MID-TERM EXAM 1:

PROB. 1: 4/13 GOT RIGHT

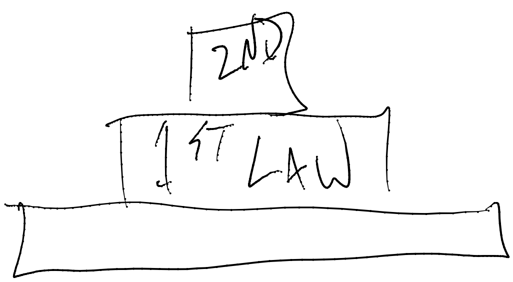
PROB. 2: 1/13 GOT RIGHT [$T_r = \frac{T}{T_{CR}} = 1.03$ 5

PROB. 3: 5/13 GOT RIGHT

PROB. 4: 4/13 GOT RIGHT

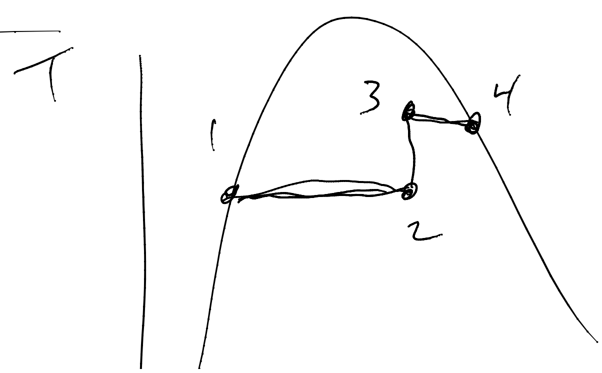
95	74	43
95	69	30
90	58	15
87	55	
80	52	

$\bar{X} = 64.9$



FIRST LAW APPLICATIONS

PROB. 4



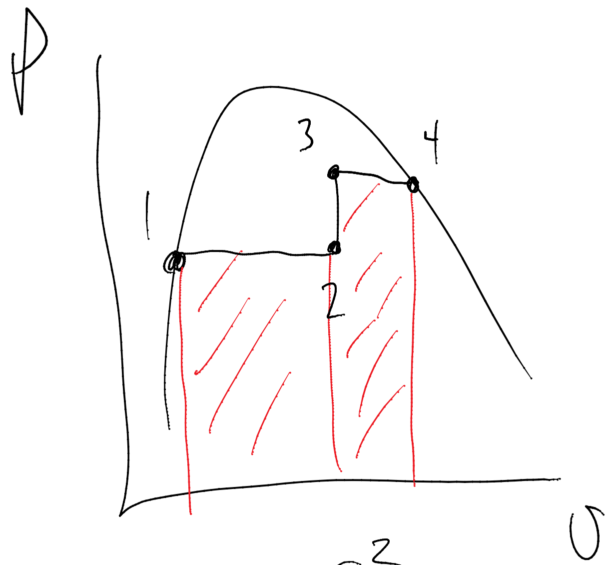
$P_1 = P_2 = 0.2\ MPa$

$P_1 = P_2 = 0.2$ MPa

$P_3 = P_4 = 0.5$ MPa

$X_2 = 0.30$

FIND ${}_1W_4$



$${}_1W_4 = {}_1W_2 + \cancelto{0}{{}_2W_3} + {}_3W_4$$

$$\int_1^2 P\,dV$$

$${}_1W_4 = P_1(V_2 - V_1) + P_3(V_4 - V_3)$$

$${}_1W_4 = P_1 m(\upsilon_2 - \upsilon_1) + P_3 m(\upsilon_4 - \upsilon_3) \qquad \upsilon = \frac{V}{m}$$

$${}_1w_4 = \frac{{}_1W_4}{m} = P_1(\upsilon_2 - \upsilon_1) + P_3(\upsilon_4 - \upsilon_3)$$

STATE 1: SAT. LIQUID, $\upsilon_1 = \upsilon_f(0.2\text{ MPa}) = 0.00106\ \frac{m^3}{kg}$

STATE 2: $\upsilon_2 = \upsilon_f + X_2(\upsilon_g - \upsilon_f)$

$$\upsilon_2 = (0.001061) + (0.3)(0.88578 - 0.001061) = 0.2665\ \frac{m^3}{kg}$$

STATE 3: $v_3 = v_2 = 0.2665 \frac{m^3}{kg}$

STATE 4: $v_4 = v_g(0.5^{MPa}) = 0.37483 \frac{m^3}{kg}$

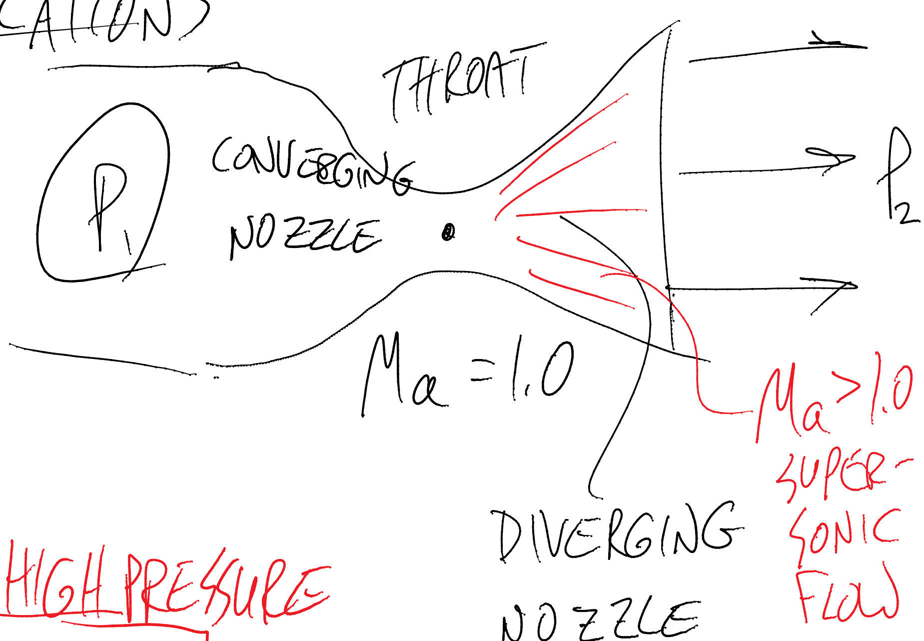
$$ {}_1W_4 = \Big[(200^{kPa})\left(0.2665 - 0.001061 \tfrac{m^3}{kg}\right) + (500^{kPa})\left(0.37483 - 0.2665 \tfrac{m^3}{kg}\right) \Big] \left(\frac{\frac{kN}{m^2}}{kPa} \right) \left(\frac{kJ}{kN \cdot m} \right) $$

$$ \boxed{{}_1W_4 = 107.2 \frac{kJ}{kg}} $$

FIRST LAW APPLICATIONS

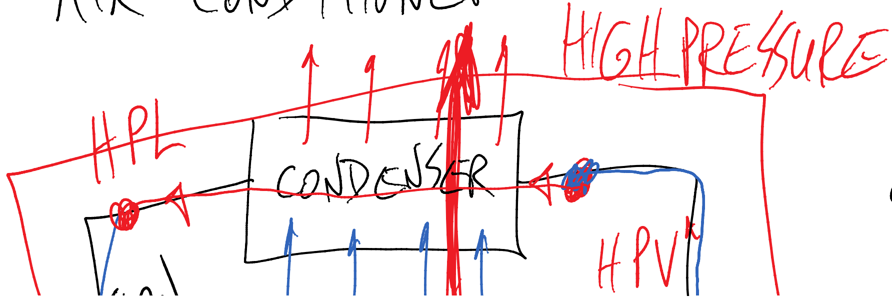
$P_1 > 2.0 P_2 = 2 \cdot P_{atm}$

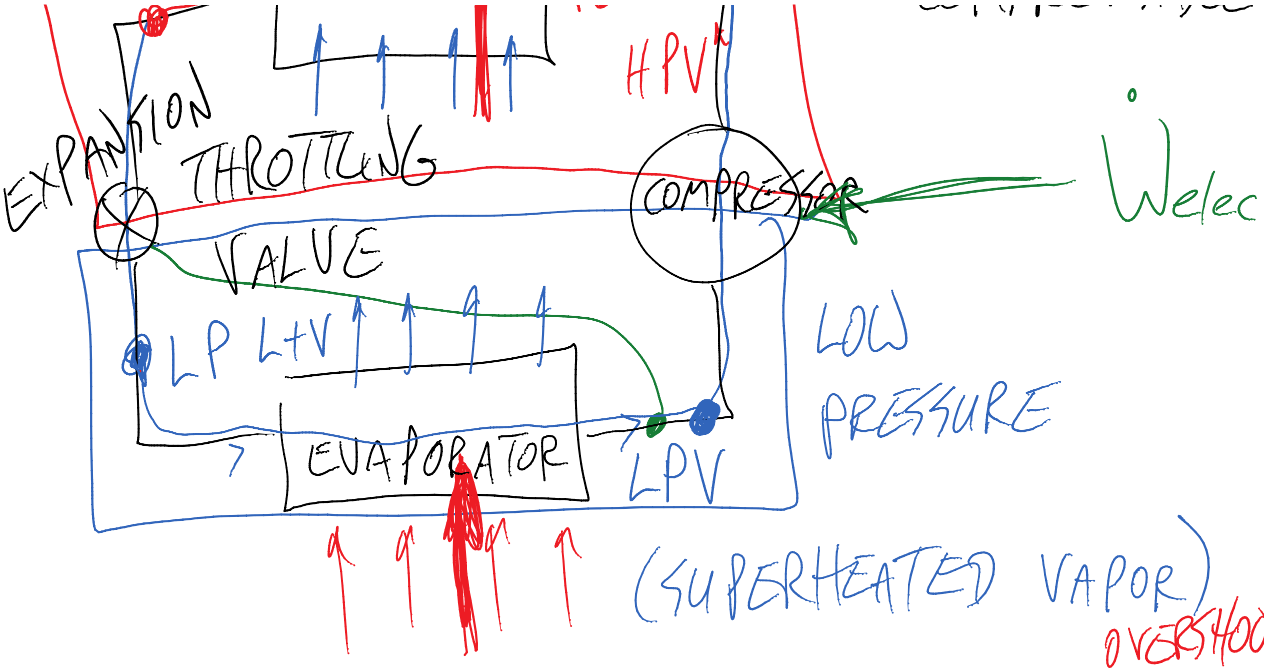
ROCKET ENGINE:



COMPRESSIBLE FLOW

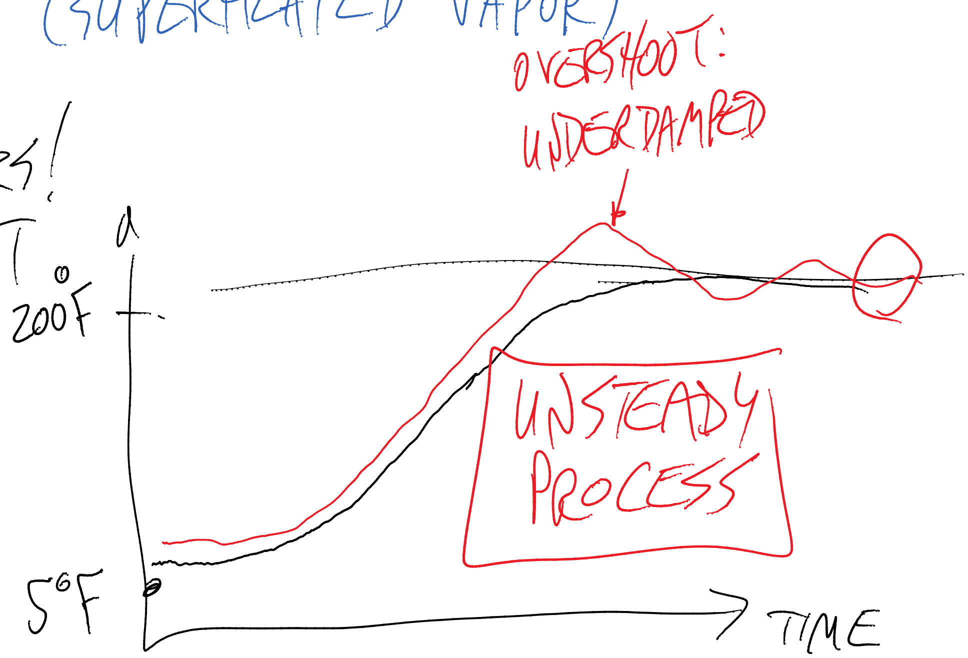
AIR CONDITIONER:

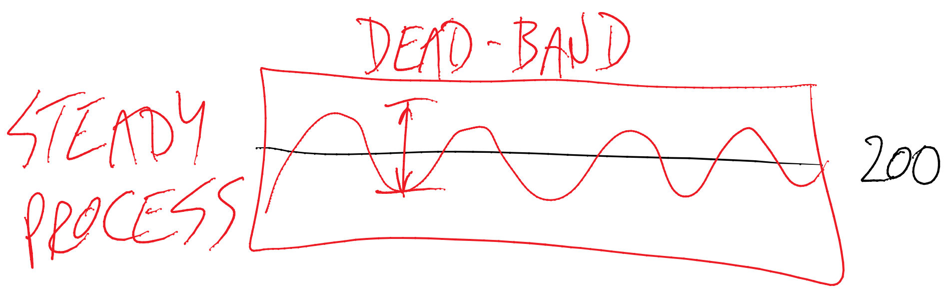




HEAT EXCHANGERS!

ENGINE:





UNSTEADY: FILLING A CONTAINER WITH WORKING FLUID, OR UNFILLING A CONTAINER.

FIRST LAW OF THERMO

CONSERVATION OF ENERGY FOR A CLOSED SYSTEM

$$E_{IN} - E_{OUT} = \Delta E_{SYSTEM} = (E_2 - E_1)$$

TOTAL ENERGY CONSISTS OF INTERNAL ENERGY, KINETIC ENERGY, AND POTENTIAL ENERGY

$$E = \mathcal{U} + KE + PE = mu + \frac{1}{2}m|\vec{V}|^2 + mgz$$

$\mathcal{U}$ = INTERNAL ENERGY

u = SPECIFIC INTERNAL ENERGY

$$E_{IN} - E_{OUT} = m\Big[\underbrace{(u_2 - u_1)}_{\text{INT. EN.}} + \underbrace{\frac{1}{2}\left(|\vec{V}_2|^2 - |\vec{V}_1|^2\right)}_{\text{KINETIC EN.}} + \underbrace{g(z_2 - z_1)}_{\text{POTENTIAL EN.}}\Big]$$

IN MANY CASES, ΔKE AND ΔPE CAN BE NEGLECTED.

$$E_{IN} - E_{OUT} = m(u_2 - u_1)$$

ENERGY CAN CROSS SYSTEM BOUNDARIES AS WORK AND HEAT.

$$E_{IN} - E_{OUT} = Q - W = \Sigma Q - \Sigma W$$

FIRST LAW FOR A CLOSED SYSTEM:

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

SIGN CONVENTION:

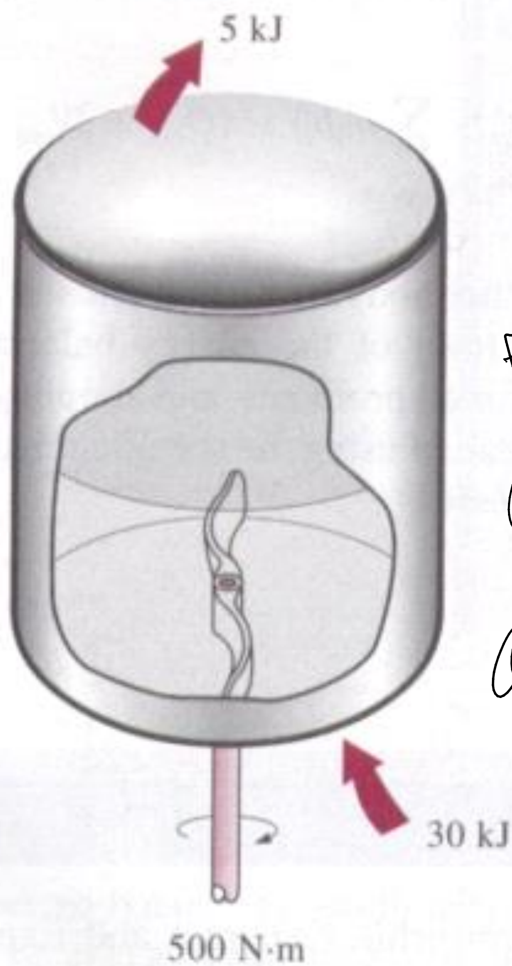
HEAT TRANSFERRED TO A SYSTEM IS POSITIVE.

HEAT TRANSFERRED FROM A SYSTEM IS NEGATIVE.

FOR A CYCLE, $u_2 = u_1 \Rightarrow \Sigma Q = \Sigma W$

Prob. 4-5

4–5 Water is being heated in a closed pan on top of a range while being stirred by a paddle wheel. During the process, 30 kJ of heat is transferred to the water, and 5 kJ of heat is lost to the surrounding air. The paddle-wheel work amounts to 500 N · m. Determine the final energy of the system if its initial energy is 10 kJ. *Answer: 35.5 kJ*



INITIAL ENERGY (INTERNAL) $= \mathcal{U}_1 = 10^{kJ}$

FIND FINAL INTERNAL ENERGY OF SYSTEM

FIRST LAW:

$$Q - W = \Delta \mathcal{U} = \mathcal{U}_2 - \mathcal{U}_1$$

$$Q = 30 - 5^{kJ} = +25^{kJ}$$

$$W = \left(-500^{N \cdot m}\right)\left(\frac{kJ}{1000\ N \cdot m}\right)$$

$$W = -0.5^{kJ}$$

$$\mathcal{U}_2 = \mathcal{U}_1 + Q - W$$

$$\boxed{\mathcal{U}_2} = \left(10^{kJ}\right) + \left(25^{kJ}\right) - \left(-0.5^{kJ}\right) \boxed{= 35.5^{kJ}}$$

Prob. 4-12

4–12 A 0.5-m^3 rigid tank contains refrigerant-134a initially at 200 kPa and 40 percent quality. Heat is now transferred to the refrigerant until the pressure reaches 800 kPa. Determine (*a*) the mass of the refrigerant in the tank and (*b*) the amount of heat transferred. Also, show the process on a *P*-*v* diagram with respect to saturation lines.

$V = 0.5\ m^3$, R-134a, $P_1 = 200$ kPa, $X_1 = 0.4$,

$P_2 = 800$ kPa

a) FIND MASS

$$v_1 = v_f + X_1 (v_g - v_f)$$

@ $P_1 = P_{sat} = 200$ kPa

$$v_1 = (0.0007532) + (0.4)(0.0993 - 0.0007532) = 0.04017\ \frac{m^3}{kg}$$

$$v = \frac{V}{m_1},\quad \boxed{m} = \frac{V}{v_1} = \frac{(0.5\ m^3)}{\left(0.04017\ \frac{m^3}{kg}\right)} = \boxed{12.45\ kg}$$

b) FIND Q: FIRST LAW OF THERMO:

$$Q - \cancel{W}^{\,0} = m(u_2 - u_1)$$

PV-WORK:

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

PV-WORK:

FOR A RIGID CONTAINER, $W = \int_1^2 P\,dV = 0$

$$Q = m(u_2 - u_1)$$

$$u_1 = u_f + x_1(u_g - u_f) = u_f + x_1 u_{fg}$$

$$u_{fg} = u_g - u_f$$

$$u_1 = (36.69) + (0.4)(221.43 - 36.69) = 110.6 \ \frac{kJ}{kg}$$

HOW TO FIND u_2?

$P_2 = 800$ kPa, $v_2 = v_1 = 0.04017 \ \frac{m^3}{kg}$

FOR $P_2 = P_{sat} = 800$ kPa,

$$\boxed{v_f = 0.0008454, \quad v_g = 0.0255 \ \frac{m^3}{kg}}$$

SINCE $v_2 > v_g \Rightarrow$ S.H.V.

$v \left(\frac{m^3}{kg}\right)$	$u \left(\frac{kJ}{kg}\right)$

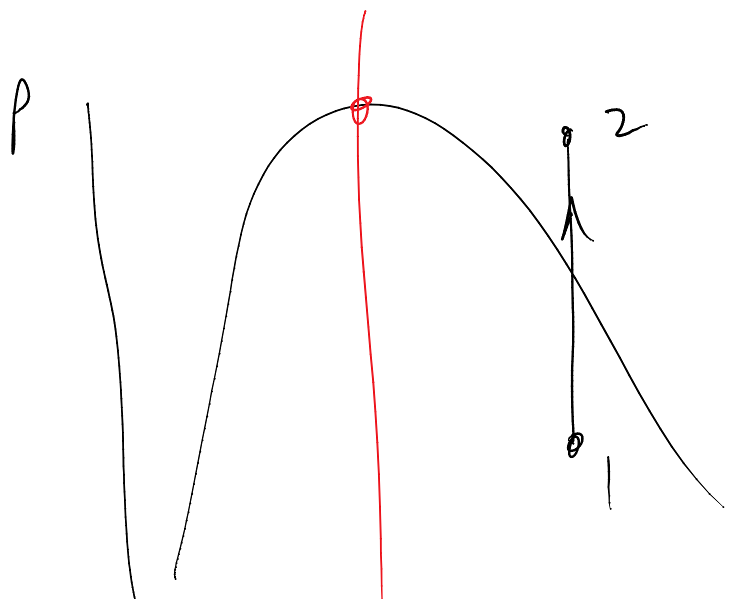
$v\left(\frac{m}{kg}\right)$	$u\left(\frac{kJ}{kg}\right)$
0.03997	348.09
0.04113	358.15

$$u = u_1 + \left(\frac{u_2 - u_1}{v_2 - v_1}\right)(v - v_1)$$

$$u = (348.09) + \left(\frac{358.15 - 348.09}{0.04113 - 0.03997}\right)(0.04017 - 0.3997)$$

$$u_2 = 348.6 \ \frac{kJ}{kg}$$

$$\boxed{{}_1Q_2} = (12.45 \ kg)\left(348.6 - 110.6 \ \frac{kJ}{kg}\right) = \boxed{2978 \ kJ}$$



Internal Energy and Enthalpy

FIRST LAW: $Q - W = m(u_2 - u_1)$

INTERNAL ENERGY – ENTHALPY

u = SPECIFIC INTERNAL ENERGY (NO FLOW)

$h \equiv u + Pv$ = SPECIFIC ENTHALPY (FLOWING SYSTEMS)

WE'LL USE THESE PROPERTIES TO DEFINE SPECIFIC HEATS.

IN A PROCESS, THE CHANGE IN INTERNAL ENERGY IS EVALUATED USING THE CHAIN RULE:

LET $u = u(T, v)$

$$du = \left(\frac{\partial u}{\partial T}\right)_v \cdot dT + \left(\frac{\partial u}{\partial v}\right)_T \cdot dv$$

$$C_v = \left(\frac{\partial u}{\partial T}\right)_v$$

C_v = SPECIFIC HEAT AT CONSTANT VOLUME (NON-FLOWING SYSTEMS)

THE CHANGE IN ENTHALPY IS $[h = h(P, T)]$

$$dh = \left(\frac{\partial h}{\partial T}\right)_P \cdot dT + \left(\frac{\partial h}{\partial P}\right)_T \cdot dT$$

$$C_p = \left(\frac{\partial h}{\partial T}\right)_p = \text{SPECIFIC HEAT AT CONSTANT PRESSURE}$$

(FLOWING SYSTEMS)

FOR AN IDEAL GAS,

$$u = u(T)$$

$$C_v = \left(\frac{\partial u}{\partial T}\right)_v = \frac{du}{dT} \qquad Pv = RT$$

$$h = u + Pv = u(T) + RT \Rightarrow h = h(T)$$

$$C_p = \left(\frac{\partial h}{\partial T}\right)_p = \frac{dh}{dT}$$

$$du = C_v\,dT \qquad \text{SEPARATION OF VARIABLES}$$

$$\int_1^2 du = \int_1^2 C_v\,dT$$

WEAK FUNCTIONS OF TEMPERATURE:

$$C_v = C_v(T)$$

ASSUME SMALL TEMPERATURE CHANGES:

$$C_v = \text{CONSTANT}$$

$$u_2 - u_1 = C_v(T_2 - T_1)$$ FOR IDEAL GASES

$$dh = C_p\, dT$$

$$\int_1^2 dh = \int_1^2 C_p\, dT \quad ; \quad C_p = C_p(T) \text{ WEAKLY}$$

ASSUME C_p = CONSTANT

$$h_2 - h_1 = C_p(T_2 - T_1)$$

FOR AN IDEAL GAS,

$h = u + RT$: DIFFERENTIATE W.R.T. T GIVES:

$$\frac{dh}{dT} = \frac{du}{dT} + R$$

$$\boxed{C_p = C_v + R}$$

$$\left.\begin{aligned} u_2 - u_1 &= C_v(T_2 - T_1) \\ h_2 - h_1 &= C_p(T_2 - T_1) \end{aligned}\right\}$$ NOT APPLICABLE UNDER THE SATURATION DOME!!!

$$\boxed{u_{fg} = u_g - u_f \quad \text{OR} \quad h_{fg} = h_g - h_f}$$

LATENT HEAT OF VAPORIZATION/CONDENSATION

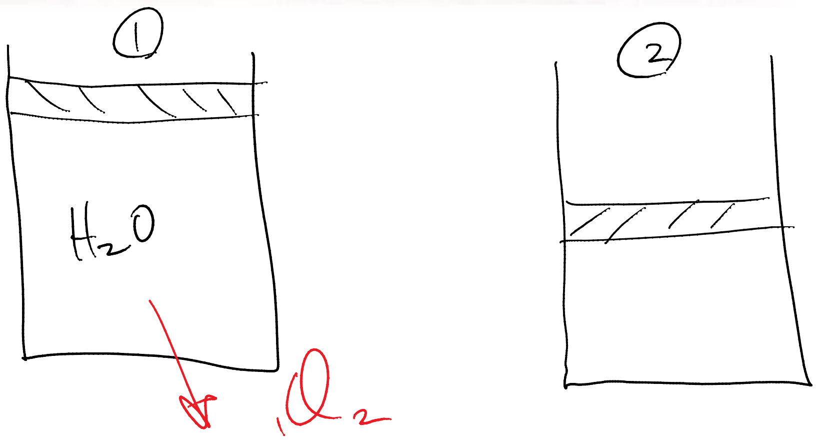
Prob. 4-21

4–21 A piston-cylinder device contains steam initially at 1 MPa, 350°C, and 1.5 m³. Steam is allowed to cool at constant pressure until it first starts condensing. Show the process on a *T-v* diagram with respect to saturation lines and determine (*a*) the mass of the steam, (*b*) the final temperature, and (*c*) the amount of heat transfer.

$P_1 = 1\ \text{MPa}$

$T_1 = 350°C$

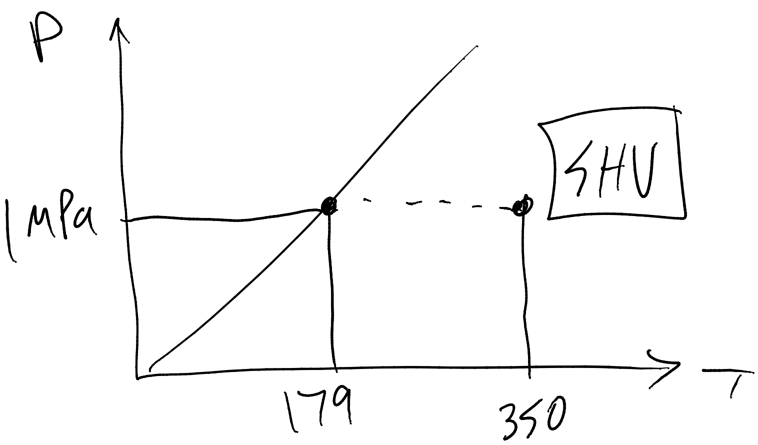
$V_1 = 1.5\ m^3$



$P_2 = P_1 = 1\ \text{MPa}$

$X_2 = 1.0$ SAT. VAPOR

a) FIND MASS: STATE 1:



AT $P_{sat} = 1\ \text{MPa}$

$T_{sat} = 179.91°C$

$v_1 = 0.2825\ \frac{m^3}{kg}$

$v = \frac{V}{m}, \quad m = \frac{V}{v}$

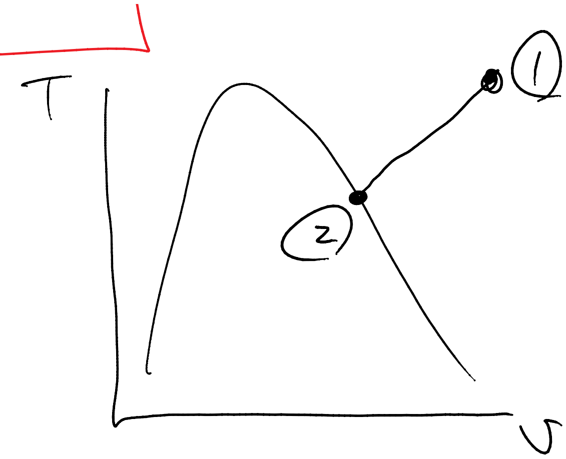
$$\boxed{m} = \frac{(1.5\ m^3)}{\left(0.2825\ \frac{m^3}{kg}\right)} = \boxed{5.31\ kg}$$

b) FIND T_2

$$\boxed{T_2} = T_{sat}(P_{sat} = 1\ \text{MPa}) = \boxed{179.91°C}$$

$T_2 = T_{sat} (P_{sat}$ ...

$$v_2 = v_g(1\,\text{MPa}) = 0.19444\ \frac{m^3}{kg}$$



$$T_1 = 350°C,\quad v_1 = 0.2825\ \frac{m^3}{kg}$$

$$T_2 = 180°C,\quad v_2 = 0.1944\ \frac{m^3}{kg}$$

c) FIND ${}_1Q_2$: FIRST LAW

$$Q - W = m(u_2 - u_1) = U_2 - U_1$$

FOR A CONSTANT- PRESSURE PROCESS,

$$ {}_1W_2 = \int_1^2 P\,dV = P(V_2 - V_1)$$

$$Q - P(V_2 - V_1) = U_2 - U_1$$

$$Q = (U_2 + PV_2) - (U_1 + PV_1)$$

$H \equiv U + PV$ ENTHALPY , $h = \frac{H}{m}$ = SPECIFIC ENTHALPY

$$Q = H_2 - H_1 = m(h_2 - h_1) \quad *$$

$h_1 = 3157.7\ \frac{kJ}{kg}$ SHV TABLE

$h_2 = h_g(1\,\text{MPa}) = 2778.1\ \frac{kJ}{kg}$ SAT. PRESSURE TABLE

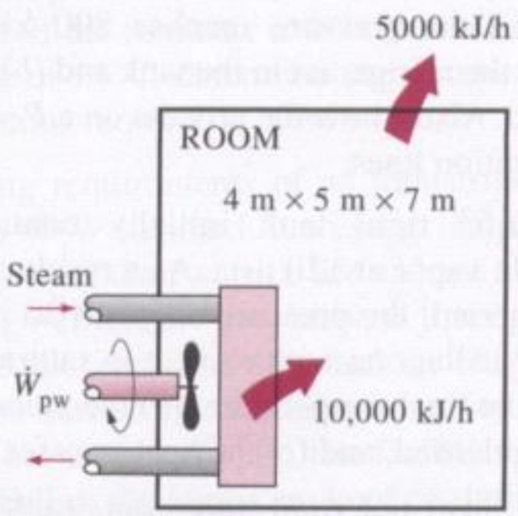
$$\boxed{Q} = (5.31\ kg)\left(2778.1 - 3157.7\ \frac{kJ}{kg}\right) = \boxed{-2016\ kJ}$$

$$\boxed{{}_1Q_2} = (5.31\ \text{kg})\left(2778.1 - 3157.7\ \frac{\text{kJ}}{\text{kg}}\right) = \boxed{-2016\ \text{kJ}}$$

HEAT TRANSFERRED FROM THE SYSTEM.

Prob. 4-29

4–29 A 4-m × 5-m × 7-m room is heated by the radiator of a steam-heating system. The steam radiator transfers heat at a rate of 10,000 kJ/h, and a 100-W fan is used to distribute the warm air in the room. The rate of heat loss from the room is estimated to be about 5000 kJ/h. If the initial temperature of the room air is 10°C, determine how long it will take for the air temperature to rise to 20°C. Assume constant specific heats at room temperature.



$V = (4^m)(5^m)(7^m)$

$V = 140\ m^3$ AIR

$\dot{Q}_{IN} = 10{,}000 \frac{KJ}{HR}$

$\dot{W}_{FAN} = 100^W$

$\dot{Q}_{LOSS} = 5000 \frac{KJ}{HR}$

$T_1 = 10°C, \quad T_2 = 20°C$

FIND TIME TO REACH T_2

$\dot{Q} = \frac{Q}{\Delta t}, \quad \dot{W} = \frac{W}{\Delta t}, \quad Q = \dot{Q} \cdot \Delta t, \quad W = \dot{W} \cdot \Delta t$

FIRST LAW: $Q - W = m(u_2 - u_1)$

$(\dot{Q} - \dot{W}) \cdot \Delta t = m(u_2 - u_1)$

ASSUME IDEAL GAS: WE FOUND:

$du = C_v\, dT$

$\int_1^2 du = \int_1^2 C_v\, dT$ ASSUME C_v = CONSTANT

$u_2 - u_1 = C_v(T_2 - T_1)$

$$u_2 - u_1 = C_v (T_2 - T_1)$$

$$\Delta t = \frac{m C_v (T_2 - T_1)}{(\dot{Q} - \dot{W})}$$

$$PV = mRT$$

$$m = \frac{PV}{RT} = \frac{(100^{\text{KPa}})(140^{m^3})}{\left(0.287 \frac{\text{KJ}}{\text{Kg-K}}\right)(10+273^{K})} = 172.4^{\text{Kg}}$$

$$\dot{Q} = \left(10{,}000 \frac{\text{KJ}}{\text{HR}} - 5000 \frac{\text{KJ}}{\text{HR}}\right)\left(\frac{\text{HR}}{3600^{s}}\right) = 1.389^{\text{KW}}$$

$$\dot{W}_{FAN} = -100^{W} = -0.1^{\text{KW}}$$

$$\Delta t = \frac{(172.4^{\text{Kg}})\left(0.718 \frac{\text{KJ}}{\text{Kg-K}}\right)(20-10^{K})}{(1.389^{\text{KW}}) - (-0.1^{\text{KW}})}$$

$$\boxed{\Delta t =} (831.3^{s})\left(\frac{\text{MIN}}{60^{s}}\right) = \boxed{13.85^{\text{MIN}}}$$

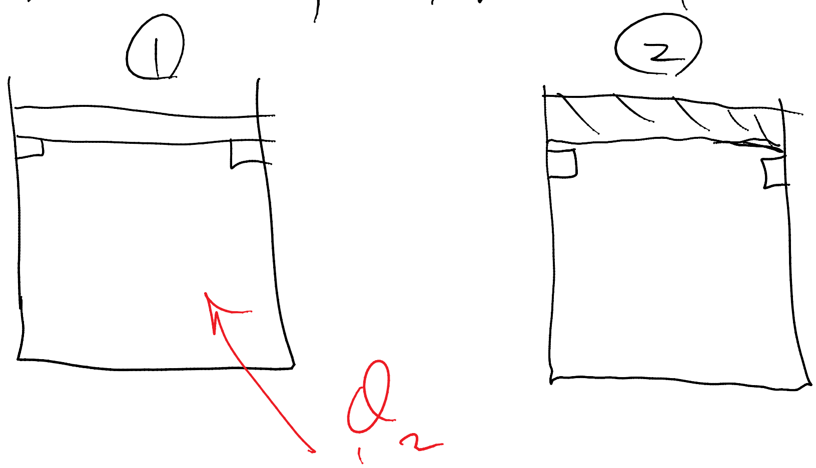
$$\left[(20^{°C} + 273)^{K} - (10^{°C} + 273)^{K}\right]$$

Prob. 4-33

4–33 A piston-cylinder device whose piston is resting on top of a set of stops initially contains 0.5 kg of helium gas at 100 kPa and 25°C. The mass of the piston is such that 500 kPa of pressure is required to raise it. How much heat must be transferred to the helium before the piston starts rising?
Answer: 1857 kJ

He, $m = 0.5\ \text{kg}$, $P_1 = 100\ \text{kPa}$, $T_1 = 25°C$

$P_2 = 500\ \text{kPa}$, FIND ${}_1Q_2$



FIRST LAW: $Q - W = m(u_2 - u_1)$

$$W = \int_1^2 P\,dV = 0$$

$$Q = m(u_2 - u_1)$$

ASSUME PERFECT GAS BEHAVIOR

$$u_2 - u_1 = C_v(T_2 - T_1)$$

$$Q = m C_v (T_2 - T_1)$$

$$PV = mRT$$

$$\frac{P}{T} = \frac{mR}{V} = \text{CONSTANT} \qquad \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

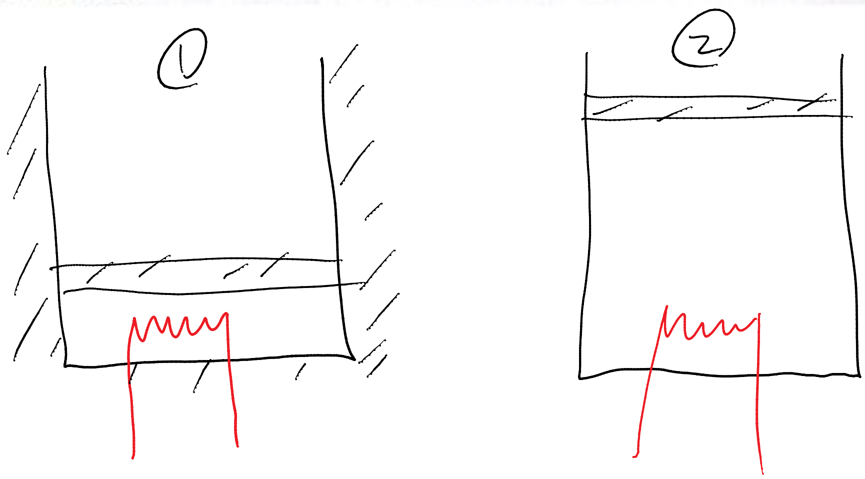
$$T_2 = T_1 \left(\frac{P_2}{P_1} \right) = (25 + 273^{K}) \left(\frac{500}{100} \right) = 1490^{K}$$

$$Q = (0.5^{kg}) \left(3.1156 \frac{kJ}{kg\text{-}K} \right) \left[(1490^{K}) - (25 + 273^{K}) \right]$$

$$\boxed{Q = 1857^{kJ}}$$

Prob. 4-37

4-37 An insulated piston-cylinder device initially contains 0.3 m³ of carbon dioxide at 200 kPa and 27°C. An electric switch is turned on, and a 110-V source supplies current to a resistance heater inside the cylinder for a period of 10 min. The pressure is held constant during the process, while the volume is doubled. Determine the current that passes through the resistance heater.



$V_1 = 0.3\ m^3$ CO_2

$P_1 = 200\ kPa$

$T_1 = 27°C$

$Q = 0,\ 110\ V$

$t = 10\ min$

$P_2 = P_1 = 200\ kPa$

$V_2 = 2V_1$

FIND CURRENT

FIRST LAW: $Q - W = U_2 - U_1$

$$W = P(V_2 - V_1) - W_{el}$$

$$-[P(V_2 - V_1) - W_{el}] = U_2 - U_1$$

$$W_{el} = (U_2 + PV_2) - (U_1 + PV_1)$$

$$W_{el} = H_2 - H_1 = m(h_2 - h_1)$$

FOR IDEAL GASES, $dh = C_p\,dT$

ASSUME C_p = CONSTANT : $h_2 - h_1 = C_p(T_2 - T_1)$

$$W_{el} = m C_p (T_2 - T_1)$$

$$PV = mRT, \quad m = \frac{PV}{RT} = \frac{(200\,\text{kPa})(0.3\,\text{m}^3)}{\left(0.1889\,\frac{\text{kJ}}{\text{kg-K}}\right)(27+273\,\text{K})}$$

$$m = 1.059\,\text{kg}$$

$$PV = mRT$$

$$\frac{V}{T} = \frac{mR}{P} = \text{CONSTANT} \qquad \frac{V_1}{T_1} = \frac{V_2}{T_2} = \frac{2V_1}{T_2}$$

$$T_2 = T_1\left(\frac{2V_1}{V_1}\right) = 2T_1 = 2(27+273\,\text{K}) = 600\,\text{K}$$

$$W_{el} = (1.059\,\text{kg})\left(0.846\,\frac{\text{kJ}}{\text{kg-K}}\right)(600-300\,\text{K}) = 268.7\,\text{kJ}$$

$$\dot{W}_{el} = \frac{W_{el}}{\Delta t}, \quad W_{el} = \dot{W}_{el}\cdot\Delta t = V\cdot I\cdot\Delta t$$

$$I = \frac{W_{el}}{V\cdot\Delta t} = \frac{(268.7\,\text{kJ})}{(110\,\text{V})(10\,\text{min})\left(\frac{60\,\text{s}}{\text{min}}\right)}\cdot\left(\frac{1000\,\text{J}}{\text{kJ}}\right)\left(\frac{\text{W}}{\frac{\text{J}}{\text{s}}}\right)$$

$$\boxed{I = 4.071\,\text{A}}$$

IF C_p IS NOT ASSUMED TO BE CONSTANT,

$$W_{el} = m(h_2 - h_1)$$

$$h = \frac{H}{m}, \quad \bar{h} = \frac{H}{N} = \text{MOLAR SPECIFIC ENTHALPY}$$

N = NUMBER OF MOLES

$m = M \cdot N$, M = MOLECULAR WEIGHT

$$N = \frac{m}{M}$$

$$\boxed{\bar{h}} = \frac{H}{N} = \frac{H}{\left(\frac{m}{M}\right)} = \left(\frac{H}{m}\right) \cdot M = \boxed{h \cdot M}$$

$$h = \frac{\bar{h}}{M} \qquad \frac{\left(\frac{kJ}{kmol}\right)}{\left(\frac{kg}{kmol}\right)} = \frac{kJ}{kg} \checkmark$$

$$W_{el} = m(h_2 - h_1)$$

$$W_{el} = \frac{m}{M}(\bar{h}_2 - \bar{h}_1)$$ C_p WEAK FUNCTION OF T

TABLE A-1: $M = 44.01 \frac{kg}{kmol}$

TABLE A-20: $T = 300^K$: $\bar{h} = 9431 \frac{kJ}{kmol}$

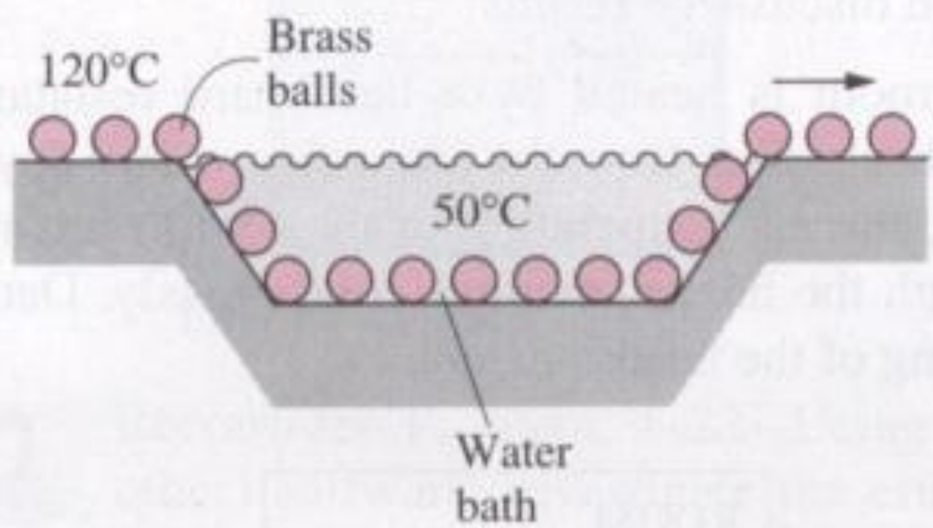
$$T = 600\,K : \quad \bar{h} = 22{,}280\ \frac{kJ}{kmol}$$

$$W_{el} = \frac{(1.059\ kg)}{\left(44.01\ \frac{kg}{kmol}\right)} \cdot \left(22{,}280 - 9431\ \frac{kJ}{kmol}\right) = 309.2\ kJ$$

$$\frac{(309.2 - 268.7)}{309.2} \times 100\% = 13.1\%$$ ERROR WHEN C_p IS ASSUMED CONSTANT

Prob. 4-45

4–45 In a manufacturing facility, 5-cm-diameter brass balls ($\rho = 8522$ kg/m^3 and $C_p = 0.385$ kJ/kg · °C) initially at 120°C are quenched in a water bath at 50°C for a period of 2 min. at a rate of 100 balls per minute. If the temperature of the balls after quenching is 74°C, determine the rate at which heat needs to be removed from the water in order to keep its temperature constant at 50°C.



First Law of Thermo for Open Systems

- CONSERVE MASS
- CONSERVE ENERGY
- UNSTEADY - FLOW PROCESSES
- STEADY - STATE PROCESSES

CONSERVATION OF MASS:

THE CHANGE OF MASS WITHIN A CONTROL VOLUME IS EQUAL TO THE MASS ENTERING MINUS THE MASS LEAVING.

$\dot{m}$ = MDOT = MASS FLOW RATE $\left(\frac{kg}{s}, \frac{LBM}{MIN}\right)$

$$\frac{dm_{cv}}{dt} = \sum_{in} \dot{m} - \sum_{out} \dot{m}$$

OVER A FINITE TIME

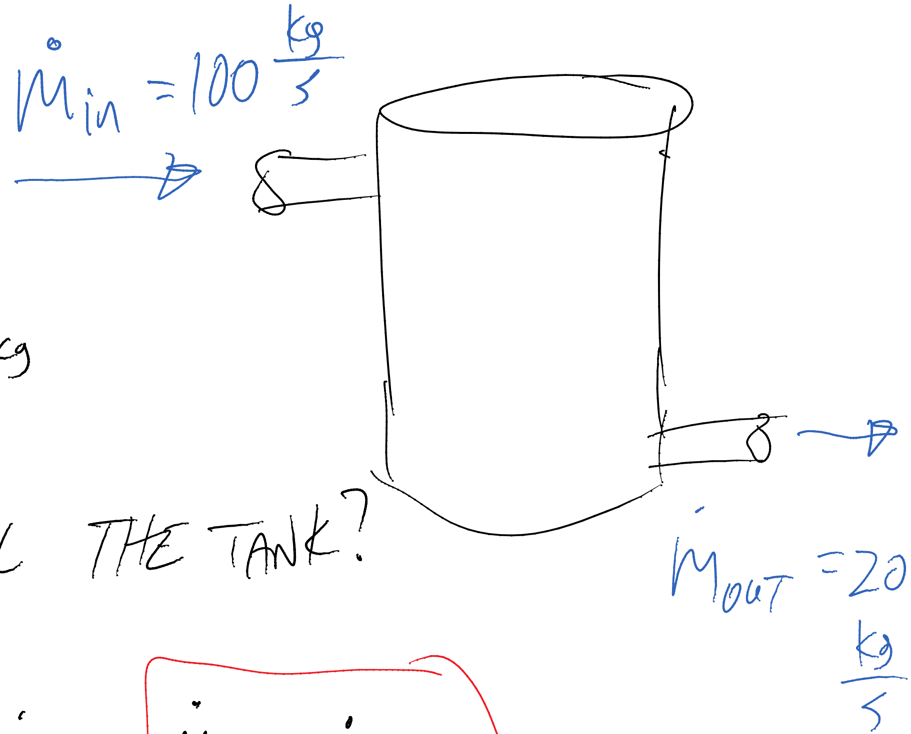
$$m_{in} - m_{out} = \Delta m_{cv} = (m_2 - m_1)$$

EXAMPLE) $\dot{m}$ 100 $\frac{kg}{}$

EXAMPLE)

$$m_{cv}(t=0) = 1000 \text{ kg}$$

$$m_{cv}(t=t_f) = 3000 \text{ kg}$$



HOW LONG TO FILL THE TANK?

$$\boxed{\frac{dm_{cv}}{dt}} = \sum_{in} \dot{m} - \sum_{OUT} \dot{m} = \boxed{\dot{m}_{in} - \dot{m}_{OUT}}$$

SEPARATE VARIABLES AND INTEGRATE

$$dm_{cv} = (\dot{m}_{in} - \dot{m}_{out})\, dt$$

$$\int_{t_i}^{t_f} dm_{cv} = \int_{t_i}^{t_f} (\dot{m}_{in} - \dot{m}_{OUT})\, dt$$

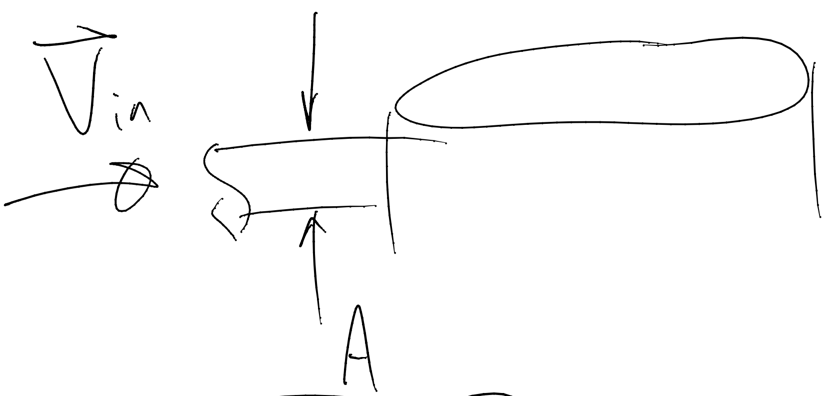
$$m_{cv}(t_f) - m_{cv}(t_i) = (\dot{m}_{in} - \dot{m}_{out})(t_f - t_i)$$

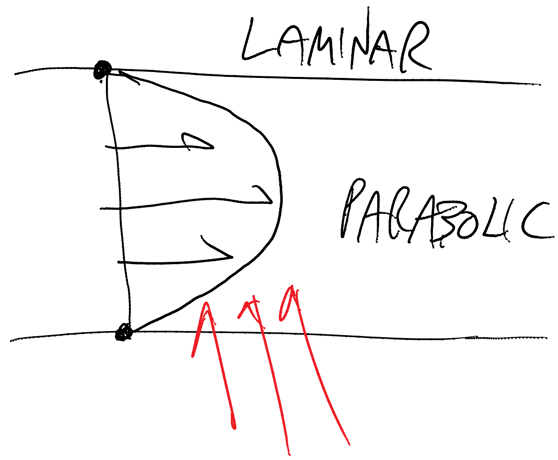
LET $t_i = 0$

$$t_f = \frac{M_{cv}(t_f) - M_{cv}(t_i)}{(\dot{m}_{in} - \dot{m}_{out})} \qquad \frac{kg}{\left(\frac{kg}{s}\right)} = s \checkmark$$

$$\boxed{t_f =} \frac{(3000\ kg) - (1000\ kg)}{\left(100 - 20\ \frac{kg}{s}\right)} = \boxed{25\ s}$$

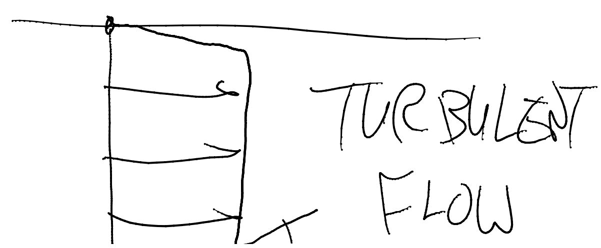
THE VELOCITY OF THE FLUID ENTERING OR EXITING THE TANK IS NEEDED FOR KINETIC ENERGY CALCULATIONS:

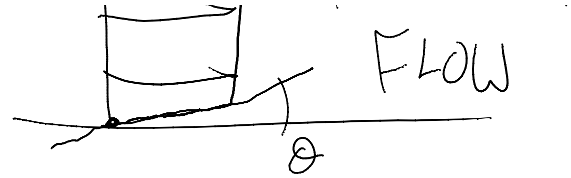




$$\boxed{\dot{m} = \rho |\vec{V}| A}$$

A = CROSS-SECTIONAL AREA





$$\dot{m} = \rho \vec{V} A = \rho \cdot \dot{V} \qquad \dot{V} = \vec{V} \cdot A \qquad \frac{m}{s} \cdot m^2 = \frac{m^3}{s}$$

$$v = \frac{V}{m}, \quad v = \frac{\dot{V}}{\dot{m}}$$

FIRST LAW OF THERMO OF OPEN SYSTEMS

PROCESS:

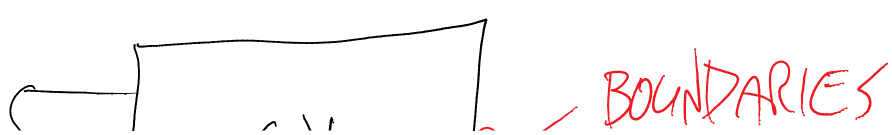
$$E_{in} - E_{OUT} = \Delta E_{SYSTEM} = (E_2 - E_1)_{CV}$$

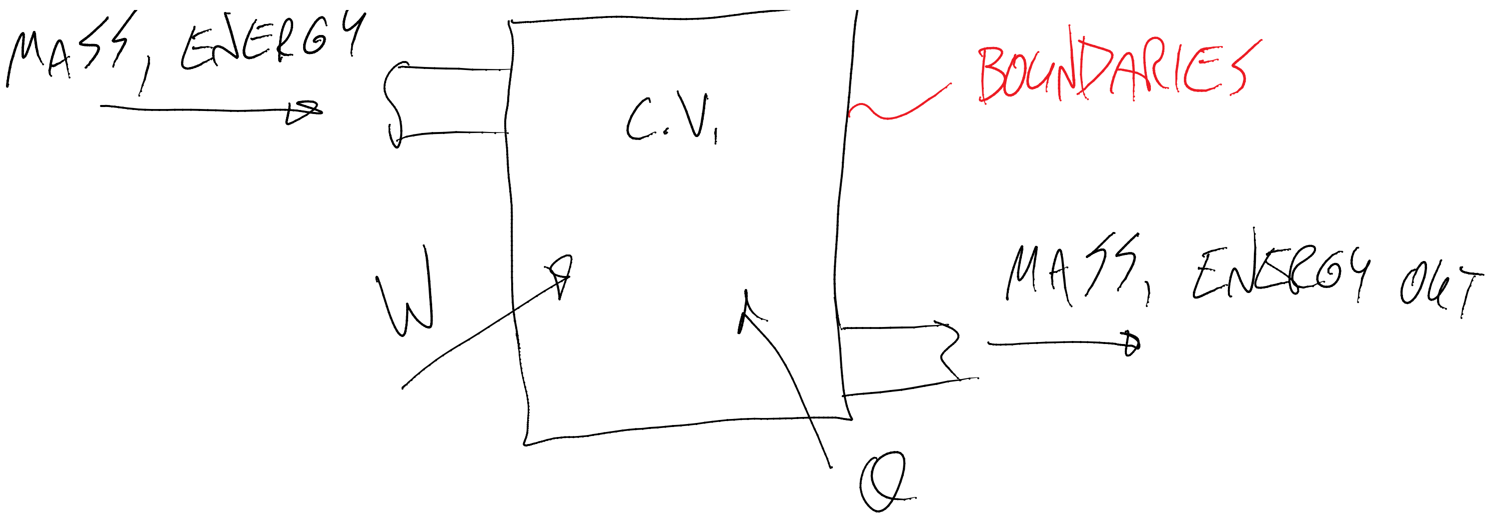
RATE EQUATION:

$$\dot{E}_{in} - \dot{E}_{OUT} = \frac{d}{dt}(E_2 - E_1)_{CV}$$

FOR AN OPEN SYSTEM, MASS AND ENERGY CAN PASS THROUGH THE SYSTEM BOUNDARIES.

MASS, ENERGY





FOR THE MASS ENTERING,

$$E_{in} = \sum m_i \left(u_i + \frac{1}{2}|\vec{V}_i|^2 + g z_i \right) \quad \text{PROCESS}$$

$$\dot{E}_{in} = \sum \dot{m}_i \left(u_i + KE_i + PE_i \right) \quad \text{RATE}$$

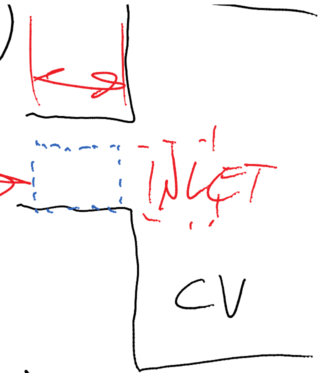
FOR THE MASS EXITING,

$$E_{out} = \sum m_e \left(u_e + KE_e + PE_e \right) \quad \text{PROCESS}$$

$$\dot{E}_{out} = \sum \dot{m}_e \left(u_e + KE_e + PE_e \right) \quad \text{RATE}$$

ENERGY ALSO ENTERS OR EXITS DUE TO THE WORK REQUIRED TO PUSH THE FLUID THROUGH THE C.V. (FLOW WORK)

THROUGH THE C.V. (FLOW WORK)



$$W_{FLOW} = F \cdot L = (P \cdot A) \cdot L = P \cdot V$$

$$W_{FLOW} = W_{OUT} - W_{in} = m_e \boxed{P_e v_e} - m_i P_i v_i$$

$$E_{in} - E_{OUT} = (E_2 - E_1)_{CV}$$

BOUNDARIES

$$\sum Q - \sum (W_{CV} + W_{FLOW}) + \sum m_i \left(u_i + \frac{1}{2}|\vec{V}_i|^2 + g z_i \right)$$

$$- \sum m_e \left(u_e + \frac{1}{2}|\vec{V}_e|^2 + g z_e \right) = m_2 \left(u_2 + \frac{1}{2}|\vec{V}_2|^2 + g z_2 \right)$$

$$- m_1 \left(u_1 + \frac{1}{2}|\vec{V}_1|^2 + g z_1 \right)$$

CONVECTION

CONTROL VOLUME

SUBSTITUTE FOR FLOW WORK: $\boxed{h = u + Pv}$

$$\boxed{\begin{aligned} &Q - W_{cv} + \sum m_i (h_i + KE_i + PE_i) - \sum m_e (h_e + KE_e + PE_e) \\ &= m_2 (u_2 + KE_2 + PE_2) - m_1 (u_1 + KE_1 + PE_1) \end{aligned}}$$

1ST LAW FOR A UNIFORM-FLOW PROCESS (FILLING A TANK)

AS A RATE EQUATION,

$$\sum \dot{Q} - \sum \dot{W}_{cv} + \sum \dot{m}_i (h_i + KE_i + PE_i) - \sum \dot{m}_e (h_e + KE_e + PE_e) = \boxed{\frac{dE_{cv}}{dt}}$$

FOR A STATE-STATE PROCESS:

$$\frac{dE_{cv}}{dt} = 0$$

$$\boxed{\dot{Q} - \dot{W}_{cv} + \dot{m}_i (h_i + KE_i + PE_i) - \dot{m}_e (h_e + KE_e + PE_e) = 0}$$

FIRST LAW FOR STEADY PROCESSES AS A RATE EQUATION.

CONSERVE MASS (CONTINUITY EQUATION):

dm_{cv} [illegible]

$$\frac{\quad}{dt} = \sum m_{in} - \sum m_{out}$$

FOR STEADY STATE PROCESSES:

$$\frac{dm_{cv}}{dt} = 0$$

$$\sum \dot{m}_{in} = \sum \dot{m}_{out}$$

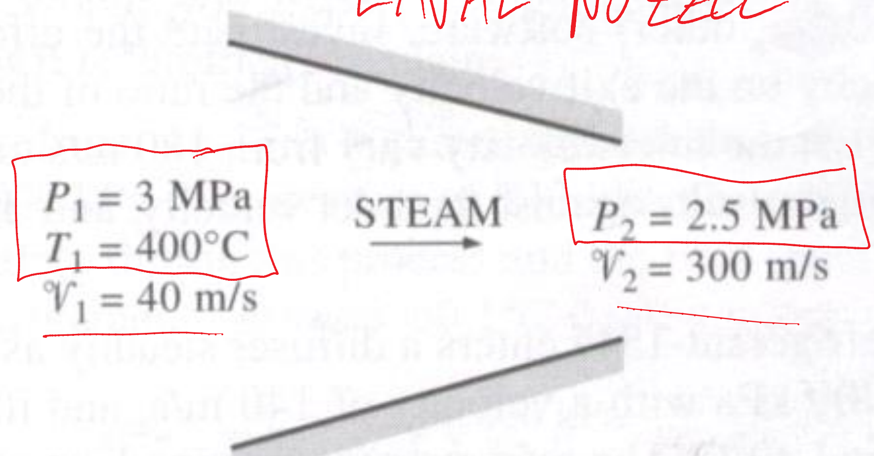
$$\boxed{\dot{m}_i = \dot{m}_e}$$

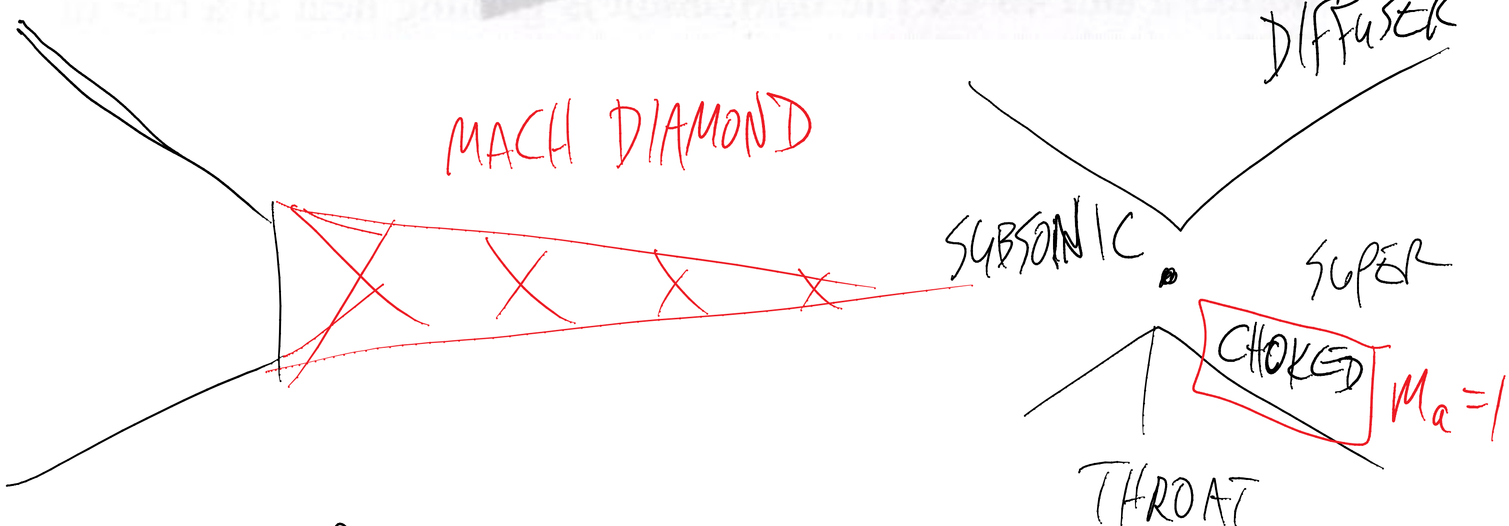
STEADY STATE CONTINUITY EQUATON

Prob. 4-65

4–65 EES Steam at 3 MPa and 400°C enters an adiabatic nozzle steadily with a velocity of 40 m/s and leaves at 2.5 MPa and 300 m/s. Determine (*a*) the exit temperature and (*b*) the ratio of the inlet to exit area A_1/A_2.

LAVAL NOZZLE





$P_i = 3$ MPa, $T_i = 400°C$

ADIABATIC = PERFECTLY INSULATED, $\dot{Q} = 0$

STEADY STATE

$\vec{V}_i = 40\ \frac{m}{s}$, $P_e = 2.5$ MPa, $\vec{V}_e = 300\ \frac{m}{s}$

a) FIND T_e b) FIND A_i/A_e

CONTINUITY: $\boxed{\dot{m}_i = \dot{m}_e}$

FIRST LAW:

$$\cancel{\dot{Q}}^{\,0} - \cancel{\dot{W}_{cv}}^{\,0} + \dot{m}_i(h_i + KE_i + PE_i) - \dot{m}_e(h_e + KE_e + PE_e) = 0$$

$$(h_i - h_e) + (KE_i - KE_e) + \cancel{(PE_i - PE_e)}^{\,0} = 0$$

$$(h_i - h_e) + \frac{1}{2}\left(|\vec{V}_i|^2 - |\vec{V}_e|^2\right) = 0$$

$$h_e = h_i + \frac{1}{2}\left(|\vec{V}_i|^2 - |\vec{V}_e|^2\right)$$

AT $P_i = 3$ MPa, $T_i = 400^\circ C$, $h_i = 3230.9\ \frac{kJ}{kg}$, $v_i = 0.09936\ \frac{m^3}{kg}$

$$h_e = \left(3230.9\ \frac{kJ}{kg}\right) + \frac{1}{2}\left(40^2 - 300^2\ \frac{m^2}{s^2}\right)\left(\frac{N \cdot s^2}{kg \cdot m}\right)\left(\frac{kN}{1000N}\right)\left(\frac{kJ}{kN \cdot m}\right)$$

$$h_e = 3186.7\ \frac{kJ}{kg} \Big\}\ SHV \qquad \boxed{T = 371.7^\circ C}$$

$h_e = 3186.7 \frac{kJ}{kg}$

$P_e = 2.5 \text{ MPa}$ S.H.V. $\boxed{T_e = 376.7^\circ C}$

INTERPOLATE

$v_e = 0.1153 \frac{m^3}{kg}$

USE CONTINUITY TO FIND A_i/A_e:

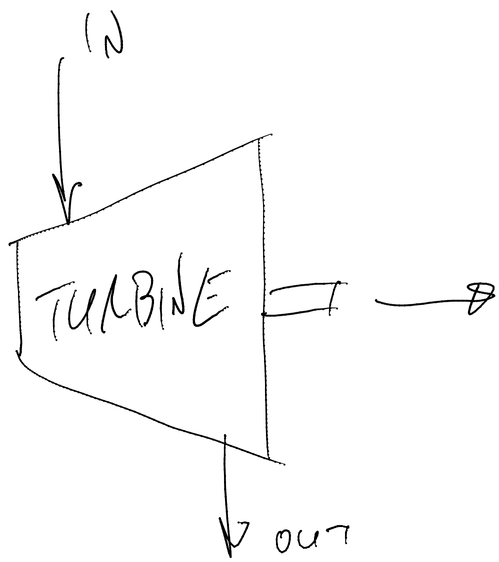
$$\rho_i |\vec{V}_i| A_i = \rho_e |\vec{V}_e| A_e \qquad (\dot{m}_i = \dot{m}_e)$$

$$\frac{A_i}{A_e} = \left(\frac{\rho_e}{\rho_i}\right)\left(\frac{\vec{V}_e}{V_i}\right) \qquad \rho = \frac{1}{v}$$

$$\boxed{\frac{A_i}{A_e}} = \left(\frac{v_i}{v_e}\right)\left(\frac{\vec{V}_e}{\vec{V}_i}\right) = \left(\frac{0.09936}{0.1153}\right)\left(\frac{300}{40}\right) \boxed{= 6.46}$$

Prob. 4-81

4–81 Steam enters an adiabatic turbine at 10 MPa and 400°C and leaves at 20 kPa with a quality of 90 percent. Neglecting the changes in kinetic and potential energies, determine the mass flow rate required for a power output of 5 MW.
Answer: 6.919 kg/s



$\dot{Q} = 0$

$P_i = 10$ MPa, $T_i = 400°C$

$\dot{W}_{cv}$ $P_e = 20$ kPa, $X_e = 0.9$

$\dot{W}_{cv} = 5$ MW

FIND $\dot{m}$

CONTINUITY: $\dot{m}_i = \dot{m}_e$

FIRST LAW: NEGLECT ΔKE, ΔPE

$$\cancel{\dot{Q}}^{0} - \dot{W} = \dot{m}\left[(h_e - h_i) + \cancel{\tfrac{1}{2}(V_e^2 - V_i^2)}^{0} + \cancel{g(z_e - z_i)}^{0}\right]$$

$$\dot{m} = \frac{\dot{W}}{(h_i - h_e)}$$

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

$u = u_f + X(u_g - u_f)$

$s = s_f + X(s_g - s_f)$

INLET: 10 MPa, 400°C, $h_i = 3096.5 \ \frac{kJ}{kg}$

EXIT: $P_e = 20^{kPa} = P_{sat}$

$$h_e = h_f + X_e(h_g - h_f) = h_f + X_e \cdot h_{fg}$$

$$h_e = (251.4) + (0.9)(2358.3) = 2373.9 \ \frac{kJ}{kg}$$

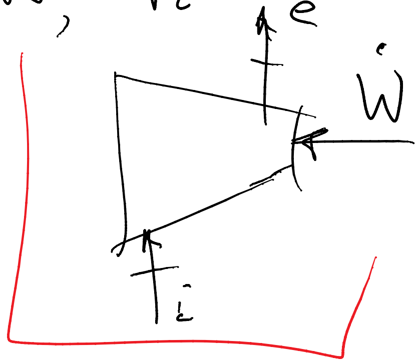
$$\dot{m} = \frac{(+5 \cancel{MW})}{\left(3096.5 - 2373.9 \ \frac{\cancel{kJ}}{kg}\right)} \cdot \left(\frac{1000 \ \cancel{kW}}{\cancel{MW}}\right)\left(\frac{\frac{\cancel{kJ}}{s}}{\cancel{kW}}\right)$$

$$\boxed{\dot{m} = 6.919 \ \frac{kg}{s}}$$

Prob. 4-86

4–86 Refrigerant-134a enters an adiabatic compressor as saturated vapor at −20°C and leaves at 0.7 MPa and 70°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.

R-134a, $\dot{Q} = 0$, $X_i = 1.0$, $T_i = -20^\circ C$, $P_e = 0.7\,\text{MPa}$, $T_e = 70^\circ C$, $\dot{m} = 1.2\,\frac{\text{kg}}{\text{s}}$, FIND $\dot{W}$, $\dot{V}_i$



FIRST LAW: $\cancelto{0}{\dot{Q}} - \dot{W} = \dot{m}(h_e - h_i)$

$\dot{W} = \dot{m}(h_i - h_e)$

$h_i = h_g(T_{sat} = -20^\circ C) = 238.41\,\frac{\text{kJ}}{\text{kg}}$

$h_e(0.7\,\text{MPa}, 70^\circ C) = 308.33\,\frac{\text{kJ}}{\text{kg}}$

$\boxed{\dot{W}} = \left(1.2\,\frac{\text{kg}}{\text{s}}\right)\left[(238.41) - (308.33)\,\frac{\text{kJ}}{\text{kg}}\right] = \boxed{-83.9\,\text{kW}}$

FIND $\dot{V}_i$:

$\boxed{\dot{m}} = \rho(\vec{V} A) = \rho \cdot \dot{V} = \boxed{\frac{\dot{V}}{v}}$ $\qquad \dot{V}_i = \dot{m} \cdot v_i$

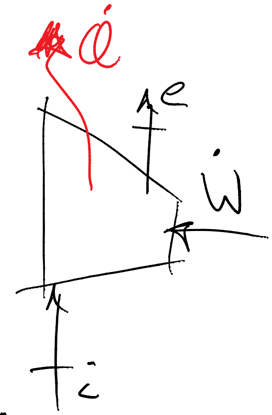
$v_i = v_g(T_{sat} = -20^\circ C) = 0.14729\,\frac{\text{m}^3}{\text{kg}}$

$\boxed{\dot{V}_i} = \left(1.2\,\frac{\text{kg}}{\text{s}}\right)\left(0.14729\,\frac{\text{m}^3}{\text{kg}}\right) = \boxed{0.1770\,\frac{\text{m}^3}{\text{s}}}$

$$\dot{V}_e = \dot{m} \cdot v_e$$

Prob. 4-88E

4–88E Air is compressed from 14.7 psia and 60°F to a pressure of 150 psia while being cooled at a rate of 10 Btu/lbm by circulating water through the compressor casing. The volume flow rate of the air at the inlet conditions is 5000 ft^3/min, and the power input to the compressor is 700 hp. Determine (*a*) the mass flow rate of the air and (*b*) the temperature at the compressor exit. *Answers:* (*a*) 6.36 lbm/s, (*b*) 801 R



$P_i = 14.7$ PSIA, $T_i = 60°F$, $P_e = 150$ PSIA, $\dot{q} = \dfrac{\dot{Q}}{\dot{m}} = -10 \dfrac{\text{Btu}}{\text{LBM}}$

$\dot{q}$ = SPECIFIC RATE OF HEAT TRANSFER

$\dot{V}_i = 5000 \dfrac{\text{ft}^3}{\text{MIN}}$, $\dot{W} = (-700 \text{ HP})\left(\dfrac{42.41 \text{ BTU/MIN}}{\text{HP}}\right) = -29{,}687 \dfrac{\text{Btu}}{\text{MIN}}$

FIND $\dot{m}$, T_e

$$\dot{m} = \rho \vec{V} A = \rho \dot{V} = \frac{\dot{V}_i}{v_i}$$

PERFECT GAS: $Pv = RT$, $v_i = \dfrac{RT_i}{P_i}$

$$\boxed{\dot{m} = \frac{\dot{V}_i P_i}{R\, T_i}} \quad \frac{\left(5000 \frac{\text{ft}^3}{\text{MIN}}\right)(14.7 \text{ PSIA})}{\left(0.3704 \frac{\text{PSIA}\cdot\text{ft}^3}{\text{LBM}\cdot°\text{R}}\right)(60 + 460\,°\text{R})} = \boxed{381.6 \frac{\text{LBM}}{\text{MIN}}}$$

FIRST LAW: $\dot{Q} - \dot{W} = \dot{m}(h_e - h_i)$

$$h_e = h_i + \frac{(\dot{Q} - \dot{W})}{\dot{m}} = h_i + \dot{q} - \frac{\dot{W}}{\dot{m}}$$

$\dot{q}$ = SPECIFIC HEAT TRANSFER RATE

$$T_i = 60°F + 460°R = 520°R$$

$$h_i(520°R) = 124.27\ \frac{Btu}{LBM} \quad (\text{TABLE A-17E})$$

$$h_e = \left(124.27\ \frac{Btu}{LBM}\right) + \left(-10\ \frac{Btu}{LBM}\right) - \frac{\left(-29{,}687\ \frac{Btu}{MIN}\right)}{\left(381.6\ \frac{LBM}{MIN}\right)}$$

$$h_e = 192.1\ \frac{Btu}{LBM} \Rightarrow \text{TABLE A-17E}$$

$$\boxed{T_e \simeq 800°R = 340°F}$$

ASSUME CONSTANT SPECIFIC HEAT:

$$\dot{Q} - \dot{W} = \dot{m}(h_e - h_i)$$

$$\Delta h = C_p \Delta T \quad \text{OR} \quad h_e - h_i = C_p(T_e - T_i)$$

$$\dot{Q} - \dot{W} = \dot{m} C_p (T_e - T_i)$$

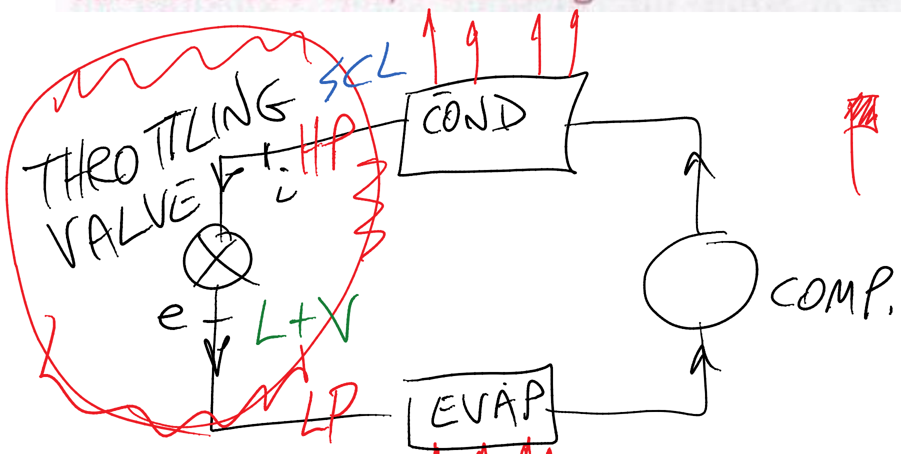
$$T_e = T_i + \frac{(\dot{Q} - \dot{W})}{\dot{m} C_p} = T_i + \frac{\dot{q}}{C_p} - \frac{\dot{W}}{\dot{m} C_p}$$

$$T_e = (60 + 460°R) + \left(\frac{-10\ \frac{Btu}{LBM}}{0.240\ \frac{Btu}{LBM \cdot °R}}\right) - \left[\frac{\left(-29{,}687\ \frac{Btu}{MIN}\right)}{\left(381.6\ \frac{LBM}{MIN}\right)\left(0.240\ \frac{Btu}{LBM \cdot R}\right)}\right]$$

$$\boxed{T_e = 802°R = 342°F}$$

Prob. 4-97

4–97 EES Refrigerant-134a at 800 kPa and 25°C is throttled to a temperature of −20°C. Determine the pressure and the internal energy of the refrigerant at the final state. *Answers:* 133 kPa, 78.8 kJ/kg



R-134a, $P_i = 800$ kPa, $T_i = 25°C$, $T_e = -20°C$

FIND P_e, u_e

FIRST LAW: NEGLECT ΔKE, ΔPE,

$$\cancel{\dot{Q}}^{0} - \cancel{\dot{W}}^{0} = \dot{m}(h_e - h_i)$$

FOR A THROTTLING PROCESS, $\dot{Q} = 0$, $\dot{W} = 0$

$$\boxed{h_e = h_i} \ * \quad \text{FIRST LAW}$$

@ $P_i = 800$ kPa, $T_i = 25°C$, SUBCOOLED LIQUID

$$h_i = h_f(T_{sat} = 25°C) = 84.33 \ \frac{kJ}{kg}$$

$$\boxed{h_e} = h_i = \boxed{84.33 \ \frac{kJ}{kg}}, \quad T_e = -20°C$$

@ $T_{sat} = -20°C$: $h_f = 24.26 \ \frac{kJ}{kg}$, $h_g = 235.31 \ \frac{kJ}{kg}$

∴ SATURATED MIXTURE

∴ SATURATED MIXTURE

$$\boxed{P_e} = P_{sat}(T_{sat} = -20^\circ C) = \boxed{133 \text{ kPa}}$$

$$u_e = u_f + x_e \cdot u_{fg}$$

FIND EXIT QUALITY:

$$h_e = h_f + x_e h_{fg}$$

$$x_e = \frac{h_e - h_f}{h_{fg}} = \frac{84.33 - 24.26}{211.05} = 0.285$$

$$\boxed{u_e} = (24.17) + (0.285)(215.84 - 24.17) = \boxed{78.7 \ \frac{kJ}{kg}}$$

Prob. 4-112

4–112 Refrigerant-134a at 800 kPa, 70°C, and 8 kg/min is cooled by water in a condenser until it exists as a saturated liquid at the same pressure. The cooling water enters the condenser at 300 kPa and 15°C and leaves at 30°C at the same pressure. Determine the mass flow rate of the cooling water required to cool the refrigerant. *Answer:* 27.0 kg/min

R-134a

$P_i = 800$ kPa

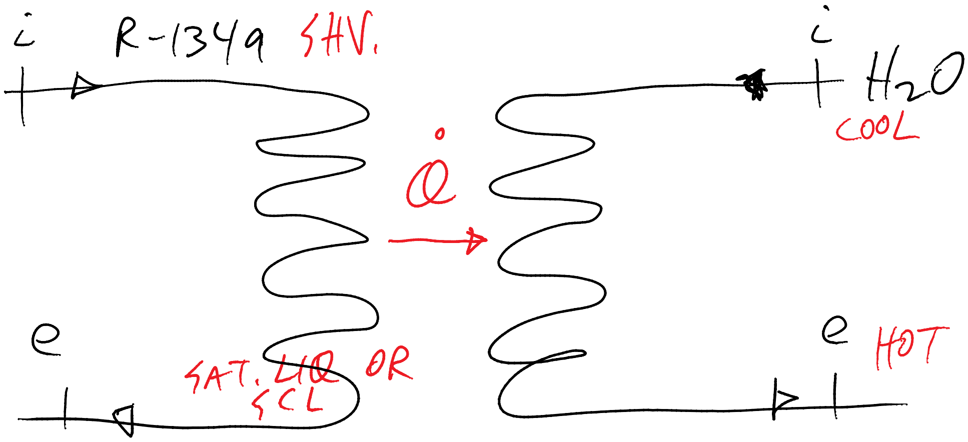
$T_i = 70°C$

$\dot{m} = 8 \frac{kg}{MIN}$

$\dot{m} = 0.1333 \frac{kg}{s}$

$P_e = P_i = 800$ kPa

$X_e = 0$



H_2O) $P_i = 300$ kPa, $T_i = 15°C$, $P_e = P_i = 300$ kPa

$T_e = 30°C$

FIND $\dot{m}_{H_2O}$

FIRST LAW FOR R-134a

$$\dot{Q} - \cancel{\dot{W}}^{\,0} = \dot{m}(h_e - h_i)$$

$$\dot{Q} = \dot{m}(h_e - h_i) \ *$$

$h_i = 305.5 \frac{kJ}{kg}$, $h_e = h_f = 93.42 \frac{kJ}{kg}$

$$\boxed{\dot{Q} =} \left(0.1333 \frac{kg}{s}\right)\left(93.42 - 305.5 \frac{kJ}{kg}\right) = \boxed{-28.28 \text{ kW}}$$

HEAT GAINED BY H_2O: $\dot{Q} = +28.28$ kW

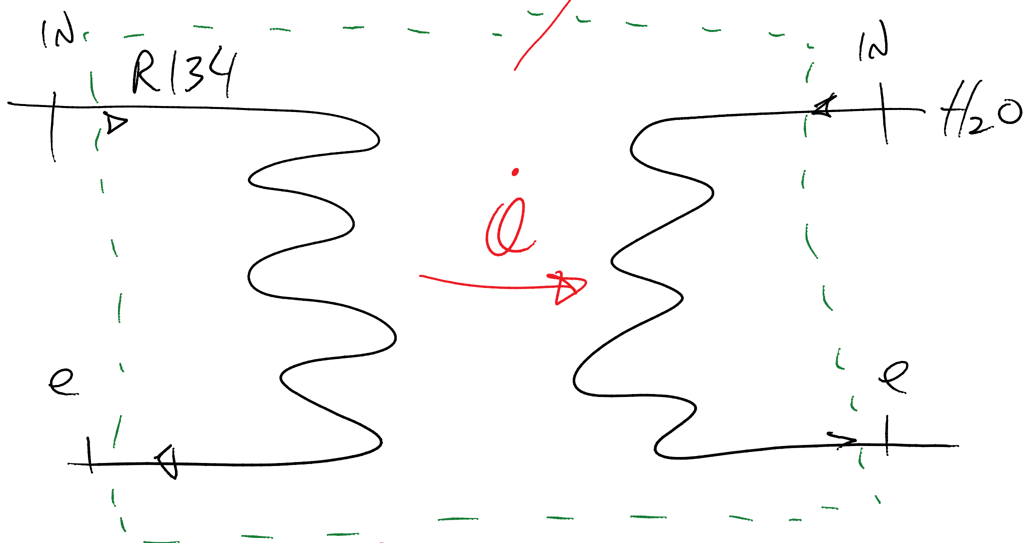
FIRST LAW FOR H_2O:

$$\dot{Q} = \dot{m}(h_e - h_i) = \dot{m}\, C_p (T_e - T_i)$$

$$\dot{m}_{H_2O} = \frac{\dot{Q}}{C_p(T_e - T_i)} = \frac{(+28.28\ \text{kW})}{\left(4.18\ \frac{\text{kJ}}{\text{kg-K}}\right)(30-15\ \text{K})}$$

$$\boxed{\dot{m}_{H_2O} = 0.451\ \frac{\text{kg}}{\text{s}}}$$

$\dot{Q} = 0$ (ADIABATIC TO ATMOSPHERE)



$$\sum \cancel{\dot{Q}}^{\,0} - \sum \cancel{\dot{W}}^{\,0} = \sum \dot{m}_e h_e - \sum \dot{m}_i h_i$$

$$\dot{m}_{e,R} \cdot h_{e,R} + \dot{m}_{e,w} \cdot h_{e,w} - (\dot{m}_{i,R} h_{i,R} + \dot{m}_{i,w} \cdot h_{i,w}) = 0$$

$$\dot{m}_{e,R} = \dot{m}_{i,R}, \quad \dot{m}_{e,w} = \dot{m}_{i,w}$$

$$\dot{m}_R (h_{e,R} - h_{i,R}) + \dot{m}_w (h_{e,w} - h_{i,w}) = 0$$

$$\dot{m}_R (h_{e,R} - h_{i,R}) + \dot{m}_w\, C_{p,w} (T_{e,w} - T_{i,w}) = 0$$

$$\dot{m}_W = \frac{\dot{m}_R(h_{i,R} - h_{e,R})}{c_{pW}(T_{e,W} - T_{i,W})}$$

Prob. 4-124E

4–124E Steam is to be condensed on the shell side of a heat exchanger at 90°F. Cooling water enters the tubes at 60°F at a rate of 115.3 lbm/s and leaves at 73°F. Assuming the heat exchanger to be well-insulated, determine the rate of heat transfer in the heat exchanger and the rate of condensation of the steam.

Prob. 4-144E

4–144E Air enters the duct of an air-conditioning system at 15 psia and 50°F at a volume flow rate of 450 ft³/min. The diameter of the duct is 10 in., and heat is transferred to the air in the duct from the surroundings at a rate of 2 Btu/s. Determine (*a*) the velocity of the air at the duct inlet and (*b*) the temperature of the air at the exit.

$P_i = 15$ PSIA

$T_i = 50°F$

$\dot{V}_i = 450 \frac{ft^3}{MIN}$

$D = 10$ IN

$\dot{Q} = +2 \frac{Btu}{s}$

FIND $\vec{V}_i$, T_e

$$\dot{m} = \rho \vec{V} A, \quad \dot{V} = \vec{V} A, \quad \vec{V}_i = \frac{\dot{V}_i}{A}, \quad A = \frac{\pi}{4} D^2$$

$$\boxed{\vec{V}_i} = \frac{4 \dot{V}_i}{\pi D^2} = \frac{4\left(450 \frac{ft^3}{MIN}\right)}{\pi (10^{IN})^2 \left(\frac{ft}{12^{IN}}\right)^2} = \boxed{825 \frac{ft}{MIN}}$$

FIND T_e: FIRST LAW: $\dot{Q} - \cancel{\dot{W}}^{\,0} = \dot{m}(h_e - h_i)$

FOR A PERFECT GAS, $\Delta h = C_p \Delta T$

$h_e - h_i = C_p (T_e - T_i)$ ASSUME C_p = CONSTANT

$$\dot{Q} = \dot{m} C_p (T_e - T_i) \ *$$

$$T_e = T_i + \frac{\dot{Q}}{\dot{m} C_p}$$

FIND $\dot{m}$: $\dot{m} = \rho \vec{V} A = \rho \dot{V} = \frac{\dot{V}}{v}$

$Pv = RT$ PERFECT GAS

$Pv = RT$ PERFECT GAS

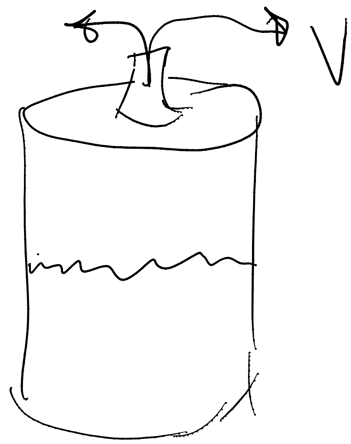
$$v = \frac{RT}{P} = \frac{\left(0.3704\ \frac{PSIA \cdot ft^3}{LBM \cdot {}^\circ R}\right)\left(50 + 460^\circ R\right)}{\left(15\ PSIA\right)} = 12.59\ \frac{ft^3}{LBM}$$

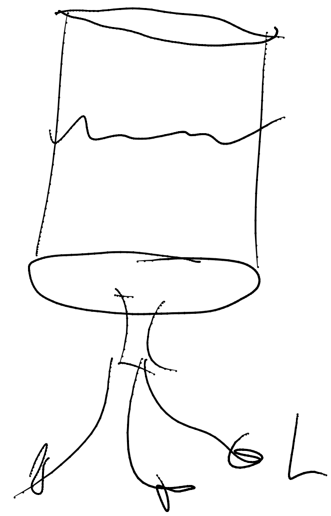
$$\dot{m} = \frac{\left(450\ \frac{ft^3}{MIN}\right)}{\left(12.59\ \frac{ft^3}{LBM}\right)} \cdot \left(\frac{MIN}{60\ s}\right) = 0.596\ \frac{LBM}{s}$$

$$\boxed{T_e} = \left(50^\circ F\right) + \frac{\left(2\ \frac{\cancel{BTU}}{\cancel{s}}\right)}{\left(0.596\ \frac{\cancel{LBM}}{\cancel{s}}\right)\left(0.240\ \frac{\cancel{BTU}}{\cancel{LBM} \cdot R}\right)} = \boxed{63.98^\circ F}$$

$$T_e = \left(50 + 460^\circ R\right) + \frac{(2)}{(0.596)(0.240)}\ {}^\circ R$$

$T_e =$





CONTINUITY EQN.

$$m_{in} - m_{out} = \Delta m_{SYSTEM}$$

FOR MULTIPLE INLETS/OUTLETS,

$$\sum m_i - \sum m_e = (m_2 - m_1)_{SYSTEM}$$

RATE EQUATION:

$$\dot{m}_{in} - \dot{m}_{out} = \frac{d}{dt}(m_{SYSTEM})$$

FIRST LAW: CONSERVATION OF ENERGY

$$Q - W = \sum m_e(h_e + KE_e + PE_e) - \sum m_i(h_i + KE_e + PE_e)$$

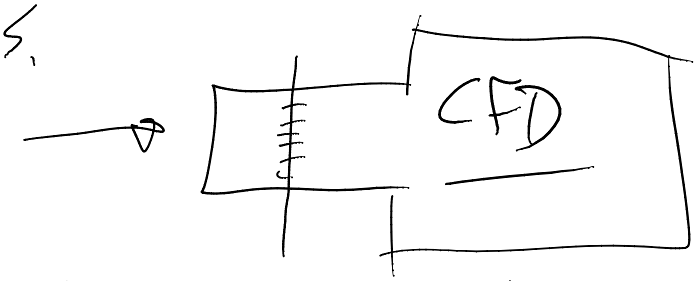
$$+ \Delta E_{SYSTEM}$$

RATE EQUATION:

$$\dot{Q} - \dot{W} = \sum \dot{m}_e(h_e + \cdots) - \sum \dot{m}_i(h_i + \cdots) + \frac{d}{dt}(E_{SYSTEM})$$

UNIFORM-FLOW PROCESS

THIS IDEALIZED CASE IS USEFUL IN CHARGING OR DISCHARGING OPERATIONS.



ASSUMPTIONS:

- THE PROPERTIES WITHIN THE C.V. ARE UNIFORM AT ANY GIVEN INSTANT.
- INLET/OUTLET PROPERTIES ARE STEADY AND UNIFORM ACROSS THE INLET/OUTLET CROSS SECTIONS.

FIRST LAW FOR UNIFORM-FLOW PROCESS:

$$\underbrace{Q - W}_{\text{HEAT/WORK}} = \underbrace{\sum m_e h_e - \sum m_i h_i}_{\text{ENTHALPY CONVECTED}} + \underbrace{\left(m_2 u_2 - m_1 u_1\right)_{CV}}_{\text{CHANGE IN INTERNAL ENERGY WITHIN THE CONTROL VOLUME}}$$

Unsteady Questions

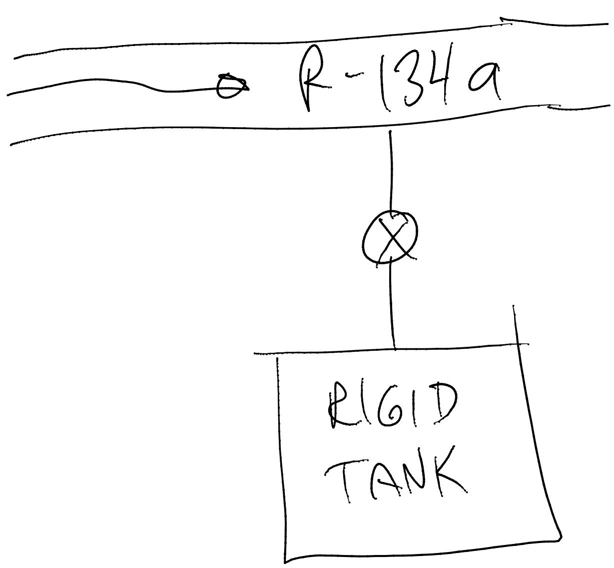
4-94C The valve of an initially evacuated, adiabatic rigid tank is opened, and air at 30°C flows in. When the pressure inside the tank reaches atmospheric pressure, the air temperature in the tank increases to 150°C. Explain what caused this temperature rise.

4-95C When a can that contains a refrigerant at 500 kPa and 25°C is slightly opened and refrigerant is allowed to escape, a layer of ice forms outside the can. Explain how that happens.

4-96C The valve of an insulated rigid vessel containing air at a high pressure is slightly opened, allowing some air to escape. Will the temperature of air in the tank change during this process? How?

Prob. 4-150

4–150 A 0.2-m^3 rigid tank initially contains refrigerant-134a at 8°C. At this state, 60 percent of the mass is in the vapor phase, and the rest is in the liquid phase. The tank is connected by a valve to a supply line where refrigerant at 1 MPa and 120°C flows steadily. Now the valve is opened slightly, and the refrigerant is allowed to enter the tank. When the pressure in the tank reaches 800 kPa, the entire refrigerant in the tank exists in the vapor phase only. At this point the valve is closed. Determine (*a*) the final temperature in the tank, (*b*) the mass of refrigerant that has entered the tank, and (*c*) the heat transfer between the system and the surroundings.



$V = 0.2^{m^3}$, R-134a,

$T_1 = 8°C$

$\frac{m_g}{m_T} = 0.6 = X_1$

$P_i = 1^{MPa}$, $T_i = 120°C$

$P_2 = 800^{kPa}$, $X_2 = 1.0$

FIND T_2, m_i, Q

ASSUME UNIFORM-FLOW PROCESS.

CONTINUITY:

$$m_i - \cancel{m_e}^{\,0} = m_2 - m_1 \Rightarrow m_i = m_2 - m_1$$

FIRST LAW:

$$Q - \cancel{W}^{\,0} = \cancel{m_e h_e}^{\,0} - m_i h_i + m_2 u_2 - m_1 u_1$$

$$Q = -m_i h_i + m_2 u_2 - m_1 u_1$$

FIND T_2: $P_2 = P_{sat} = 800\ kPa$ $(X_2 = 1.0)$

$$\boxed{T_2} = T_{sat}(P_{sat} = 800\ kPa) = \boxed{31.33°C}$$

FIND $m_i = m_2 - m_1$

$$v = \frac{V}{m}, \quad m = \frac{V}{v}$$

$$m_1 = \frac{V}{v_1}, \quad m_2 = \frac{V}{v_2}$$

$$v_1 = v_f + X_1(v_g - v_f)$$

$$v_1 = (0.0007884) + (0.6)(0.0525 - 0.0007884) = 0.03182\ \frac{m^3}{kg}$$

$$v_2 = v_g\left(P_{sat} = 800\ kPa\right) = 0.02550\ \frac{m^3}{kg}$$

$$m_i = \frac{V}{v_2} - \frac{V}{v_1} = V\left(\frac{1}{v_2} - \frac{1}{v_1}\right)$$

$$\boxed{m_i} = \left(0.2\ m^3\right)\left(\frac{1}{0.0255} - \frac{1}{0.03182}\ \frac{kg}{m^3}\right) = \boxed{1.558\ kg}$$

FIND $Q = -m_i h_i + m_2 u_2 - m_1 u_1$

$$h_i\left(1\ MPa,\ 120^\circ C\right) = 356.52\ \frac{kJ}{kg}$$

$$u_2 = u_g\left(800\ kPa\right) = 243.78\ \frac{kJ}{kg}$$

$$u_1 = u_f + x_1\left(u_g - u_f\right)$$

$$u_1 = (60.43) - (0.6)(231.46 - 60.43) = 163.0\ \frac{kJ}{kg}$$

$$Q = -\left(1.558\ kg\right)\left(356.52\ \frac{kJ}{kg}\right) + \left(\frac{0.2}{0.0255}\ kg\right)\left(243.78\ \frac{kJ}{kg}\right)$$

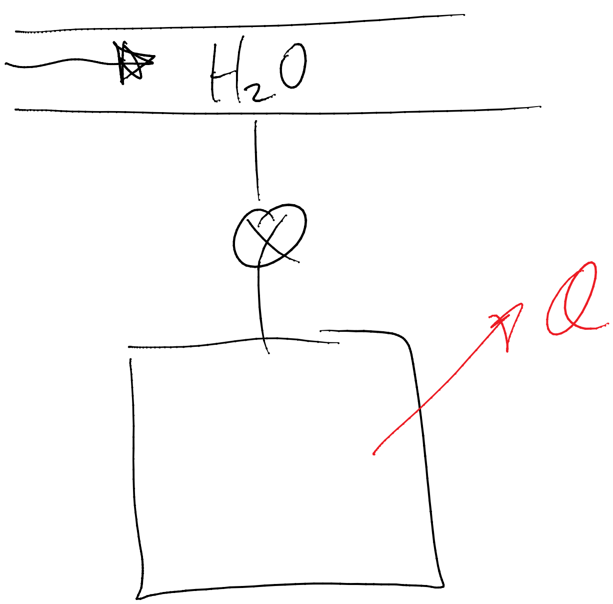
$$- \left(\frac{0.2}{0.03182}\ kg\right)\left(163.0\ \frac{kJ}{kg}\right)$$

$$\boxed{Q = +332\ \text{kJ}}$$

Prob. 4-151E

4–151E A 4-ft³ rigid tank initially contains saturated water vapor at 250°F. The tank is connected by a valve to a supply line that carries steam at 160 psia and 400°F. Now the valve is opened, and steam is allowed to enter the tank. Heat transfer takes place with the surroundings such that the temperature in the tank remains constant at 250°F at all times. The valve is closed when it is observed that one-half of the volume of the tank is occupied by liquid water. Find (*a*) the final pressure in the tank, (*b*) the amount of steam that has entered the tank, and (*c*) the amount of heat transfer.

Answers: (*a*) 29.82 psia, (*b*) 117.5 lbm, (*c*) 117,540 Btu



$V = 4\ ft^3$, $X_1 = 1.0$,

$T_1 = 250°F = T_2$

$P_i = 160$ PSIA, $T_i = 400°F$

$V_{2,f} = 2\ ft^3$

FIND P_2, m_i, Q

STATE 2: $\boxed{P_2} = P_{sat}(T_{sat} = 250°F) = \boxed{29.82\ \text{PSIA}}$

CONTINUITY: $m_i - \cancel{m_e}^{\,0} = m_2 - m_1$

CONTINUITY: $m_i - \cancel{m_e} = m_2 - m_1$

FIND m_1: $v_1 = v_g(T_1 = 250°F) = 13.826 \frac{ft^3}{LBM}$

$$\boxed{m_1} = \frac{V}{v_1} = \frac{(4\ ft^3)}{\left(13.826 \frac{ft^3}{LBM}\right)} = \boxed{0.2893\ LBM}$$

FIND $m_2 = m_{f,2} + m_{g,2}$

$$m_{f,2} = \frac{V_{f,2}}{v_f} = \frac{(2\ ft^3)}{\left(0.017001 \frac{ft^3}{LBM}\right)} = 117.6\ LBM$$ SAT. LIQ.

$$m_{g,2} = \frac{V_{g,2}}{v_g} = \frac{(2\ ft^3)}{\left(13.826 \frac{ft^3}{LBM}\right)} = 0.1446\ LBM$$ SAT. VAP.

$$\boxed{m_2} = (117.6) + (0.1446) = \boxed{117.7\ LBM}$$

$$\boxed{m_i} = 117.7 - 0.2893 = \boxed{117.4\ LBM}$$

FIND Q: FIRST LAW

$$Q - \cancelto{0}{W} = \cancelto{0}{\sum m_e h_e} - \sum m_i h_i + m_2 u_2 - m_1 u_1$$

$$Q - \cancel{W} = \sum \cancel{m_e h_e} - \sum m_i h_i + m_2 u_2 - m_1 u_1$$

$$Q = -m_i h_i + m_2 u_2 - m_1 u_1$$

$$h_i = 1217.8 \ \frac{\text{Btu}}{\text{LBM}} \quad (400^\circ\text{F}, 160 \ \text{PSIA})$$

$$u_1 = u_g(250^\circ\text{F}) = 1087.9 \ \frac{\text{Btu}}{\text{LBM}}$$

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

$$x_2 = \frac{m_g}{m_T} = \frac{0.1446}{117.7} = 0.001228$$

$$u_2 = (218.49) + (0.001228)(869.4) = 219.5 \ \frac{\text{Btu}}{\text{LBM}}$$

$$Q = -(117.4 \ \text{LBM})\left(1217.8 \ \frac{\text{Btu}}{\text{LBM}}\right) + (117.7)(219.5)$$

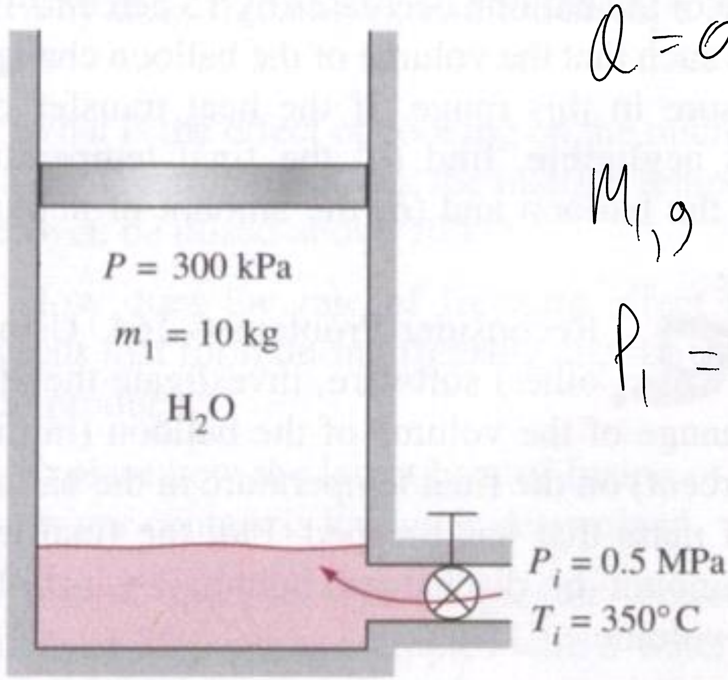
$$- (0.2893)(1087.9)$$

$$\boxed{Q = -117{,}400 \ \text{Btu}}$$

HEAT LEAVES TANK

Prob. 4-153

4–153 An insulated, vertical piston-cylinder device initially contains 10 kg of water, 8 kg of which is in the vapor phase. The mass of the piston is such that it maintains a constant pressure of 300 kPa inside the cylinder. Now steam at 0.5 MPa and 350°C is allowed to enter the cylinder from a supply line until all the liquid in the cylinder has vaporized. Determine (*a*) the final temperature in the cylinder and (*b*) the mass of the steam that has entered. *Answers:* (*a*) 133.6°C, (*b*) 9.78 kg



$Q = 0$, $m_1 = 10\ \text{kg}$,

$m_{1,g} = 8\ \text{kg}$, H_2O

$P_1 = P_2 = 300\ \text{kPa}$

$P_i = 0.5\ \text{MPa}$

$T_i = 350°C$

$X_2 = 1.0$ (SAT. VAPOR)

FIND T_2, m_i

$$\boxed{T_2} = T_{sat}(P_{sat} = 300\ \text{kPa}) = \boxed{133.52°C}$$

CONTINUITY: $m_i - \cancel{m_e}^{\,0} = m_2 - m_1$

$m_i = m_2 - m_1$

FIRST LAW!

$$\cancelto{0}{Q} - W = \cancelto{0}{m_e h_e} - m_i h_i + m_2 u_2 - m_1 u_1$$

BOUNDARY WORK: CONSTANT PRESSURE PROCESS

$$W = \int_1^2 P\,dV = P(V_2 - V_1)$$

$$-P(V_2 - V_1) = -m_i h_i + m_2 u_2 - m_1 u_1$$

$$m_i = m_2 - m_1 \quad \text{CONTINUITY}$$

$$P(V_1 - V_2) = -(m_2 - m_1) h_i + m_2 u_2 - m_1 u_1$$

$$PV_1 - PV_2 = -m_2 h_i + m_1 h_i + m_2 u_2 - m_1 u_1$$

$$PV_1 - PV_2 = m_2(u_2 - h_i) + m_1(h_i - u_1)$$

$$m_2 = \frac{V_2}{v_2}$$

$$PV_1 - PV_2 = \left(\frac{V_2}{v_2}\right)(u_2 - h_i) + m_1(h_i - u_1)$$

$$V_2 = \frac{PV_1 + m_1(u_1 - h_i)}{P + \frac{(u_2 - h_i)}{v_2}}$$

$$V_1 = m_1 v_1$$

$$v_1 = v_f + x_1(v_g - v_f)$$

$$x_1 = \frac{m_{g,1}}{m_{T,1}} = \frac{8}{10} = 0.8$$

$$v_1 = (0.0001073) + (0.8)(0.60582 - 0.0001073) = 0.4849 \ \frac{m^3}{kg}$$

$$V_1 = (10\ kg)\left(0.4849\ \frac{m^3}{kg}\right) = 4.849\ m^3$$

$$u_1 = u_f + x_1 u_{fg} = (561.1) + (0.8)(1982) = 2147\ \frac{kJ}{kg}$$

$$V_2 = \frac{\left\{(300\ kPa)(4.849\ m^3) + (10\ kg)\left[(2147) - (3168)\ \frac{kJ}{kg}\right]\right\}}{\left\{(300\ kPa) + \frac{\left[(2543) - (3168)\ \frac{kJ}{kg}\right]}{}\right\}}$$

ν_2

$$\left\{ \left(300\,kPa\right) + \frac{\left[(2543) - (3168)\right]\frac{kJ}{kg}}{\left(0.60582\,\frac{m^3}{kg}\right)} \right\}$$

$$\boxed{V_2 = 11.96\,m^3}$$

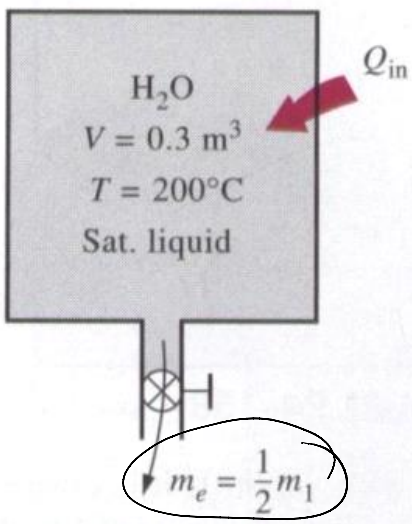
FIND $M_i = M_2 - M_1$

$$M_2 = \frac{V_2}{\nu_2} = \frac{\left(11.96\,m^3\right)}{\left(0.60582\,\frac{m^3}{kg}\right)} = 19.75\,kg$$

$$\boxed{M_i} = 19.75 - 10 = \boxed{9.75\,kg}$$

Prob. 4-155

4–155 A 0.3-m^3 rigid tank is filled with saturated liquid water at 200°C. A valve at the bottom of the tank is opened, and liquid is withdrawn from the tank. Heat is transferred to the water such that the temperature in the tank remains constant. Determine the amount of heat that must be transferred by the time one-half of the total mass has been withdrawn.



$V = 0.3\ m^3$, $X_1 = 0$, H_2O

$T_1 = 200°C$

$X_e = 0.0$, $T_2 = T_1$

$M_2 = \frac{1}{2} M_1$

FIND Q

CONTINUITY : CONSERVE MASS

$$M_i^{\nearrow 0} - M_e = M_2 - M_1$$

$$\boxed{M_e} = M_1 - M_2 = M_1 - \left(\tfrac{1}{2} M_1\right) = \boxed{\tfrac{1}{2} M_1}$$

FIND M_1 : $v = \frac{V}{m_1}$, $M_1 = \frac{V}{v_1}$

$$v_1 = v_f(T_{sat} = 200°C) = 0.001157\ \frac{m^3}{kg}$$

$$M_1 = \frac{(0.3\ m^3)}{\left(0.001157\ \frac{m^3}{kg}\right)} = 259.3\ kg$$

$$m_e = \frac{1}{2} m_1 = \frac{1}{2}\left(259.3\ \text{kg}\right) = 129.6\ \text{kg}$$

$$m_2 = \frac{1}{2} m_1 = 129.6\ \text{kg}$$

FIRST LAW:

$$\underbrace{Q - \cancelto{0}{W}}_{\text{HEAT/WORK}} = \underbrace{m_e h_e}_{\substack{\text{NRG}\\ \text{EXITING}}} - \underbrace{\cancelto{0}{m_i h_i}}_{\substack{\text{NRG}\\ \text{ENTERING}}} + \boxed{\overbrace{m_2 u_2}^{\substack{\text{NRG CV}\\ \text{FINAL}}} - \underbrace{m_1 u_1}_{\substack{\text{NRG CV}\\ \text{INITIAL}}}}$$

$$Q = m_e h_e + m_2 u_2 - m_1 u_1$$

$$Q = \left(\frac{1}{2} m_1\right) h_e + \left(\frac{1}{2} m_1\right) u_2 - m_1 u_1$$

$$Q = m_1\left(\frac{1}{2} h_e + \frac{1}{2} u_2 - u_1\right) \qquad h = \frac{H}{m},\ u = \frac{U}{m}$$

$$h_e = h_f\left(T_{sat} = 200^\circ C\right) = 852.26\ \frac{\text{kJ}}{\text{kg}}$$

$$u_1 = u_f\left(T_{sat} = 200^\circ C\right) = 850.46\ \frac{\text{kJ}}{\text{kg}}$$

$$u_2 = u_f + x_2 u_{fg}$$

$$v_2 = v_f + x_2\left(v_g - v_f\right)$$

$$x_2 = \frac{v_2 - v_f}{v_g - v_f}$$

$$v_2 = \frac{V}{M_2} = \frac{(0.3\ m^3)}{(129.6\ kg)} = 0.002314\ \frac{m^3}{kg}$$

$$X_2 = \frac{(0.002314) - (0.001157)}{(0.12721) - (0.001157)} = 0.009179$$

$$u_2 = (850.46) + (0.009179)(1743.7) = 866.5\ \frac{kJ}{kg}$$

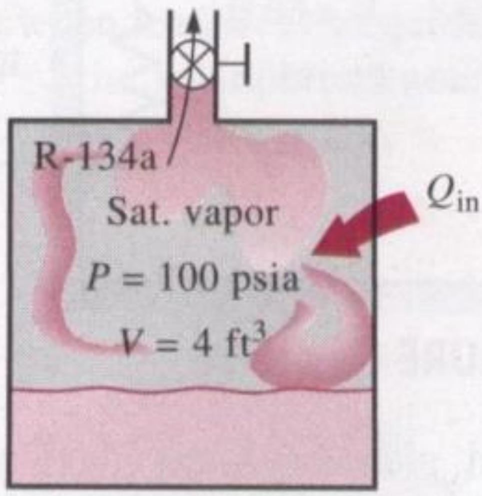
$$\frac{16}{866}$$

$$Q = (259.3\ kg)\left[\frac{1}{2}(852.26) + \frac{1}{2}(866.5) - (850.46)\ \frac{kJ}{kg}\right]$$

$$\boxed{Q = 2313\ kJ}$$

Prob. 4-157E

4–157E A 4-ft³ rigid tank contains saturated refrigerant-134a at 100 psia. Initially, 20 percent of the volume is occupied by liquid and the rest by vapor. A valve at the top of the tank is now opened, and vapor is allowed to escape slowly from the tank. Heat is transferred to the refrigerant such that the pressure inside the tank remains constant. The valve is closed when the last drop of liquid in the tank is vaporized. Determine the total heat transfer for this process.



$V = 4\ ft^3$, R-134a

$P_1 = 100$ PSIA $= P_2$

$x = \dfrac{m_g}{m_T}$

$\dfrac{V_f}{V} = 0.2$, $\dfrac{V_g}{V} = 0.8$

$x_e = x_2 = 1.0$ SAT. VAPOR

FIND Q

CONTINUITY:

$\cancel{m_i}^{\,0} - m_e = m_2 - m_1$ ✗

$m_1 = m_f + m_g$

$v = \dfrac{V}{m}$, $m = \dfrac{V}{v}$

$m_1 = \dfrac{V_f}{v_f} + \dfrac{V_g}{v_g} = \dfrac{0.2V}{v_f} + \dfrac{0.8V}{v_g}$

LIQUID

$m_1 = \dfrac{0.2(4\ ft^3)}{\ } + \dfrac{0.8(4\ ft^3)}{\ }$

$$m_1 = \boxed{\frac{0.2(4\,ft^3)}{\left(0.01332\,\frac{ft^3}{LBM}\right)}} + \boxed{\frac{0.8(4\,ft^3)}{\left(0.4747\,\frac{ft^3}{LBM}\right)}} = 60.06 + 6.74$$

VAPOR

$$m_1 = 66.8\ LB$$

$$X_1 = \frac{m_{g,1}}{m_{T,1}} = \frac{6.74}{66.8}$$

$$m_2 = \frac{V}{v_2}$$

$$v_2 = v_g(100\ PSIA) = 0.4747\ \frac{ft^3}{LBM}$$

$$m_2 = \frac{(4\,ft^3)}{\left(0.4747\,\frac{ft^3}{LBM}\right)} = 8.426\ LBM$$

$$m_e = m_1 - m_2 = 66.8 - 8.426 = 58.37\ LBM$$

FIRST LAW:

$$Q - \cancelto{0}{W} = m_e h_e - \cancelto{0}{m_i h_i} + m_2 u_2 - m_1 u_1$$

$$Q = m_e h_e + m_2 u_2 - m_1 u_1$$

$$h_e = h_g(100\ PSIA) = 112.46\ \frac{Btu}{LBM}$$

$$u_2 = u_g(100\ PSIA) = 103.68\ \frac{Btu}{LBM}$$

$$u_1 = u_f + x_1 u_{fg}$$

$$x_1 = \frac{m_{g,1}}{m_{T,1}} = \frac{6.74}{66.8} = 0.1009$$

$$u_1 = (37.62) + (0.1009)(104.99 - 37.64) = 44.42 \ \frac{Btu}{LBM}$$

$$Q = (58.37)(112.46) + (8.426)(103.68) - (66.8)(44.42)$$

$$\boxed{Q = 4474 \ Btu}$$

Prob. 4-159

4–159 A 4-L pressure cooker has an operating pressure of 175 kPa. Initially, one-half of the volume is filled with liquid and the other half with vapor. If it is desired that the pressure cooker not run out of liquid water for 1 h, determine the highest rate of heat transfer allowed.

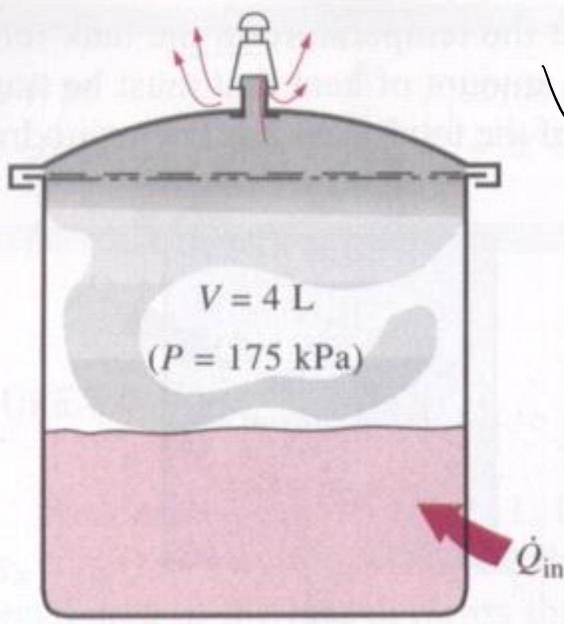


FIGURE P4–159

$V = (4^{L})\left(\frac{m^3}{1000^{L}}\right) = 0.004 \; m^3$

$P_1 = P_2 = 175 \; kPa$

$V_{f,1} = V_{g,1} = \frac{1}{2}V = 0.002 \; m^3$

$t = 1^{HR} = 3600^{s}$

$X_2 = 1.0$ SAT. VAPOR

FIND $\dot{Q}$

CONTINUITY: $\cancel{M_i}^{0} - M_e = M_2 - M_1$

$M_e = M_1 - M_2$

FIND M_1, M_2: $\quad v = \frac{V}{M}, \quad M = \frac{V}{v}$

$M_{f,1} = \frac{V_{f,1}}{v_{f,1}} = \frac{(0.002 \; m^3)}{(0.001057 \; \frac{m^3}{kg})} = 1.892 \; kg$

$M_{g,1} = \frac{V_{g,1}}{v_{g,1}} = \frac{(0.002 \; m^3)}{(1.0037 \; \frac{m^3}{kg})} = 0.001993 \; kg$

$$m_1 = m_{f,1} + m_{g,1} = 1.894 \text{ kg}$$

$$m_2 = \frac{V}{v_2}$$

$$v_2 = v_g\left(P_{sat} = 175 \text{ kPa}\right) = 1.0037 \frac{m^3}{kg}$$

$$m_2 = \frac{\left(0.004 \text{ m}^3\right)}{\left(1.0037 \frac{m^3}{kg}\right)} = 0.003985 \text{ kg}$$

$$m_e = m_1 - m_2 = (1.894) - (0.003985) = 1.890 \text{ kg}$$

FIRST LAW: $Q - \cancel{W}^{\,0} = m_e h_e - \cancel{m_i h_i}^{\,0} + m_2 u_2 - m_1 u_1$

$$Q = m_e h_e + m_2 u_2 - m_1 u_1$$

$$\dot{Q} = \frac{Q}{\Delta t} \Rightarrow Q = \dot{Q} \cdot \Delta t$$

$$\dot{Q} \cdot \Delta t = m_e h_e + m_2 u_2 - m_1 u_1$$

$$\dot{Q} = \left(\frac{1}{\Delta t}\right)\left(m_e h_e + m_2 u_2 - m_1 u_1\right)$$

$$h_e = h_g\left(P_{sat} = 175 \text{ kPa}\right) = 2700.2 \frac{kJ}{kg}$$

$$u_2 = u_g(P_{sat} = 175\,kPa) = 2524.5 \frac{kJ}{kg}$$

$$u_1 = u_f + x_1 u_{fg}$$

$$x_1 = \frac{m_{g,1}}{m_{T,1}} = \frac{0.001993}{1.894} = 0.001052$$

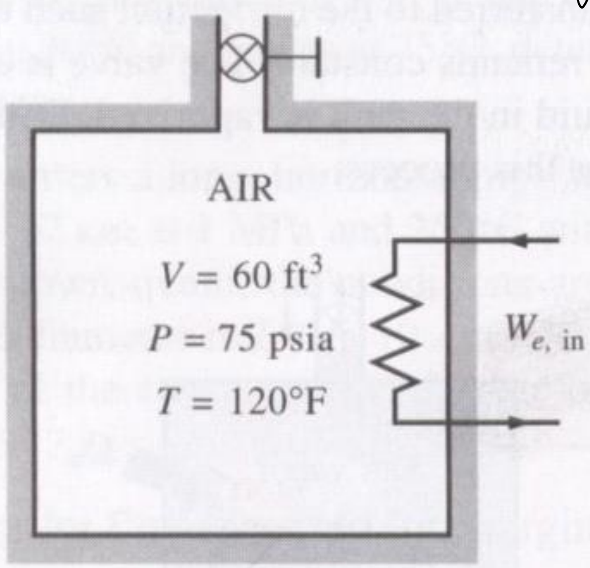
$$u_1 = (486.82) + (0.001052)(2037.7) = 489.0 \frac{kJ}{kg}$$

$$\dot{Q} = \frac{\cancel{(1.890\,kg)(2700.2\,\frac{kJ}{kg}) + (0.003985)(2524.5) - (1.894)(489)}}{(3600\,s)}$$

$$\boxed{\dot{Q} = 1.163\,kW}$$

Prob. 4-161E

4–161E An insulated 60-ft³ rigid tank contains air at 75 psia and 120°F. A valve connected to the tank is now opened, and air is allowed to escape until the pressure inside drops to 30 psia. The air temperature during this process is maintained constant by an electric resistance heater placed in the tank. Determine the electrical work done during this process.



$Q = 0$, $V = 60\ ft^3$, AIR

$P_1 = 75$ PSIA, $T_1 = 120°F$,

$P_2 = 30$ PSIA

$T_2 = T_1 = 120°F$

FIND W_e

CONTINUITY: $\cancel{M_i}^{\,0} - M_e = M_2 - M_1$ $Pv = RT$

$PV = MRT$

$M_e = M_1 - M_2$

$$M_1 = \frac{P_1 V}{R T_1} = \frac{(75\ PSIA)(60\ ft^3)}{\left(0.3704\ \frac{PSIA \cdot ft^3}{LBM \cdot R}\right)(120 + 460\ R)} = 20.95\ LBM$$

$$M_2 = \frac{P_2 V}{R T_2} = \frac{(30)(60)}{(0.3704)(120 + 460)} = 8.38\ LBM$$

$$M_e = M_1 - M_2 = (20.95) - (8.38) = 12.57\ LBM$$

$M_e = M_1 - M_2 = (20.95) - (8.38) = 12.57$

FIRST LAW: $\cancel{Q}^{\,0} - W = M_e h_e - \cancel{M_i h_i}^{\,0} + M_2 u_2 - M_1 u_1$

$W = -M_e h_e - M_2 u_2 + M_1 u_1$

TABLE A-17E: AT $T = 580°R$

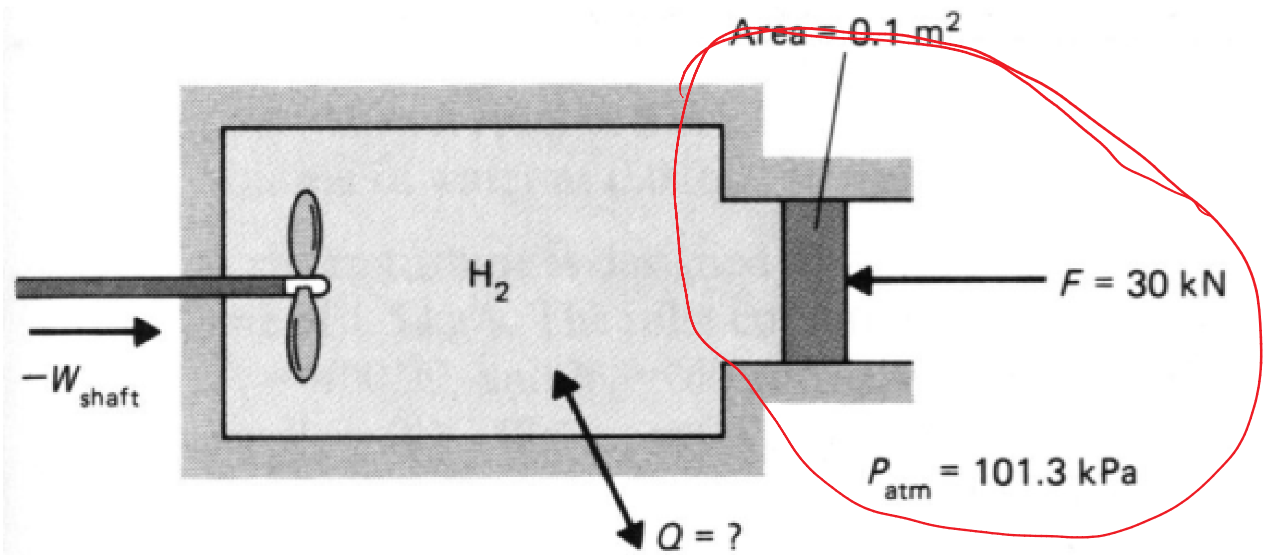
$h_e = 138.66 \frac{Btu}{LBM}$, $u_1 = u_2 = 98.90 \frac{Btu}{LBM}$

$W = -(12.57 \, LBM)\left(138.66 \frac{Btu}{LBM}\right) - (8.38)(98.9) + (20.95)(98.9)$

$\boxed{W = -500 \, Btu}$

summer 2013 prob 1

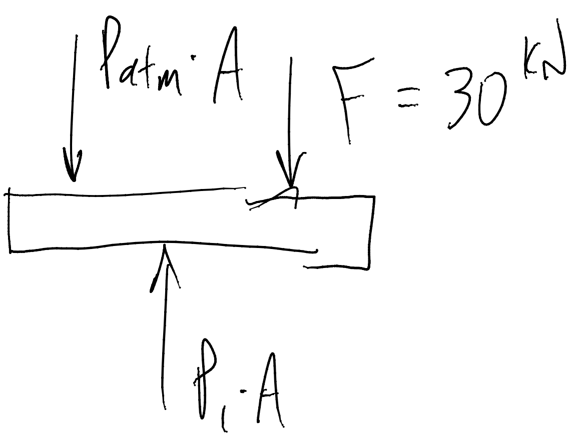
Problem 1: (30 points) The frictionless piston-cylinder device contains 5 kg of hydrogen at a temperature of 400ºC. When 4000 kJ of shaft work is transferred to the working fluid, the temperature rises to 450ºC. Determine the amount of heat transferred (kJ) during the process.



$m = 5^{kg}$ H_2, $T_1 = 400°C$, $W_s = -4000^{kJ}$

$T_2 = 450°C$, FIND Q

FBD PISTION: STATE 1:



$$P_1 \cdot A - P_{atm} \cdot A - F = 0$$

$$P_1 = P_{atm} + \frac{F}{A}$$

FBD OF PISTON AT STATE 2 IS THE SAME.

$$\therefore P_2 = P_1 = \left(101.3\ ^{kPa}\right) + \frac{\left(30\ ^{kN}\right)}{\left(0.1\ m^2\right)} = 401.3\ ^{kPa}$$

FIRST LAW: $Q - W = U_2 - U_1 = m\left(u_2 - u_1\right)$

$$Q - \boxed{\left(W_{SHAFT} + W_{PV}\right)} = m\left(u_2 - u_1\right)$$

$$Q = W_s + mP\left(v_2 - v_1\right) + m\left(u_2 - u_1\right) \quad u + Pv$$

$$h \equiv P \cdot v + u$$

$$Q = W_s + mP\left(h_2 - h_1\right)$$

FOR IDEAL GAS, $dh = C_p\, dT$

$h_2 - h_1 = C_p\left(T_2 - T_1\right)$ ASSUMING C_p = CONSTANT

$$Q = W_s + m\, C_p\left(T_2 - T_1\right)$$

$$Q = \left(-4000\ ^{kJ}\right) + \left(5.0\ ^{kg}\right)\left(14.307\ \frac{kJ}{kg\text{-}K}\right)\left(450 - 400\ ^{K}\right)$$

$$\boxed{Q = -423\ ^{kJ}}$$

TABLE A-17

$$\boxed{Q = -423}$$

$$\bar{u}_1 = 13{,}828 \ \frac{\text{KJ}}{\text{KMOL}}, \quad \bar{u}_2 = 14{,}887 \ \frac{\text{KJ}}{\text{KMOL}}$$

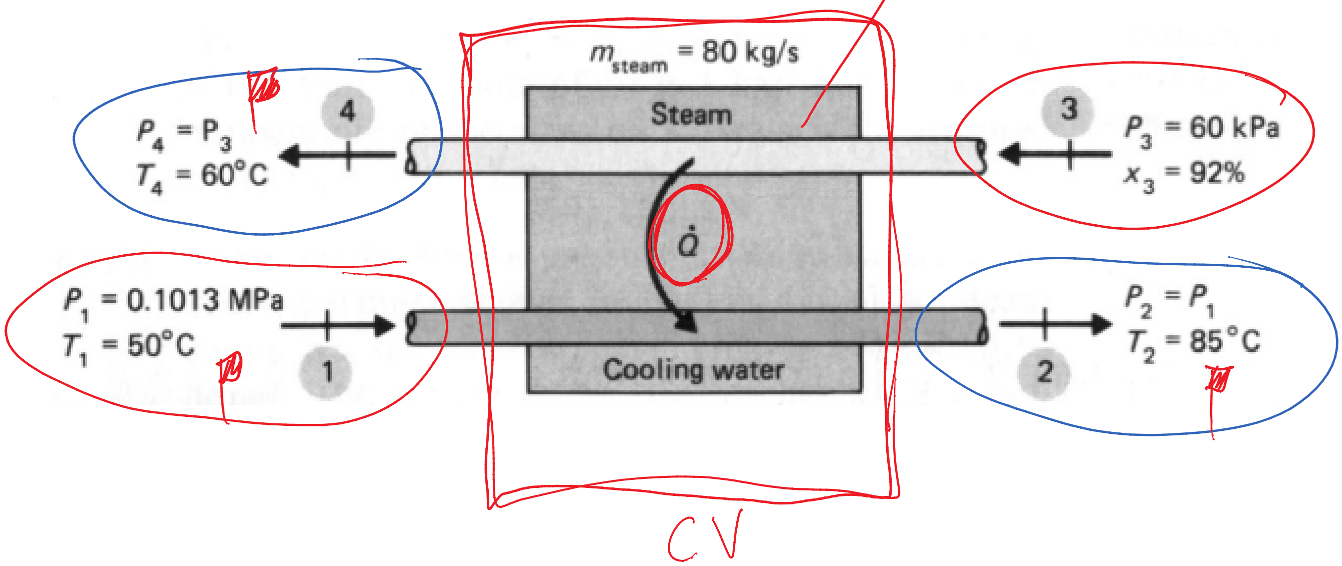
$$M = 2.016 \ \frac{\text{Kg}}{\text{KMOL}}$$

$$\boxed{u_2 - u_1 = \frac{(14{,}887 - 13{,}828)\ \frac{\text{KJ}}{\cancel{\text{KMOL}}}}{\left(2.016 \ \frac{\text{Kg}}{\cancel{\text{KMOL}}}\right)} = 525.3 \ \frac{\text{KJ}}{\text{Kg}}}$$

summer 2013 prob 2

$\dot{Q} = 0$

Problem 2: (40 points) An adiabatic condenser operates as shown. If the process is steady-state steady flow, determine the mass flow rate of cooling water required (kg/s).



FIND $\dot{m}_{cw}$

FIRST LAW: $\cancel{\dot{Q}}^{0} - \cancel{\dot{W}}^{0} = \sum \dot{m}_e h_e - \sum \dot{m}_i h_i$

$$0 = \dot{m}_2 h_2 + \dot{m}_4 h_4 - (\dot{m}_1 h_1 + \dot{m}_3 h_3)$$

$$0 = \dot{m}_{cw} h_2 + \dot{m}_s h_4 - \dot{m}_{cw} h_1 - \dot{m}_s h_3$$

$$0 = \dot{m}_{cw} (h_2 - h_1) - m_s (h_3 - h_4)$$

$$\dot{m}_{cw} = \dot{m}_s \left[\frac{(h_3 - h_4)}{(h_2 - h_1)} \right]$$

$$\dot{m}_{cw} = \dot{m}_s \left[\overline{\quad (h_2 - h_1) \quad} \right]$$

FOR SUBCOOLED LIQUIDS, $\Delta h = C_p \Delta T$

$$h_2 - h_1 = C_{p,cw} (T_2 - T_1)$$

$$\dot{m}_{cw} = \dot{m}_s \left[\frac{(h_3 - h_4)}{C_p (T_2 - T_1)} \right]$$

$$h_3 = h_f + X_3 h_{fg}$$

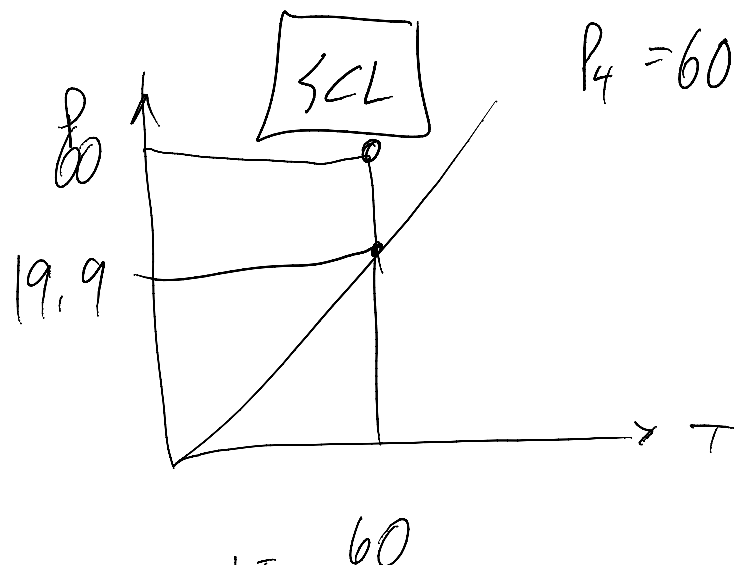
$$h_3 = (358.1) + (0.92)(2294) = 2468.6 \ \frac{kJ}{kg}$$

$P_4 = 60 \ kPa$, $T_4 = 60°C$

FIND h_4:

SCL ASSUME

$h = h_f$ AT TEMP.



$$h_4 \simeq h_f(60°C) = 358.1 \ \frac{kJ}{kg}$$

$$= \quad \frac{kg}{} \Big) \left[\frac{(2468.6 - 251)}{} \frac{kJ}{kg} \right] = 1217 \ \frac{kg}{}$$

$$\boxed{\dot{m}_{cw}} = \left(80\ \frac{kg}{s}\right)\left[\frac{(2468.6 - 251)\ \cancel{\frac{kJ}{kg}}}{\left(4.18\ \frac{kJ}{kg\text{-}K}\right)(85 - 50^\circ C)}\right] = \boxed{1212\ \frac{kg}{s}}$$

$$\frac{m^3}{kg} \qquad \frac{kg}{m^3}$$

$$v = \frac{1}{\rho}$$

summer 2013 prob 3

Problem 3: (30 points) Air at 1 atm and 20°C initially fills a bottle of 0.1-m^3 volume. The bottle is attached to an air line that provides air at 20°C and 50 atm, and the bottle is charged to a pressure of 50 atm. There is heat transfer from the bottle, so the air within is held at 20°C throughout the process. Determine the heat transfer during the process.

AIR, $P_1 = 1^{atm}$, $T_1 = 20°C = T_2$, $V = 0.1^{m^3}$

$T_i = 20°C$, $P_i = 50^{atm}$, $P_2 = 50^{atm}$ —

FIND Q: UNIFORM-FLOW PROCESS

CONTINUITY: $m_i - \cancel{m_e}^{\,0} = m_2 - m_1$

PERFECT GAS: $PV = mRT$

$$m_1 = \frac{P_1 V}{R T_1} = \frac{(1^{atm})\left(\frac{100\ kPa}{atm}\right)(0.1^{m^3})}{\left(0.287 \frac{kJ}{kg\text{-}K}\right)(20+273^{K})} = 0.1189^{kg}$$

$$m_2 = \frac{P_2 V}{R T_2} = \frac{(50^{atm})\left(\frac{100\ kPa}{atm}\right)(0.1^{m^3})}{\left(0.287 \frac{kJ}{kg\text{-}K}\right)(20+273^{K})} = 5.946^{kg}$$

$m_i = 5.946 - 0.1189 = 5.827^{kg}$

FIRST LAW: $Q - \cancel{W}^{\,0} = \cancel{m_e h_e}^{\,0} - m_i h_i + m_2 u_2 - m_1 u_1$

FIRST LAW: $\underbrace{Q - \cancel{W}}_{\text{WORK/HEAT}} = \underbrace{\cancel{m_e h_e} - m_i h_i}_{\text{NRG FLOW}} + \underbrace{m_2 u_2 - m_1 u_1}_{\Delta \text{ NRG SYSTEM}}$

$$Q = -m_i h_i + m_2 u_2 - m_1 u_1$$

AIR PROPERTIES: TABLE A-17

$T = 20 + 273 = 293\ K$

$h = 293\ \frac{kJ}{kg}$, $u = 209\ \frac{kJ}{kg}$

$$Q = -\left(5.827\ kg\right)\left(293\ \frac{kJ}{kg}\right) + (5.946)(209) - (0.1189)(209)$$

$$\boxed{Q = -489\ kJ}$$

LEAVING SYSTEM

summer 2012 prob 1

Problem 1: (25 points) 1.4 kg of liquid water initially at 10ºC is to be heated to 95ºC in a teapot equipped with a 1000 W electric heating element inside. The specific heat of water can be taken to be 4.18 kJ/(kg-K). The heat loss from the water during heating can be neglected. Find the time it takes to heat the water to the desired temperature. (Answer: t = 8.29 min.)

$m = 1.4\ \text{kg}\ H_2O$, $T_1 = 10°C$, $T_2 = 95°C$, $\dot{Q} = +1000\ W$

$\dot{W}_{el} = -1000\ W$

$C_p = 4.18\ \frac{kJ}{kg-K}$ FIND Δt

FIRST LAW: $Q - W = U_2 - U_1 = m(u_2 - u_1)$

FOR LIQUIDS AND SOLIDS, $C_v = C_p = C$

$\dot{Q} = \frac{Q}{\Delta t}$, $\dot{W} = \frac{W}{\Delta t}$

$du = C\,dT$, $u_2 - u_1 = C \cdot (T_2 - T_1)$

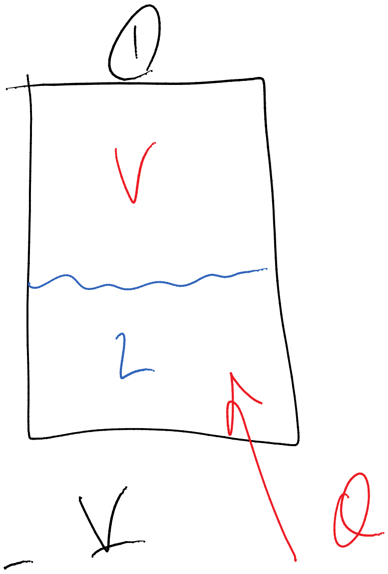
$\dot{Q} \cdot \Delta t = mC(T_2 - T_1)$

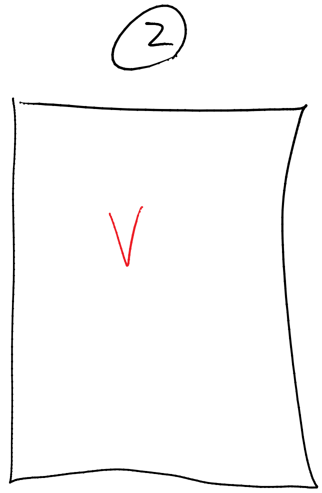
$$\Delta t = \frac{mC(T_2 - T_1)}{\dot{Q}}$$

$$\boxed{\Delta t} = \frac{(1.4\,\text{kg})\left(4.18\,\frac{\text{kJ}}{\text{kg-K}}\right)(95-10^{\circ}\text{C})}{\left(1000\,\frac{\text{J}}{\text{s}}\right)} \cdot \left(\frac{1000\,\text{J}}{\text{kJ}}\right) = \boxed{497\,\text{s}}$$

summer 2012 prob 2

Problem 2: (50 points) A rigid vessel having a volume of 5 m^3 contains 0.05 m^3 of saturated liquid water and 4.95 m^3 of saturated water vapor at 0.1 MPa. Heat is transferred until the vessel is filled with saturated vapor. Determine the heat transfer for this process and show the process on a *P-v* diagram with respect to saturation lines. (Answer: $Q = 1.049 \times 10^5$ kJ)





$V = 5\ m^3,$

$V_{f,1} = 0.05\ m^3$

$V_{g,1} = 4.95\ m^3$

$P_1 = 0.1\ MPa$

$X_2 = 1.0$

$v = \frac{V}{m}, \quad m_{f,1} = \frac{V_{f,1}}{v_{f,1}} = \frac{(0.05\ m^3)}{(0.001043\ \frac{m^3}{kg})}$

$m_{f,1} = 47.94\ kg, \quad m_{g,1} = \frac{V_{g,1}}{v_{g,1}} = \frac{(4.95\ m^3)}{(1.6941\ \frac{m^3}{kg})} = 2.922\ kg$

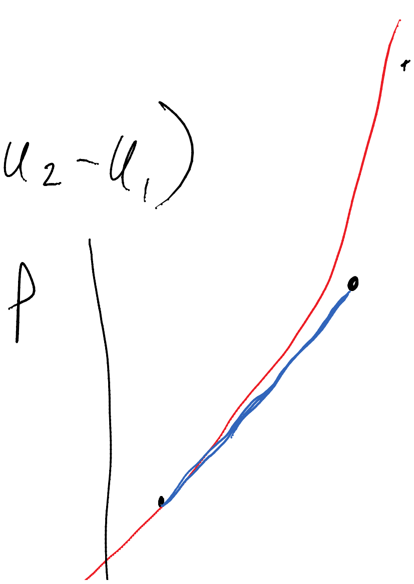
$m_T = m_{f,1} + m_{g,1} = 50.86\ kg$

FIRST LAW: $Q - \cancel{W}^{\,0} = U_2 - U_1 = m(u_2 - u_1)$

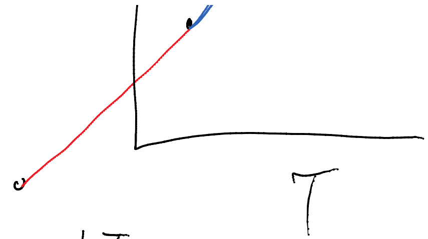
$Q = m(u_2 - u_1)$

$u_1 = u_f + x_1 u_{fg}$

$m_{g,1} \quad (2.922$



$$X_1 = \frac{m_{g,1}}{m_T} = \frac{(2.922)}{(50.86)} = 0.05745$$



$$u_1 = (417.4) + (0.05745)(2088.2) = 537.4 \ \frac{kJ}{kg}$$

P	v	
		1
		2

$$P = P_1 + \left(\frac{P_2 - P_1}{v_2 - v_1}\right)(v - v_1)$$

FIND u_2: $\quad v_2 = v_1$

$$v_1 = v_f + X_1 (v_g - v_f)$$

$$v_1 = (0.001043) + (0.05745)(1.694 - 0.001043) = 0.09831 \ \frac{m^3}{kg}$$

$$\boxed{v_2 = \boxed{0.09831} \ \frac{m^3}{kg} = v_g}$$

INTERPOLATE:

$v \left(\frac{m^3}{kg}\right)$	$u \left(\frac{kJ}{kg}\right)$	
0.099587	2599.1	1

0.09831

0.09755

0.09831

0.094987	2594.1 (1)
0.088717	2600.9 (2)

0.09755

0.09831

$$u = u_1 + \left(\frac{u_2 - u_1}{v_2 - v_1} \right) (v - v_1)$$

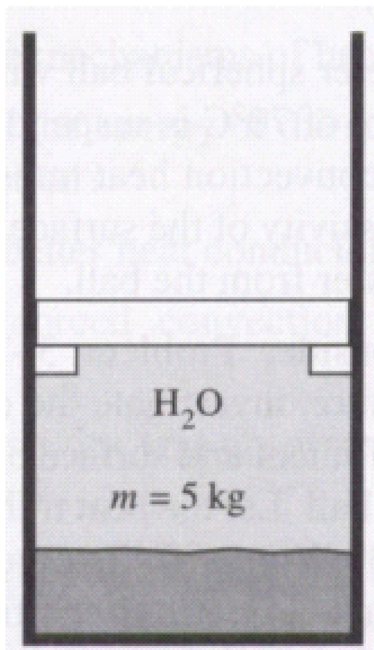
$u_2 = 2599.3 \ \frac{KJ}{kg}$, $\boxed{Q = 1.049 \times 10^5 \ KJ}$

summer 2012 prob 3

Problem 3: (25 points) A cylinder fitted with a frictionless piston has an initial volume of 2 ft^3 and contains nitrogen at 20 lbf/in^2 and 80ºF. The piston is moved, compressing the nitrogen until the pressure is 160 lbf/in^2 and the temperature is 300ºF. During this compression process heat is transferred from the nitrogen and the work done on the nitrogen is 9.15 Btu. Determine the amount of this heat transfer. Do **not** assume that the specific heat is constant during this process. (Answer: $Q = -1.577$ Btu)

Winter 2010 prob 1

1. (40 points) A mass of 5 kg of water is contained in a piston-cylinder device at 125 kPa. Initially, 2 kg of the water is in the liquid phase and the rest is in the vapor phase. Heat is now transferred to the water, and the piston, which is resting on a set of stops, starts moving when the pressure inside reaches 300 kPa. Heat transfer continues until the total volume increases by 20 percent. Determine the heat transferred during this process and show the process on a *P-v* diagram with respect to saturation lines.



Winter 2010 prob 2

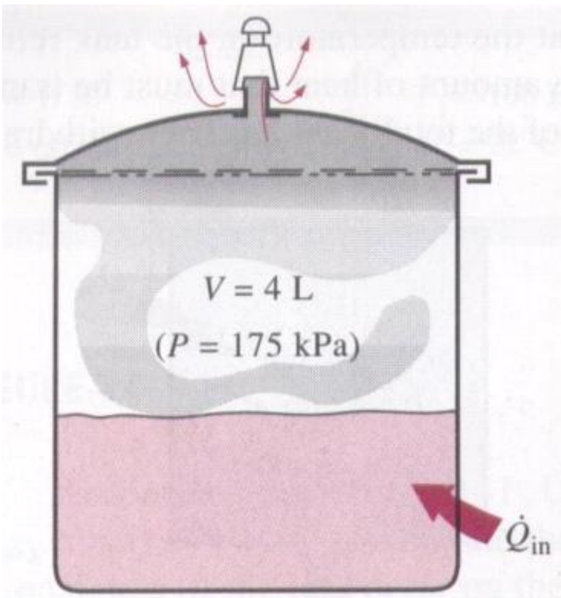
2. (20 points) 1000 kg of liquid water at 80ºC is brought into a well-insulated and well-sealed 4-m × 5-m × 6-m room initially at 22ºC and 100 kPa. Assuming constant specific heats for both air and water at room temperature, determine the final equilibrium temperature in the room. *Answer*: 78.1ºC.

Winter 2010 prob 3

3. (15 points) Air is compressed from 14.7 psia and 60ºF to a pressure of 150 psia while being cooled at a rate of 10 Btu/lbm by circulating water through the compressor casing. The volume flow rate of the air at the inlet conditions is 5000 ft^3/min, and the power input to the compressor is 700 hp. Determine (*a*) the mass flow rate of the air and (*b*) the temperature at the compressor exit. Answers: (*a*) 6.36 lbm/s, (*b*) 801ºR.

Winter 2010 prob 3

4. (25 points) A 4-L pressure cooker has an operating pressure of 175 kPa. Initially, one-half of the volume is filled with liquid and the other half with vapor. If it is desired that the pressure cooker not run out of liquid water for 1 hour, determine the highest rate of heat transfer allowed.



Wednesday, July 02, 2014
4:33 PM

$$v_3 = \frac{(1.5\ ft^3)}{(5\ LB)} = 0.3\ \frac{ft^3}{LBM}$$

$$P_3 = 40\ PSIA$$

$$v_3 = v_f + X_3(v_g - v_f)$$

$$X_3 = 0.270 = \frac{M_g}{M_T} \Rightarrow$$

$$M_{g,3} = 0.27(5\ LBM) =$$

$$M_{f,3} = M_T - M_{g,3} = (5\ LBM) - (1.35\ LBM) = 3.65\ LBM$$

4-66: $P_2 = 330.8\ KPa$

4-79: $\Delta KE = -1.95\ \frac{KJ}{kg}$, $\dot{W} = 10.2\ MW$, $A = 0.00446\ m^2$