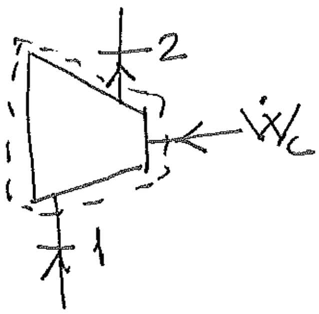
CANKAYA UNIVERSITY
FACULTY OF ENGINEERING AND ARCHITECTURE
MECHANICAL ENGINEERING DEPARTMENT
ME 211 THERMODYNAMICS I

FALL 2016

HW # 4

1) Refrigerant-134a enters an adiabatic compressor as saturated vapor at -24 ^{0}C and leaves at 0.8 MPa and 60 ^{0}C. The mass flow rate of the refrigerant is 1.2 kg/s. Determine (*a*) the power input to the compressor and (*b*) the volume flow rate of the refrigerant at the compressor inlet



SSSF device
$\Delta KE \approx 0$
$\Delta PE \approx 0$
$\dot{Q}_{cv} = 0$

1) $\dot{Q}_{cv} - \dot{W}_{cv} = \sum \dot{m}_e (h_e + \frac{1}{2}V_e^2 + gz_e) - \sum \dot{m}_i (h_i + \frac{1}{2}V_i^2 + gz_i)$

$-(-\dot{W}_c) = \dot{m}_2 h_2 - \dot{m}_1 h_1$

2) $\sum \dot{m}_e = \sum \dot{m}_i \Rightarrow \dot{m}_1 = \dot{m}_2 = \dot{m}$

$\therefore \quad \dot{W}_c = \dot{m}(h_2 - h_1)$

$\left.\begin{array}{l} T_1 = -24\,°C \\ x_1 = 1 \end{array}\right] \begin{array}{l} h_1 = h_g = 235.94 \text{ kJ/kg} \\ v = v_g = 0.17398 \text{ m}^3\text{/kg} \end{array}$

$P_2 = 0.8\text{ MPa} = 8\text{ bar} \longrightarrow T_{SAT} = 31.33\,°C$

$T_2 = 60\,°C$

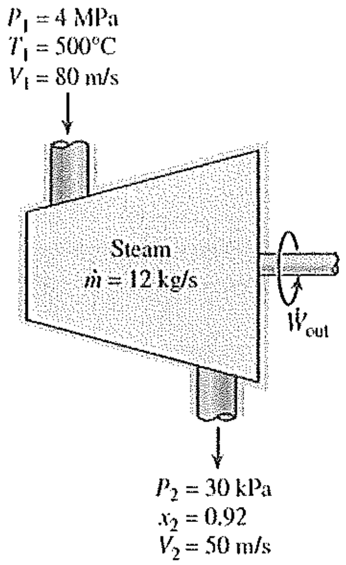
$T_2 > T_{SAT}$
superheated vapor

$\therefore h_2 \cong 296.82 \text{ kJ/kg}$

$\dot{W}_c = (1.2 \frac{kg}{s})(296.82 - 235.94) \simeq 73 \text{ kJ/s}$

b) $\dot{V} = \dot{m} v_1 = (1.2)(\frac{kg}{s})(0.17398 \frac{kg}{s}) \simeq 0.209 \text{ m}^3\text{/s}$

2) Steam flows steadily through an adiabatic turbine. The inlet conditions of the steam are 4 MPa, 5008C, and 80 m/s, and the exit conditions are 30 kPa, 92 percent quality, and 50 m/s.The mass flow rate of the steam is 12 kg/s. Determine (*a*) the change in kinetic energy, (*b*) the power output, and (*c*) the turbine inlet area.



SSSF
$\Delta PE \approx 0$
$Q_{cv} = 0$

$-\dot{W}_t = \dot{m}\left[(h_2 - h_1) + \frac{1}{2}\Delta KE\right]$

$P_1 = 4\ MPa = 40\ bar \rightarrow T_{SAT} = 250.4°C$
$T_1 = 500°C$
$T_1 > T_{SAT}$ superheated
$h_1 \approx 3446\ kJ/kg$
$v_1 = 0.086442\ m^3/kg$

② $P_2 = 30\ kPa = 0.3\ bar$
$X_2 = 0.92$

$h_2 = h_f + X_2 h_{fg}$
$= 289.27 + 0.92(2335.3)$
$\approx 2437.7\ kJ/kg$

a) $\frac{1}{2}\Delta KE = \frac{1}{2}(V_2^2 - V_1^2) = \frac{1}{2}(50^2 - 80^2)\left(\frac{m^2}{s^2}\right)\left(\frac{1\ kJ/kg}{1000\ m^2/s^2}\right)$

$= -1.95\ kJ/kg$

Note very small term compared to enthalp term

b) $\dot{W}_t = -\dot{m}\left[h_2 - h_1 + \frac{V_2^2 - V_1^2}{2}\right]$

$= (-)(12\ \frac{kg}{s})[2437.7 - 3446) - 1.95] = 12123\ kW$
$= 12.123\ MW$

c) $\dot{m} = \rho_1 V_1 A_1 = \frac{V_1 A_1}{v_1}$

$A_1 = \frac{\dot{m} v_1}{V_1} = \frac{(12\ \frac{kg}{s})(0.086442\ \frac{m^3}{kg})}{80\ m/s}$

$= 0.013\ m^2$

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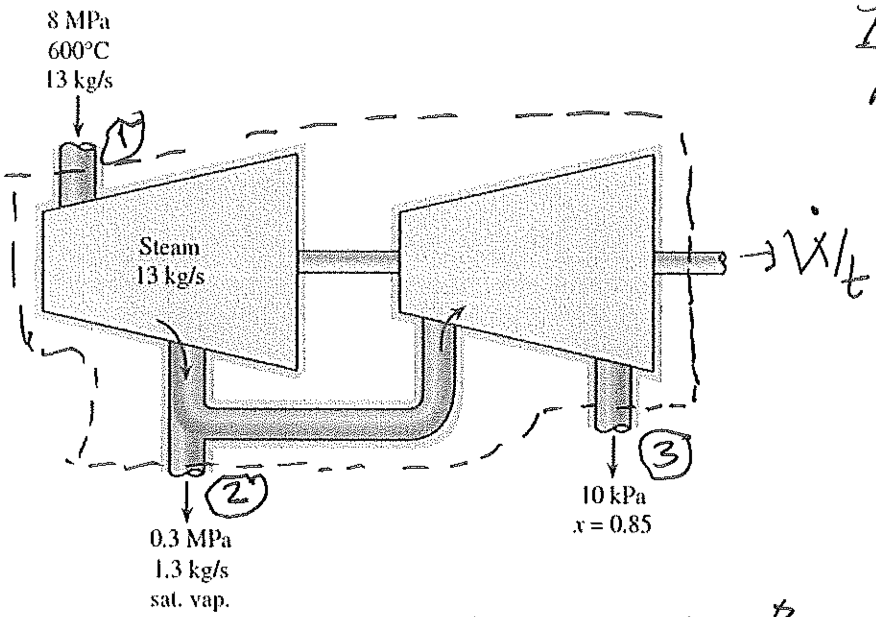
3) Steam enters a steady-flow turbine with a mass flow rate of 13 kg/s at 600 ^{0}C, 8 MPa, and a negligible velocity. The steam expands in the turbine to a saturated vapor at 300 kPa where 10 percent of the steam is removed for some other use. The remainder of the steam continues to expand to the turbine exit where the pressure is 10 kPa and quality is 85 percent. If the turbine is adiabatic, determine the rate of work done by the steam during this process.



SSSF
$\Delta KE = 0$
$\Delta PE = 0$
$\dot{Q}_{CV} = 0$ ← adiabatic

we will take control volume as shown.

$$\dot{Q}_{CV} - \dot{W}_{CV} = \sum \dot{m}_e \left(h_e + \tfrac{1}{2}V_e^2 + gz_e\right) - \sum \dot{m}_i \left(h_i + \tfrac{1}{2}V_i^2 + gz_i\right)$$

$$-\dot{W}_t = \dot{m}_3 h_3 + \dot{m}_2 h_2 - \dot{m}_1 h_1$$

$$\dot{W}_t = \dot{m}_1 h_1 - (\dot{m}_3 h_3 + \dot{m}_2 h_2)$$

now $\dot{m}_2 = 0.1\,\dot{m}_1$

$\dot{m}_3 = 0.9\,\dot{m}_1$

$$\dot{W}_t = \dot{m}_1 \left[h_1 - 0.1 h_2 - 0.9 h_3\right]$$

$P_1 = 80$ bar $\longrightarrow T_{SAT} = 295.1$ °C $\quad T_1 > T_{SAT}$ superheated

$T_1 = 600$°C

$h_1 \cong 3642.4 \frac{kJ}{kg}$

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$P_2 = 0.3\,MPa = 3\,bar$, $x_2 = 1$ $\Big]$ $h_2 = h_g \cong 2724.9\,kJ/kg$

$P_3 = 10\,kPa = 0.1\,bar$, $x_2 = 0.85$ $\Big]$ $h_3 = h_f + x_2 h_{fg}$

$= 191.81 + 0.85(2392.1)$

$\approx 2225.1\,kJ/kg$

$\dot{W}_t = (1.3\ \frac{kg}{s})[3642.4 - 0.1 \times 2724.9 - 0.9 \times 2225.1)$

$= 17{,}796\,kW \cong 17.8\,MW$

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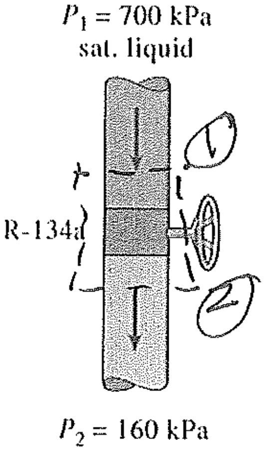
4) Refrigerant-134a is throttled from the saturated liquid state at 700 kPa to a pressure of 160 kPa. Determine the temperature drop during this process and the final specific volume of the refrigerant.



SSSF

$\Delta KE = 0$ $\Delta PE = 0$

$\dot{Q} - \dot{W}_{cv} = \sum \dot{m}_e (h_e + \frac{1}{2} V_e^2 + g z_e) - \sum \dot{m}_i (h_i + \frac{1}{2} V_i^2 + g z_i)$

Throtling process, $Q_{cv} = 0$, no work

$\dot{m}_1 h_1 = \dot{m}_2 h_2$

2) $\sum \dot{m}_i = \sum \dot{m}_e \Rightarrow \dot{m}_1 = \dot{m}_2 = \dot{m}$

$\therefore h_1 = h_2$

now $P_1 = 0.7 MPa = 7 bar$, $X_1 = 0$] $T_1 = T_{SAT} = 26.69°C$, $h_1 = h_f = 88.82 \frac{kJ}{kg}$

state (2) $P_2 = 160 kPa = 1.6$ bar

$h_2 = h_1 = 88.82$ kJ/kg

At 1.6 bar $h_f = 31.38$ kJ/kg $h_g = 241.14$ kJ/kg

$h_f < h_2 < h_g \rightarrow$ saturated liq. + vapor mixture

$\therefore T_2 = T_{SAT} = -15.6°C$

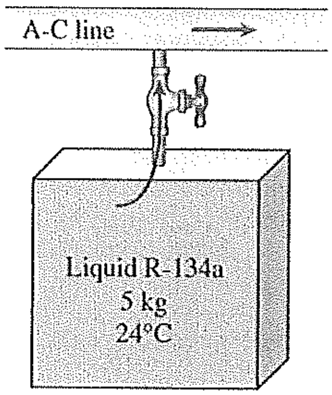
$h_2 = h_f + x_2 h_{fg} \rightarrow x_2 = \frac{h_2 - h_f}{h_{fg}} = \frac{88.82 - 31.18}{209.96}$

$= 0.2745$

$V_2 = V_f + x_2 V_{fg} = 0.0007435 + 0.2745 (0.12355 - 0.0007435)$

$= 0.0345$ m3/kg

5) An air-conditioning system is to be filled from a rigid container that initially contains 5 kg of liquid R-134a at 24 ^{0}C. The valve connecting this container to the air-conditioning system is now opened until the mass in the container is 0.25 kg, at which time the valve is closed. During this time, only liquid R-134a flows from the container. Presuming that the process is isothermal while the valve is open, determine the final quality of the R-134a in the container and the total heat transfer.



USUF process

$\Delta KE = \Delta PE = 0 \quad W_{cv} = 0$

conservation of mass

$$(m_2 - m_1)_{cv} = \sum \dot{m}_i^{\,0} - \sum \dot{m}_e$$

$$Q_{cv} + \sum m_i \left(h_i + \tfrac{1}{2} V_i^2 + g z_i\right)^{0} = \sum m_e \left(h_e + \tfrac{1}{2} V_e^{2\,0} + g z_e^{\,0}\right)$$

$$+ \left[m_2\left(u_2 + \tfrac{1}{2} V_2^{2\,0} + g z_2^{\,0}\right) - m_1\left(u_1 + \tfrac{1}{2} V_1^{2\,0} + g z_1^{\,0}\right)\right]_{cv} + W_{cv}^{\,0}$$

① $-m_e = (m_2 - m_1) \rightarrow m_e = m_1 - m_2$

② $Q_{cv} = m_e h_e + m_2 u_2 - m_1 u_1$

① $\left.\begin{matrix} T_1 = 24\,^\circ C \\ x_1 = 0 \end{matrix}\right]$ $v_1 = 0.0008260$ m^3/kg
$u_1 = 84.44$ kJ/kg
$h_e = 84.98$ kJ/kg

Volume of tank

$\forall = m_1 v_1 = (5\text{ kg})(0.000826) = 0.00413$ m^3/kg

(See Next page)

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(2) $v_2 = \frac{V}{m_2} = \frac{0.00413 \, m^3/kg}{0.25 \, kg}$

$= 0.01652 \, m^3/kg$

now in state (2) we have

$T_2 = 24\,°C$ ← process is taking place under isothermal conditions

$v_2 = 0.01652 \, \frac{m^3}{kg}$

for $T_2 = 24\,°C$ $v_f = 0.000826 \, m^3/kg$

$v_g = 0.031869$ "

so $v_2 = v_f + x_2(v_g - v_f)$

so $x_2 = 0.5056$

$u_2 = u_f + x_2(u_g - u_f) = 84.44 + 0.5056(243.13 - 84.44)$

$= 164.67 \, kJ/kg$

$Q_{cv} = m_2 u_2 - m_1 u_1 + (m_1 - m_2) h_e$

$= (0.25)(164.67) - (5)(84.44) + (5 - 0.25)(84.98)$

$= 22.6 \, kJ$