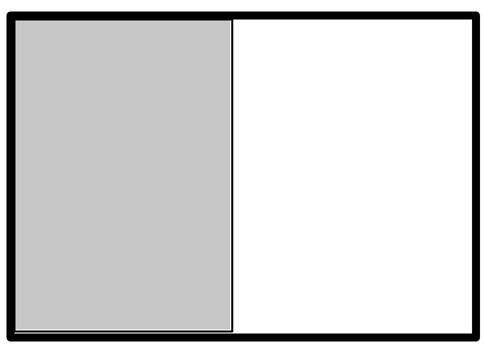
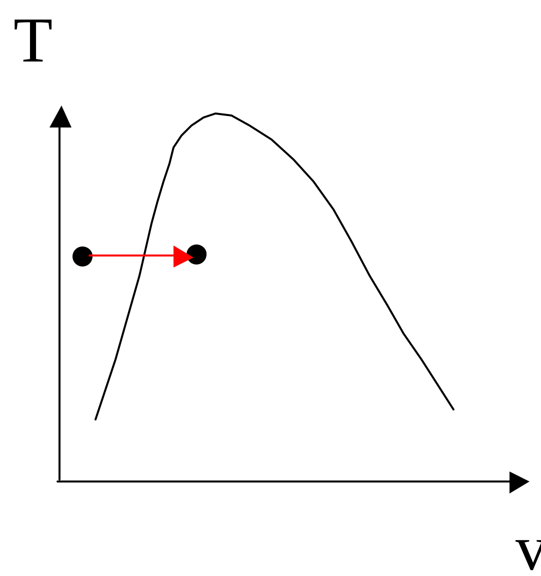
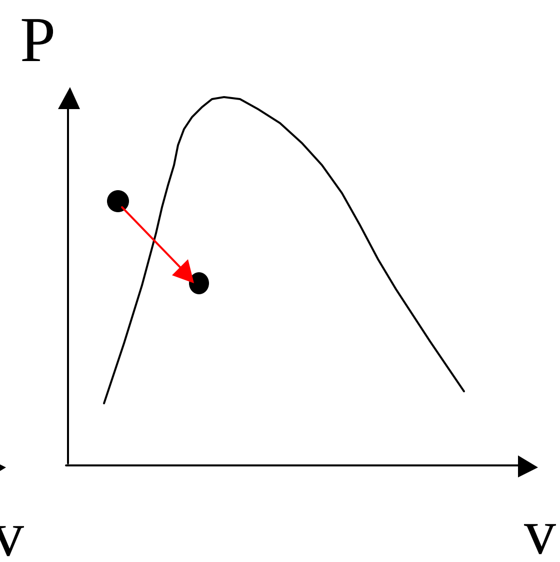
Example: Unrestrained Expansion

A rigid tank is partitioned into two equal parts as shown. One side of the tank contains 1 kg water at 100 kPa and at room temperature of 20°C and the other side is totally evacuated. The partitioned is then removed to allow the water expands into the entire tank. (a) What is the volume of the tank? (b) What will be the final temperature long time after the expansion if the tank is exchanging heat with its surroundings? (c) What is the final pressure of the tank? (d) What is the total amount of heat transfer between the tank and its surroundings? (e) Draw the transition process on T-v and P-v diagrams.







At a pressure of 100 kPa, the saturation temperature is 99.63°C, therefore, the liquid exists as a compressed (or subcooled) liquid. A liquid is incompressible and its properties are relatively independent of its pressure. We can approximate the compressed liquid as a saturated liquid at the given temperature.

$$v_1 \cong v_{f\,@20°C} = 0.001002(m^3/kg)$$

$$V_1 = mv_1 = (1)(0.001) = 0.001(m^3)$$

After expansion, the final volume is twice of the original volume:

(a) Volume of the tank: $V_2 = 2V_1 = 0.002(m^3)$, $v_2 = 0.002(m^3/kg)$

(b) The final temperature should still be equal to the room temperature after the system reaches final equilibrium.

(c) At 20°C, $v_f = 0.001002\ m^3/kg$, $v_g = 57.79\ m^3/kg$

$v_f < v_2 < v_g$, therefore the state 2 after the expansion should be a mixture of saturated liquid and vapor.

The saturation pressure at this temperature 20°C is 2.339 kPa

It is lower than the initial temperature of 100 kPa as expected

(d) The quality of the mixture x_2 can be determined as:

$$v_2 = v_f + x_2(v_g - v_f), \quad \text{or } x_2 = \frac{v_2 - v_f}{v_g - v_f} = \frac{0.002 - 0.001}{57.79 - 0.001} = 1.73 \times 10^{-5} \text{ very low quality}$$

As the liquid expands, there is no work done by the system since there is no movement of the rigid tank, $W_{12}=0$.

Energy balance: $E_2 - E_1 = Q_{12} - W_{12} = Q_{12}$ (No work, steady state, no energy flows in and out, no generation)

$m(u_2 - u_1) = Q_{12}$

$u_1 = u_{f@20°C} = 83.95(kJ/kg),$

$u_f = 83.95(kJ/kg),\ u_g = 2402.9(kJ/kg)\ @\ 20°C$

$$Q_{12} = m\{[u_f + x_2(u_g - u_f)] - u_1\}$$

$$= (1)\{[83.95 + 1.73\times10^{-5}(2402.9 - 83.95)] - 83.95\} = 0.04(kJ)$$