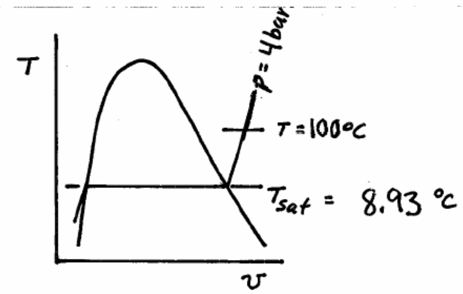
PROBLEM 3.11*



$p = 4$ bar, $T = 100°C$

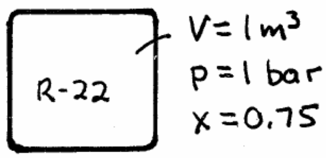
Table A-12: superheated vapor

$v = 0.07327\ m^3/kg$

$$m = \frac{V}{v} = \frac{(0.1\ m^3)}{(0.07327\ m^3/kg)}$$

$= 1.36\ kg \longleftarrow$ m

PROBLEM 3.15*



Using data from Table A-8:

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

$$= 0.7093 \times 10^{-3} + (0.75)(0.2152 - 0.7093 \times 10^{-3})$$

$$= 0.1616\ m^3/kg$$

$$m = \frac{V}{v} = \frac{(1\ m^3)}{(0.1616\ m^3/kg)}$$

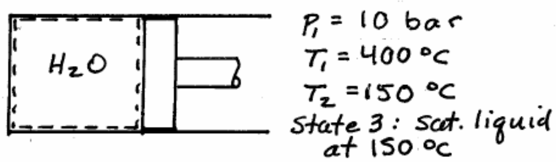
$m = 6.189\ kg \longleftarrow$ m

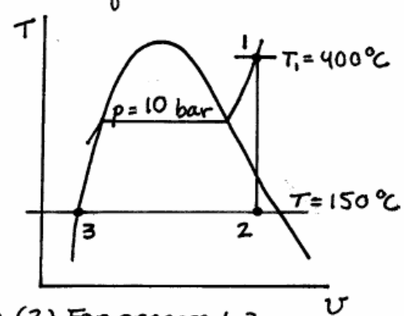
PROBLEM 3.34*

KNOWN: Water vapor undergoes a constant volume cooling process followed by isothermal condensation to saturated liquid.

FIND: Evaluate the work per unit mass.

SCHEMATIC & GIVEN DATA:





ASSUMPTIONS: (1) The water is the closed system. (2) For process 1-2, the volume is constant. (3) For process 2-3, the temperature is constant. (4) Volume change is the only work mode.

ANALYSIS: By assumptions (2) and (4), only process 2-3 involves work. To evaluate the work, begin with Eq. 2.17

$$W = \int_{V_1}^{V_2} p\,dV \Rightarrow \frac{W}{m} = \int_{v_1}^{v_2} p\,dv$$

Next, we fix each state and obtain relevant data. Since the mass and volume are constant to process 1-2, $v_2 = v_1$. From Table A-4; $v_1 = 0.3066\ m^3/kg$.

With $v_2 = v_1 = 0.3066$, we see in Table A-2 at 150°C that $v_f < v_2 < v_g$. Thus, state 2 is in the two-phase, liquid-vapor region. Since the temperature is constant for process 2-3, so is the pressure. That is

$$P_2 = P_3 = P_{sat @ 150°C} = 4.758\ bar$$

Finally, from Table A-2, $v_3 = v_{f @ 150°C} = 1.0905 \times 10^{-3}\ m^3/kg$. Thus

$$\frac{W}{m} = \int_{v_1}^{v_2} p\,dv = p_2(v_3 - v_2)$$

$$= (4.758\text{ bar})(1.0905\times10^{-3} - 0.3066)\frac{m^3}{kg}\left|\frac{10^5\text{ N/m}^2}{1\text{ bar}}\right|\left|\frac{1\text{ kJ}}{10^3\text{ N}\cdot\text{m}}\right|$$

① $$= -145.4\text{ kJ/kg} \longleftarrow \quad W/m$$

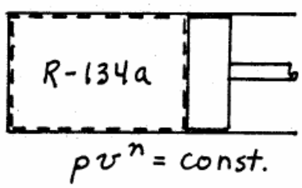
1. The negative sign denotes energy transfer to the system by work during process 2-3.

PROBLEM 3.53

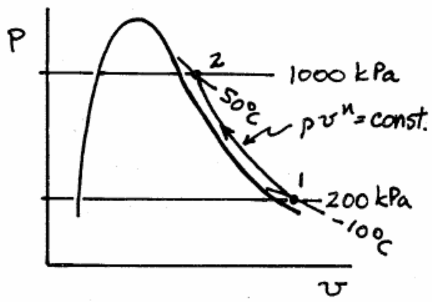
KNOWN: Refrigerant 134a undergoes a process for which pv^n = constant between two specified states.

FIND: Determine the work and heat transfer for the process, each per unit of mass.

SCHEMATIC & GIVEN DATA:



$p_1 = 200$ kPa
$T_1 = -10°C$
$p_2 = 1000$ kPa
$T_2 = 50°C$



ASSUMPTIONS: 1. The refrigerant is a closed system. 2. The process is described by pv^n = constant. 3. Kinetic and potential energy effects are negligible.

ANALYSIS: Using Eq. 2.17

$$\frac{W}{m} = \int_{v_1}^{v_2} p\,dv = \int_{v_1}^{v_2} \frac{\text{const.}}{v^n}\,dv$$

$$= \frac{p_2 v_2 - p_1 v_1}{1-n} \qquad (*)$$

To find the polytropic exponent n, we first must determine the initial and final specific volumes. Using Table A-12

$$p_1 = 200\text{ kPa},\ T_1 = -10°C \Rightarrow v_1 = 0.09938\text{ m}^3/\text{kg}$$

$$p_2 = 1000\text{ kPa},\ T_2 = 50°C \Rightarrow v_2 = 0.02171\text{ m}^3/\text{kg}$$

Thus, for the polytropic process

$$p_1 v_1^n = p_2 v_2^n \Rightarrow \log(p_2/p_1) = n\log(v_1/v_2)$$

$$n = \frac{\log(p_2/p_1)}{\log(v_1/v_2)} = \frac{\log(1000/200)}{\log(.09938/.02171)} = 1.058$$

Inserting values in Eq. (*)

$$\frac{W}{m} = \frac{(1000\text{ kPa})(0.02171\text{ m}^3/\text{kg}) - (200)(.09938)}{(1-1.058)}\left|\frac{10^3\text{ N/m}^2}{1\text{ kPa}}\right|\left|\frac{1\text{ kJ}}{10^3\text{ N}\cdot\text{m}}\right|$$

$$= -31.62\text{ kJ/kg} \longleftarrow \quad W/m$$

The heat transfer is found by using an energy balance

$$\cancel{\Delta KE}^{0} + \cancel{\Delta PE}^{0} + \Delta U = Q - W$$

with $\Delta U = m(u_2 - u_1)$

$$\frac{Q}{m} = (u_2 - u_1) + \frac{W}{m}$$

From Table A-12; $u_1 = 221.50$ kJ/kg and $u_2 = 258.48$ kJ/kg. With the result from Problem 3.36 for W/m

$$\frac{Q}{m} = (258.48 - 221.50) + (-31.62 \text{ kJ/kg})$$

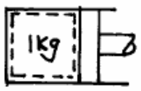
$$= +5.36 \text{ kJ/kg} \longleftarrow \underline{Q/m}$$

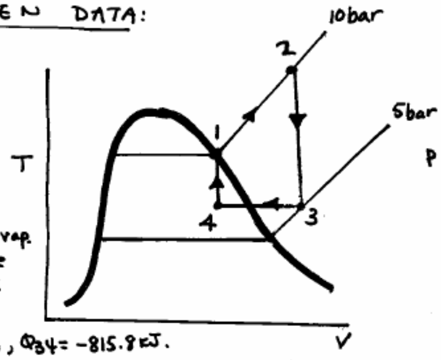
PROBLEM 3.67

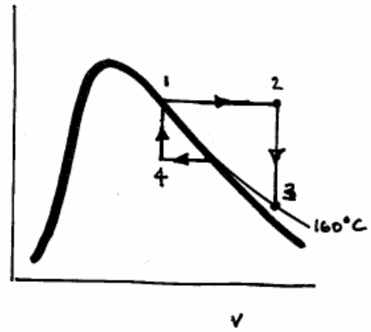
KNOWN: One kg of water undergoes a thermodynamic cycle composed of four processes.

FIND: Determine the thermal efficiency

SCHEMATIC & GIVEN DATA:







1-2: constant pressure at 10 bar from sat. vap.

2-3: constant volume to 5 bar, 160°C

3-4 isothermal compression, $Q_{34} = -815.8$ kJ.

4-1 constant volume

ASSUMPTIONS: 1. The water is the closed system. 2. Volume change is the only work mode. 3. Kinetic and potential energy effects can be ignored.

ANALYSIS: The thermal efficiency of a power cycle is $\eta = W_{cycle}/Q_{in}$ (see discussion of Eqs. 2.42, 43), where $W_{cycle} = W_{12} + W_{23} + W_{34} + W_{41}$.

Process 1-2: state 1 is fixed. State 2 is fixed by $p_2 = 10$ bar, $v_2 = v_3$. From Table A-4

$$v_3 = 0.3835 \frac{m^3}{kg}, \quad u_3 = 2575.2 \text{ kJ/kg}$$

$$\Rightarrow W_{12} = \int_1^2 p\,dV = pm(v_2 - v_1) = (10\text{ bar})\left|\frac{10^5 N/m^2}{1\text{ bar}}\right|(1\text{ kg})(0.3835 - 0.1944)\frac{m^3}{kg}\left|\frac{1\text{ kJ}}{10^3 N\cdot m}\right|$$

$$= 189.1 \text{ kJ}$$

An energy balance reduces to give $Q = \Delta U + W$, or

$$Q_{12} = m(u_2 - u_1) + W = (1\text{kg})[3231.8 - 2583.6] + 189.1\text{ kJ} = 837.3\text{ kJ}$$

where u_2 is obtained from Table A-3 using $p_2, v_2 (= v_3)$.

Process 2-3: $W_{23} = 0$

$$Q_{23} = m(u_3 - u_2) + \cancel{W_{23}}^{0} = (1\text{kg})[2575.2 - 3231.8] = -656.6\text{ kJ}$$

Process 3-4: $Q_{34} = -815.8$ kJ (given). Then, $\Delta U = Q_{34} - W_{34}$ gives

$$W_{34} = Q_{34} - \Delta U = Q_{34} - m(u_4 - u_3)$$

State 4 is fixed by $T_4 = 160°C$, $v_4 = v_1$

$$\therefore x_4 = \frac{v_4 - v_f}{v_g - v_f} = \frac{0.1944 - 1.102/10^3}{0.3071 - 1.102/10^3} = 0.6317$$

$$\Rightarrow u_4 = u_f + x_4(u_g - u_f) = 674.86 + (0.6317)(2568.4 - 674.86) = 1871 \text{ kJ/kg}$$

$$\Rightarrow W_{34} = -815.8 - (1)[1871 - 2575.2] = -111.6\text{ kJ}$$

Process 4–1: $W_{41} = 0$, and

$$Q_{41} = \Delta U + \cancel{W_{41}}^{\,0} = m(u_1 - u_4)$$

$$= (1\,kg)[2583.6 - 1871]\frac{kJ}{kg} = 712.6\,kJ$$

The net work is then

$$W_{cycle} = W_{12} + W_{23} + W_{34} + W_{41}$$

① $$= 189.1 + 0 + (-111.6) + 0 = 77.5\,kJ$$

To obtain Q_{in},

$$Q_{in} = Q_{12} + Q_{41} = 837.3 + 712.6 = 1549.9\,kJ$$

Then

$$\eta = \left(\frac{77.5}{1549.9}\right) = 0.05 \quad (5\%)$$

---

① As a check, note that for every cycle $Q_{cycle} = W_{cycle}$.

$$Q_{cycle} = Q_{12} + Q_{23} + Q_{34} + Q_{41}$$

$$= 837.3 + (-656.6) + (-815.8) + 712.6 = 77.5\,kJ$$

which agrees with W_{cycle} calculated using the work quantities.