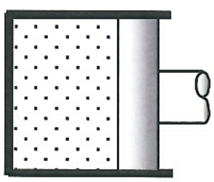
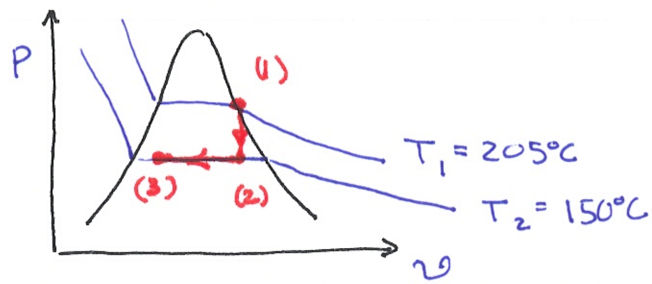
Example

A closed system contains 0.15 kg of water. Initially the water is a saturated vapor at 205°C. The water is cooled at constant volume until the temperature is 150°C and is then compressed at constant temperature until the volume is half the original value.

a) Sketch the *P-v* diagram for this two-step process.
b) Find the work in or out of the steam *for each step.*
c) Find the heat transfer in or out of the steam *for each step.*



a)



b) $W_{12} = -\int_1^2 P\,dV = \boxed{0}$ ($dV = 0$)

$$W_{23} = -\int_2^3 P\,dV = -m\int_2^3 P\,dv = -mP\int_2^3 dv = -mP(v_3 - v_2)$$

I NOW KNOW THIS IS ALSO CONST P THANKS TO THE P-v DIAGRAM!

PROPERTIES

(1) $T_1 = 205°C$
$v_1 = v_g(205°C) = 0.11521 \text{ m}^3/\text{kg}$
$P_1 = P_{SAT} = 1.723 \text{ MPa}$

(2) $T_2 = 150°C$
$P_2 = P_{SAT} = 0.4758 \text{ MPa}$
$v_2 = v_1 = 0.11521$

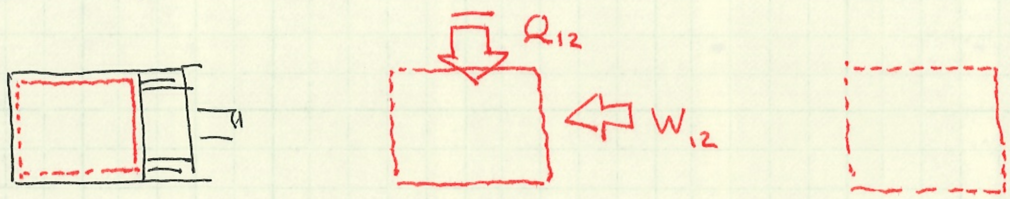
(3) $T_3 = 150°C$
$v_3 = v_2/2 = 0.05761 \text{ m}^3/\text{kg}$

$v_f < v_3 < v_g \Rightarrow$ STILL A MIXTURE

$$W_{23} = -(0.15 \text{ kg})(475.8 \text{ kPa})(0.05761 - 0.11521)\frac{\text{m}^3}{\text{kg}}\left\langle\frac{\text{kJ}}{\text{kPa}\cdot\text{m}^3}\right\rangle$$

$$= \boxed{4.11 \text{ kJ}}$$

(C) USE CONSERVATION of ENERGY



(1) (1) → (2) (2)

CLOSED SYS., FINITE TIME

$$E_2 - E_1 = Q_{12} + W_{12} \quad (W_{12} \to 0)$$

$$U_2 - U_1 = Q_{12} \qquad \text{(NO KE, PE)}$$

$$m(u_2 - u_1) = Q_{12} \qquad (1)$$

MORE PROPERTIES

$$u_1 = u_g(205°C) = 2597.5 \text{ kJ/kg}$$

$$u_2 = (1 - x_2)u_f + x_2 u_g$$

TO FIND x_2:

$$v_2 = (1 - x_2)v_f + x_2 v_g = (1 - x_2)(0.001009 \tfrac{m^3}{kg}) + x_2 (0.3928) \tfrac{m^3}{kg}$$

$$= 0.11521 \text{ m}^3/\text{kg}$$

$$\Rightarrow x_2 = 0.2913$$

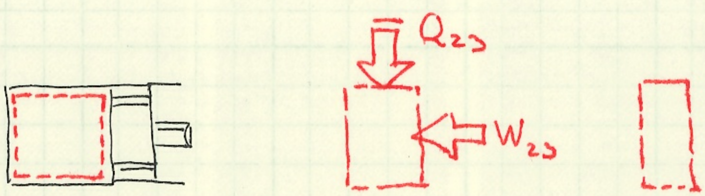
$$\therefore u_2 = (1 - 0.2913)\,631.68 + (0.2913)(2559.5)$$

$$= 1193.3 \text{ kJ/kg}$$

(1) BECOMES

$$Q_{12} = (0.15 \text{ kg})(1193.3 - 2597.5)\frac{\text{kJ}}{\text{kg}} = -210.6 \text{ kJ}$$

$$= \boxed{210.6 \text{ kJ OUT}}$$



(2) (2) → (3) (3)

CLOSED SYS, FINITE TIME

$$E_3 - E_2 = Q_{23} + W_{23}$$

$$U_3 - U_2 = Q_{23} + W_{23}$$

$$m(u_3 - u_2) = Q_{23} + W_{23} \qquad Q_{23} = m(u_3 - u_2) + W_{23}$$

EVEN MORE PROPERTIES

$$v_3 = (1-x_3)v_f + x_3 v_g$$

$$0.05761 = (1-x_3)(0.001091) + x_3(0.3928)$$

$$\Rightarrow x_3 = 0.1443$$

$$u_3 = (1-x_3)u_f + x_3 u_g = (1-0.1443)(631.68) + 0.1443(2559.5)$$

$$= 909.8 \text{ KJ/kg}$$

$$\therefore Q_{23} = (0.15\text{ kg})(909.8 - 1193.3)\frac{\text{KJ}}{\text{kg}} - 4.11\text{ KJ}$$

$$= -46.6 \text{ KJ} = \boxed{46.6 \text{ KJ OUT}}$$