Thermal Physics

Steam table problems

Problem 1.- Calculate the specific volume and the specific enthalpy of steam at 35% quality and pressure of 20kPa.

Solution: We get the values from the saturated water table:

$$v = v_f(1-x) + v_g(x) = 0.001017\frac{m^3}{kg}(1-0.35) + 7.649\frac{m^3}{kg}(0.35) = \mathbf{2.69\ m^3/kg}$$

$$h = h_f(1-x) + h_g(x) = 251.4\frac{kJ}{kg}(1-0.35) + 2609\frac{kJ}{kg}(0.35) = \mathbf{1{,}078\ kJ/kg}$$

Problem 2.- Steam at 550kPa and quality 92% occupies a rigid vessel of $0.4m^3$ Calculate the mass, internal energy and enthalpy.

Solution: To find the mass, let us first calculate the specific volume:

$$v = v_f(1-x) + v_g(x) = 0.001097\frac{m^3}{kg}(1-0.92) + 0.3427\frac{m^3}{kg}(0.92) = 0.3154\ m^3/kg$$

By definition the specific volume is the actual volume divided by the mass: $v = \frac{V}{m}$, so the mass is:

$$m = \frac{V}{v} = \frac{0.4m^3}{0.3154m^3/kg} = \mathbf{1.27\ kg}$$

Internal energy: We first find the specific internal energy and multiply by the mass:

$$u = u_f(1-x) + u_g(x) = 655.32\frac{kJ}{kg}(1-0.92) + 2564.5\frac{kJ}{kg}(0.92) = 2412\frac{kJ}{kg}$$

$$U = mu = 1.27kg\left(2412\frac{kJ}{kg}\right) = \mathbf{3{,}063\ J}$$

Enthalpy:

$$h = h_f(1-x) + h_g(x) = 665.93\frac{kJ}{kg}(1-0.92) + 2753\frac{kJ}{kg}(0.92) = 2586\frac{kJ}{kg}$$

$$H = mh = 1.27kg\left(2586\frac{kJ}{kg}\right) = \mathbf{3{,}284\ J}$$

Problem 3.- One kg of a water-vapor mixture at 1.2 MPa with a quality of 0.8 is heated to a temperature of 250 ºC. Determine the heat necessary if the process is carried out at

a) Constant pressure.
b) Constant volume.

Solution: Let us calculate the initial values first:
Specific volume:

$$v = v_f(1-x) + v_g(x) = 0.001139\frac{m^3}{kg}(1-0.8) + 0.16333\frac{m^3}{kg}(0.8) = 0.1309\frac{m^3}{kg}$$

Internal energy:

$$u = u_f(1-x) + u_g(x) = 797.29\frac{kJ}{kg}(1-0.8) + 2588.8\frac{kJ}{kg}(0.8) = 2230.5\frac{kJ}{kg}$$

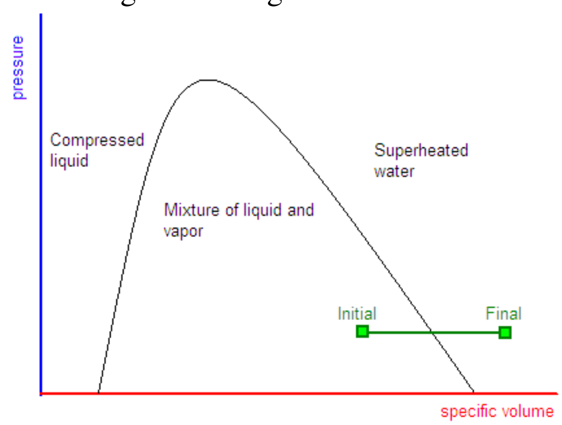
U=mu= 2230 kJ

Enthalpy:

$$h = h_f(1-x) + h_g(x) = 798.65\frac{kJ}{kg}(1-0.8) + 2784.8\frac{kJ}{kg}(0.8) = 2387.6\frac{kJ}{kg}$$

H=mh=2387.6 kJ

a) If the process is at constant pressure, the final state will be superheated water vapor. This process is shown in the schematic figure as the green line.



Since the process is at constant pressure, the heat is equal to the change in enthalpy.
The enthalpy in the final state comes from the superheated water tables:

$h_{final} = 2935$ kJ/kg

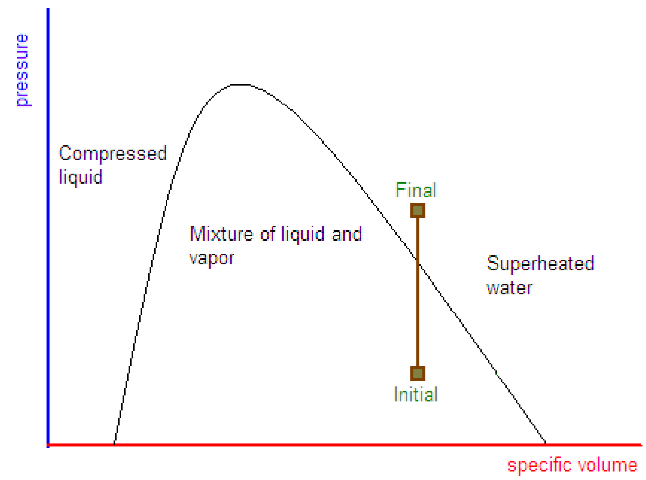
H = mh = 2935 kJ

Then, the heat will be: Q=2935 kJ – 2387.6 kJ = **547 kJ**

b) If the process is done at constant volume it means that the specific volume will stay constant at $0.1309 m^3/kg$.

A check of the saturated tables reveals that at 250ºC the specific volume of saturated vapor is $0.04978 m^3/kg$, which is less than the volume in our problem, so the final state of the water in this problem is superheated vapor.

This process is shown in the schematic figure as the brown line.



To determine the final condition of the water, we look in the superheated water tables to find the specific volume 0.1309 m^3/kg at T=250ºC. We find that the pressure will be between 1.6 MPa and 1.8 MPa.

Since the process is at constant volume, the heat is equal to the change in internal energy.

The internal energy in the final state is taken from the superheated water tables. We can approximate it by taking an average between the values at 1.6MPa and 1.8MPa (a more accurate value could be obtained with an interpolation).

$$u_{final} = \frac{2692.3\text{kJ/kg} + 2686.0\text{kJ/kg}}{2} = 2689\text{kJ/kg} \rightarrow U_{final} = 2689\text{kJ}$$

The heat is equal to:

Q=2689 kJ – 2230.5 kJ = **459 kJ**

Problem 4.- A closed rigid vessel contains 125g of liquid and 7.5g of water vapor in equilibrium at 0.5Mpa. Determine the volume of the mixture.

Solution: The volume of the liquid is:

0.125kg(0.001093m^3/kg)=0.000137 m^3

The volume of the vapor is:

0.0075kg(0.3749m^3/kg)=0.002812 m^3.

The total volume is: **0.002948 m^3**

Problem 5.- Find the specific latent heat of evaporation of water at 200kPa.

The specific latent heat of evaporation is the amount of heat necessary to convert 1 unit of mass of a substance from the liquid to the gas phase at constant pressure and temperature.

Solution: To find the specific latent heat of evaporation we subtract h_f from h_g:

L = 2706.7 kJ/kg - 504.7 kJ/kg = **2,202 kJ/kg**

Problem 6.- A rigid tank of volume 1 m^3 contains saturated steam at 100 kPa. If you cool the water to T=90 °C, calculate the quality of the new mixture.

Solution: Since the water is in the state of saturated steam, its specific volume will be v_g, that we can find in the table:

$$v = v_g = 1.694 \frac{m^3}{kg}$$

When dropping the temperature to T=90 °C, some of the water will condense giving a quality of less than one. In any case, the specific volume is constant, so at the new conditions:

$$1.694 \frac{m^3}{kg} = v_f(1-x) + v_g(x)$$

We find the values of v_f and v_g by interpolation with the table and solve for x:

$$1.694 \frac{m^3}{kg} = 0.001036 \frac{m^3}{kg}(1-x) + 2.391 \frac{m^3}{kg}(x) \rightarrow x = \mathbf{0.71}$$

Problem 7.- Calculate the mass of 15m^3 of water (mixed phase liquid-vapor) at 500kPa and quality of 50%.

Solution: the specific volume is

$$v = v_f(1-x) + v_g(x) = 0.001093(1-0.5) + 0.3749(0.5) = 0.188 \frac{m^3}{kg}$$

To find the mass $m = \dfrac{15m^3}{0.188 \frac{m^3}{kg}} = \mathbf{80\ kg}$

Problem 8.- A closed rigid vessel contains 50g of liquid water and 50g of water vapor in equilibrium at 0.1Mpa.

a) Determine the volume of the mixture.

b) Estimate at what temperature the water would be all in the saturated gas state.

Solution:

a) $V = 0.05 \times v_\ell + 0.05 \times v_g = 0.05 \times 0.001043 + 0.05 \times 1.694 =$ **$0.0848\ m^3$**

b) We have to find when is that $v_g = 0.848 m^3 / kg$ and looking at the tables we see that it happens at a temperature a bit higher that 122 °C