For dry saturated vapor $x = 1$ (which is said to have a quality of 100%)

For mixed region $0 < x < 1$

Wetness Fraction: is defined as the mass of liquid in 1 kg of a mixture of liquid and vapor.

$$\text{Wetness Fraction} = 1 - \text{Dryness Fraction} \qquad \dots\dots\dots\dots\dots\dots\dots (6.2)$$

For one kilogram of wet vapor, there are x kg of vapor, and $(1 - x)$ kg of liquid. Hence to calculate the specific volume at this point:

$$v = (1 - x)v_f + xv_g \qquad \dots\dots\dots\dots\dots\dots\dots (6.3)$$

The volume of the liquid is negligibly small compared to the volume of dry saturated vapor. Moreover, for practical problems:

$$v = xv_g \qquad \dots\dots\dots\dots\dots\dots\dots (6.4)$$

The enthalpy of a wet vapor is given by the sum of the enthalpy of the liquid plus the enthalpy of the dry vapor:

$$h = (1 - x)h_f + xh_g$$

$$h = h_f + x(h_g - h_f)$$

$$h = h_f + xh_{fg} \qquad \dots\dots\dots\dots\dots\dots\dots (6.5)$$

Similarly the internal energy equation is:

$$u = u_f + xu_{fg} \qquad \dots\dots\dots\dots\dots\dots\dots (6.6)$$

And the entropy equation is:

$$s = s_f + xs_{fg} \qquad \dots\dots\dots\dots\dots\dots\dots (6.7)$$

3. Superheated vapor: when water is in the superheated vapor phase, (table 4) is used to get the required properties. To use this table, two properties must be known:

$$P + T \rightarrow \text{Table 4} \rightarrow \text{required property}$$

$$P + \text{any other property } (v, u, h, s) \rightarrow \text{Table 4} \rightarrow \text{required property}$$

$$T + \text{any other property } (v, u, h, s) \rightarrow \text{Table 4} \rightarrow \text{required property}$$

4. Compressed (Subcooled) liquid: when water is in the compressed liquid phase, (table 5) is used to get the required properties. To use this table, two properties must be known. So the same rules as with the superheated vapor are applied here.

Finding the Phase of Water

We can identify the state of water using the saturation tables (i.e. table 2 and table 3). Two known properties are required to identify the state of water as follows:

If $P < P_{sat.}$ at T

$T > T_{sat.}$ at P

$v > v_g$ at T or P

$u > u_g$ at T or P

$h > h_g$ at T or P

$s > s_g$ at T or P

then the water is in the superheated vapor state.

If $P > P_{sat.}$ at T

$T < T_{sat.}$ at P

$v < v_f$ at T or P

$u < u_f$ at T or P

$h < h_f$ at T or P

$s < s_f$ at T or P

then the water is in the compressed liquid state.

If the property equals the saturation value, then the water is in the saturated state (vapor or liquid).

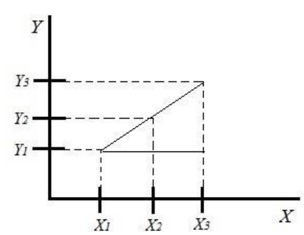
If ($property_f < property < property_g$), then the water is in the wet vapor state.

Linear Interpolation

When the required property value is located between two known values in the tables, we can calculate the required value by linear interpolation. Assume that $(Y_1, Y_2, Y_3, X_1, X_3)$ are known and (X_2) is the required value. By assuming a linear relationship:

$$Slop = \frac{(X_2 - X_1)}{(Y_2 - Y_1)} = \frac{(X_3 - X_1)}{(Y_3 - Y_1)}$$

$$X_2 = X_1 + \left(\frac{Y_2 - Y_1}{Y_3 - Y_1}\right)(X_3 - X_1)$$



Example (6.1): A rigid tank contains saturated liquid water at 90°C. Determine the pressure in the tank and the specific volume of the water.

Solution:

From table 2 at 90°C for saturated liquid, we get:

$\boldsymbol{P_{sat.} = 70.14\ \mathrm{kPa}}$ **Ans.**

$\boldsymbol{v = v_f = 0.001036\ \mathrm{m^3/kg}}$ **Ans.**

Example (6.2): Determine the specific volume, internal energy, enthalpy and entropy for a mixture of 10% quality at 0.15 MPa.

Solution:

Given, $x = 0.1$

At 0.15 MPa, from table 3:

$v_g = 1.1593\ \mathrm{m^3/kg}$

$u_f = 466.94\ \mathrm{kJ/kg},$ $u_{fg} = 2052.7\ \mathrm{kJ/kg}$

$h_f = 467.11\ \mathrm{kJ/kg},$ $h_{fg} = 2226.5\ \mathrm{kJ/kg}$

$s_f = 1.4336\ \mathrm{kJ/kg.K},$ $s_{fg} = 5.7897\ \mathrm{kJ/kg.K}$

Specific volume, $v = x.v_g$

$= 0.1 \times 1.159 = 0.1159\ \mathrm{m^3/kg}$

Internal energy, $u = u_f + x.u_{fg}$

$= 466.94 + 0.1 \times 2052.7 = 672.21\ \mathrm{kJ/kg}$

Enthalpy, $h = h_f + x.h_{fg}$

$= 467.11 + 0.1 \times 2226.5 = 689.759\ \mathrm{kJ/kg}$

Entropy, $s = s_f + x.s_{fg}$

$= 1.4336 + 0.1 \times 5.7897 = 2.01257\ \mathrm{kJ/kg.K}$

$\boldsymbol{v = 0.1159\ \mathrm{m^3/kg}}$ **Ans.**

$\boldsymbol{u = 672.21\ \mathrm{kJ/kg}}$ **Ans.**

$\boldsymbol{h = 689.759\ \mathrm{kJ/kg}}$ **Ans.**

$\boldsymbol{s = 2.01257\ \mathrm{kJ/kg.K}}$ **Ans.**

Example (6.3): Determine the temperature of superheated steam at a state of 0.5 MPa and enthalpy 2960.7 kJ/kg.

Solution:

From table 4 at P = 0.5 MPa and h = 2960.7 kJ/kg, we get:

$\boldsymbol{T = 250\ °C}$ **Ans.**

Example (6.4): Determine the phase for each of the following water states:

a. 120°C, 500 kPa

b. 120°C, 0.5 m^3/kg

Solution:

a. From table 2 with 120°C. The saturation pressure is 198.5 kPa, so we have a compressed liquid. We could also have used table 3 with 500 kPa and found the saturation temperature as 151.86°C, so we would say that it is a subcooled liquid.

b. From table 2 with 120°C we notice that:

$v_f = 0.00106 < v < v_g = 0.89186\ \mathrm{m^3/kg}$

So the state is a two-phase mixture of liquid and vapor.

Example (6.5): Determine the temperature for water at a pressure of 300 kPa and 1 m^3/kg.

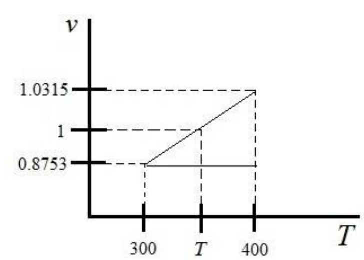
Solution:

From table 3 at 300 kPa, we can see that $v > v_g$, so we have superheated vapor.

From table 4 at 300 kPa and $v = 1\ \mathrm{m^3/kg}$, we can see that the value of T can be found by interpolation between 300°C and 400°C at 300 kPa.

$$\frac{T - 300}{1 - 0.8753} = \frac{400 - 300}{1.0315 - 0.8753}$$

$\boldsymbol{T = 379.8°C}$ **Ans.**



Exercises

Problem (6.1): For water at 0.1 MPa with a quality of 10%, find the specific volume, internal energy, enthalpy and entropy.

Problem (6.2): Determine the temperature and quality for water at a pressure of 0.3 MPa and 0.5 m^3/kg.

Problem (6.3): Determine the phase of water at the state of 10°C and 10 kPa.

Problem (6.4): Determine the properties of water at the state of 1 MPa and 200°C.

Problem (6.5): Determine the pressure of water at 200°C with $v = 0.4$ m^3/kg.