❖ Specific volume at *state 1*
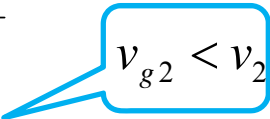
$$v_1 = v_{f1} + x_1(v_{g1} - v_{f1})$$

$$= 0.001108 + (0.11)(0.2728 - 0.001108)$$

$$= 0.031 \frac{m^3}{kg}$$

State 2:

❖ Information :

$$P_2 = 8\,MPa \quad v_2 = 0.031 \tfrac{m^3}{kg}$$

❖ From Saturated table:

$$v_{f,2} = 0.001384 \quad \frac{m^3}{kg}$$

$$v_{g,2} = 0.02352 \quad \frac{m^3}{kg}$$

$$v_{g2} < v_2$$

❖ Since that it is in superheated region, use superheated table:

$$T_2 = 361.8^o C$$

$$h_2 = 3024 \tfrac{kJ}{kg}$$

$$u_2 = 2776 \tfrac{kJ}{kg}$$

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 (vapor phase only), temperature and pressure are no longer dependent properties and they can conveniently be used as the two independent properties in the tables. The format of the superheated vapor tables is illustrated in Fig. 3.23.

- In these tables, the properties are listed against temperature for selected pressures starting with the saturated vapor data.

- The saturation temperature is given in parentheses following the pressure value.

T,°C	v, m³/kg	u, kJ/kg	h, kJ/kg
$P = 0.1$ MPa (99.63°C)			
Sat.	1.6940	2506.1	2675.5
100	1.6958	2506.7	2676.2
150	1.9364	2582.8	2776.4
⋮	⋮	⋮	⋮
1300	7.260	4683.5	5409.5
$P = 0.5$ MPa (151.86°C)			
Sat.	0.3749	2561.2	2748.7
200	0.4249	2642.9	2855.4
250	0.4744	2723.5	2960.7

Fig. 3.23: Superheated vapor table

Superheated vapor is characterized by

Lower pressures ($P < P_{sat}$ at a given T)
Higher temperatures ($T > T_{sat}$ 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)
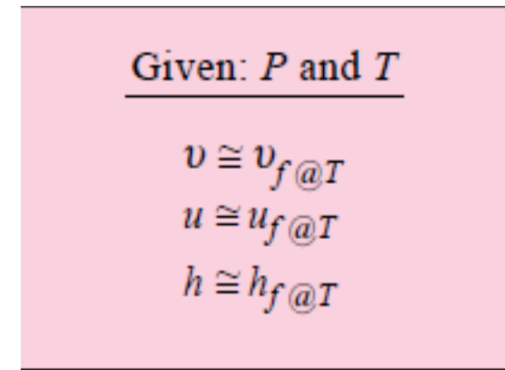
Compressed Liquid

In the absence of compressed liquid data, a general approximation is *to treat compressed liquid as saturated liquid at the given temperature* (Fig. 3.24). 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 very high pressures can be reduced significantly by evaluating it from

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

Given: P and T

$$v \cong v_{f@T}$$
$$u \cong u_{f@T}$$
$$h \cong h_{f@T}$$

Fig. 3.24:
A compressed liquid may be approximated as a saturated liquid at the given temperature.

instead of taking it to be just h_f. Here P_{sat} is the saturation pressure at the given temperature.

In general, a compressed liquid is characterized by

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

Lower temperatures ($T < T_{sat}$ 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 3.6: Compressed Liquid as Saturated Liquid

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?

Solution: The exact and approximate values of the internal energy of liquid water are to be determined.
Analysis: At 80°C, the saturation pressure of water is 47.39 kPa, and since 5 MPa > P_{sat}, we obviously have compressed liquid, as shown in Fig. 3.25.
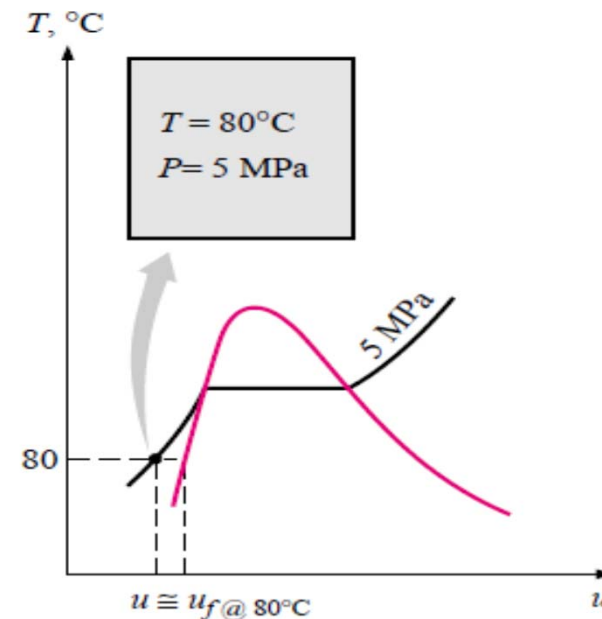
Fig. 3.25: *Schematic and T-u diagram*

(*a*) From the compressed liquid table

$$P = 5 \text{ MPa} \atop T = 80°C \Big\} \quad u = 333.72 \text{ kJ/kg}$$

(*b*) From the saturation table , we get

$$u \cong u_{f@\,80°C} = 334.86 \text{ kJ/kg}$$

The error involved is

$$\frac{334.86 - 333.72}{333.72} \times 100 = 0.34\%$$

which is less than 1 percent.

Superheated Vapour Region

Specific enthalpy of super heated vapour at pressure P and temperature T is calculated by

$$h = h_g + C_p(T - T_s)$$

where C_p = specific heat of superheated vapour

T_s = saturation temperature of vapour

h_g = specific enthalpy of saturated vapour

Specific entropy of superheated vapour at p and T is calculated by

$$s = s_g + C_p \ln\left(\frac{T}{T_s}\right)$$

Specific volume of superheated vapour

$$v = v_g \times \frac{T}{T_s}$$

Linear Interpolation of Properties

Interpolation is a means of determining the value of an unknown data point based on the values of known surrounding data points.

Example 3.7: Find the specific enthalpy of superheated vapour of temperature 953°C at pressure of 0.3 bar.

Solution: Refer the superheated vapour table of pressure 0.3 bar. In that table, the value of specific enthalpy corresponding to the given temperature is not given as shown in the table given below. Then, we can apply linear interpolation method to find out the unknown value.

States	t	h
1	950	4519
2	953	???
3	960	4544

The formula for linear interpolation is expressed as

$$h_2 = h_1 + \frac{t_2 - t_1}{t_3 - t_1}\left(h_3 - h_1\right)$$

Therefore, the value of specific enthalpy at 0.3 bar and 953 °C is

$$h_2 = 4519 + \frac{953 - 950}{960 - 950}\left(4544 - 4519\right)$$

$$h_2 = 4526.5 \text{ kJ / kg}$$

Thank You