Thermodynamics, MECH2010 Fall 2019, Test 1a 2019/10/07

Prof Fu-Lin Tsung

Name Chinese_______________ Name, Pinyin ________________Student number _____________

Name, English_______________

1	2	3	4	5	6	7	Total
20	20	10	15	20	10	5	100

Sign your name

I, __________________________, will/did not cheat/copy any portion of this test.

Estimate your score. If it's within +/- 2 points, you get one extra point _____________

-1 for incorrect or missing unit

if not specified, -1 for signs calculation error

-2 for signs physics error

1) A lab space designed to hold 60 students is to be cooled by multiple number of small wall air-conditioners each w/ cooling capacity of 5 kW. There are 80 light bulbs in the room, each with rating of 25 W. The total rate of heat transfer to the lab through walls, windows, floor and ceiling is estimated to be 18,000 kJ/h. Assume each student dissipate heat at a rate of 360 kJ/h. Determine the total number of air-conditioners required for the lab if the room air is to be maintained at a constant temp of 24 °C.

Hint: simpler to do energy balance on the rate basis, careful of units.

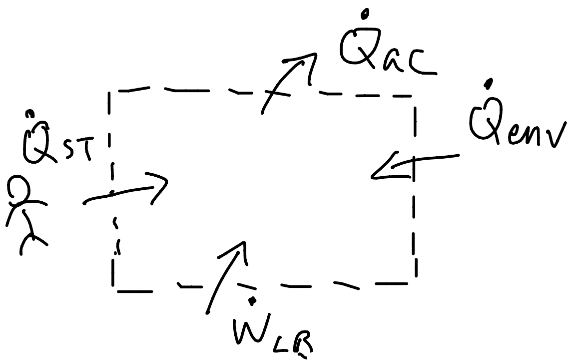
a) (6) Identify the closed system. Sketch the system with clearly labeled arrows showing all energy transfer processes

b) (6) Perform the **energy balance** (i.e. reduce the 1st law of thermo for your system, in equation form, in terms from your clearly labeled arrows and variables sketch)

c) (8) Substitute # s and perform the calculation needed to find the answer

a)

HVAC



env : enviroment
ac : air conditioners
ST : students
LB : light bulbs

b)

$$\Delta \dot{E} = \dot{Q}_{in} - \dot{W}_{out} \qquad \Delta KE = \Delta PE = 0$$

$$\Delta \dot{U} = (\dot{Q}_{ST} + \dot{Q}_{env} - \dot{Q}_{ac}) - (-\dot{W}_{LB})$$

accept $-(-\dot{W}_{LB})$ as $+\dot{Q}_{LB}$

$\Delta \dot{U} = 0$ (const temperature, pressure)

$$\dot{Q}_{ac} = \dot{Q}_{ST} + \dot{Q}_{env} + \dot{W}_{LB}$$

c)

$$\dot{Q}_{ST} = 60 \times 360 \ kJ/hr \ \frac{hr}{3600\ s} = \underline{6 \ kW}$$

$$\dot{Q}_{env} = 18{,}000 \ kJ/hr \ \frac{hr}{3600\ s} = \underline{5 \ kW}$$

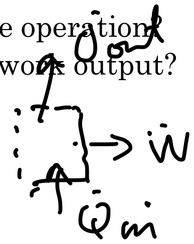
$$\dot{W}_{LB} = 80 \times 25 \ W = \underline{2 \ kW}$$

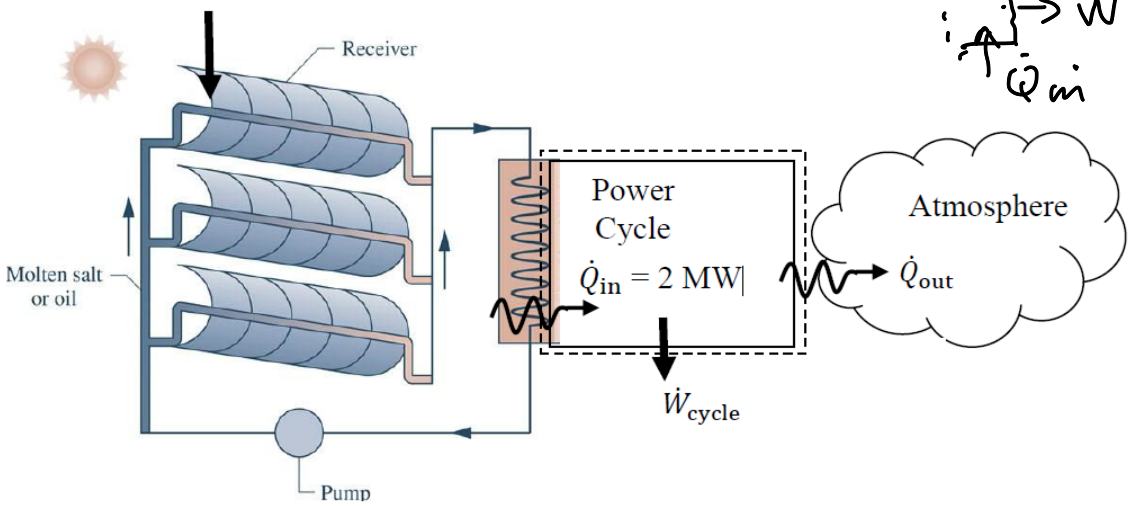
$$\dot{Q}_{ac} = \underline{13 \ kW}$$

$$\# = \frac{\dot{Q}_{ac}}{5 \ kW} = \frac{13}{5} = \underline{2.XX}$$

$\boxed{\text{needs 3 units of air-conditioner}}$

2) A concentrating solar collector system provides energy by heat transfer to a power cycle at a rate of 2 *MW*. The cycle thermal efficiency is 36%.
a) (8) Determine the power developed by the cycle, in *MW*
b) (6) What is the total work output, in *MW-h*, for 4380 hrs of steady-state operation?
c) (6) If the work is valued at ¥0.56 / *kW-h*, what is the total value of the work output?





2.85

a)

$$\eta = \frac{\dot{W}}{\dot{Q}_{in}}$$

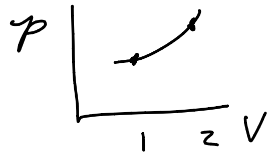
$$\dot{W} = 0.36(2)MW = \boxed{0.72\ MW}$$

b) $0.72\ MW(4380\ hr) = 3154\ MW\text{-}h$

c) ¥ ⇒ $¥0.56/\cancel{kW\text{-}h}\ \ 3154\ \cancel{MW\text{-}h}\ \frac{1000\ \cancel{kW}}{1\ \cancel{MW}} = \boxed{¥1.77 \times 10^6}$

(10)

3) A simple piston-cylinder undergoes an expansion process w/ the relationship between pressure and volume given by $pV^n = C$, where C is a constant. If the volume goes from V_1 to V_2, derive an expression for work done by the system, if n $\neq$ 1.



$$PV^n = C$$

$$W = \int_{V_1}^{V_2} P\,dV, \qquad P = \frac{C}{V^n}$$

$$\frac{d}{dx}x^n = nx^{n-1}$$

$$\int n x^{n-1} = x^n$$

$$= \int_{V_1}^{V_2} \frac{C}{V^n}\,dV = C\int_{V_1}^{V_2} V^{-n}\,dV$$

$$W = \frac{C}{1-n} V^{1-n} \Big|_{V_1}^{V_2} \quad \text{or} \quad W = \frac{C}{1-n}\left(V_2^{1-n} - V_1^{1-n}\right)$$

$$C = P\forall^n$$

$$W = \frac{P_2\forall_2^n}{1-n}\forall_2^{1-n} - \frac{P_1\forall_1^n}{1-n}\forall_1^{1-n}$$

$$\boxed{W = \frac{1}{1-n}\left(P_2\forall_2 - P_1\forall_1\right)}$$

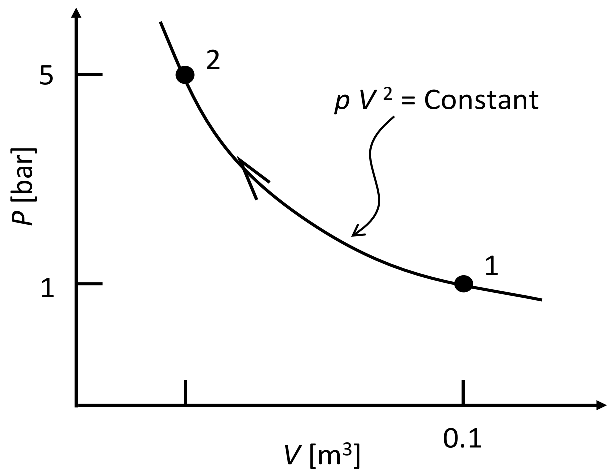
either one is O.K.

(15)

4) A gas in a piston-cylinder assembly undergoes a process which $pV^2 = C$. Find

(8) a) the final volume occupied by the gas in [m^3]

(7) b) work for the process in [kJ]



$$PV^2 = C$$

a) $$P_1 V_1^2 = C = P_2 V_2^2$$

$$V_2^2 = \frac{P_1}{P_2} V_1^2$$

$$V_2 = \sqrt{\frac{P_1}{P_2}}\, V_1$$

$$= \sqrt{\frac{1}{5}}\, 0.1\, m^3 = \boxed{0.0447\, m^3}$$

b) $$W = \frac{1}{1-n}\left(P_2 V_2 - P_1 V_1\right) \ldots \text{ from } 3)$$

$$n = 2$$

$$W = \frac{1}{1-2}\left(500{,}000 \cdot 0.0447 - 100{,}000 \cdot 0.1\right) \frac{N}{m^2}\, m^3$$

$$= -12{,}350\ N \cdot m = \boxed{-12.35\ KJ}$$

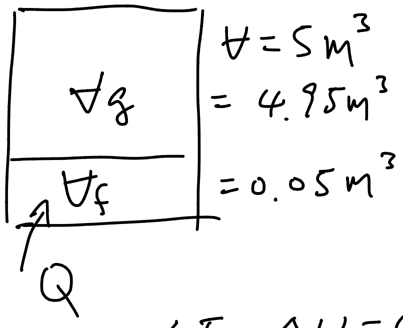
⊖ because work done on system!

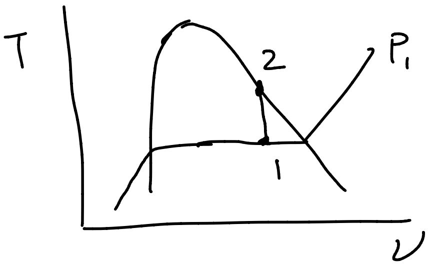
If they use $$W = \frac{C}{1-n}\left(V_2^{1-n} - V_1^{1-n}\right)$$

$C = P_1 V_1^2$ or $P_2 V_2^2$

(20)

5) Water is in a fixed container with $V = 5\ m^3$. Initially there is $V_f = 0.05\ m^3$ of liquid water and $V_g = 4.95\ m^3$ of water vapor. The initial pressure is $P_1 = 100\ kPa$. Heat is added isochorically until the saturated vapor state in reached. Determine ${}_1Q_2$.





$$\Delta E = \Delta U = Q - \cancel{W}^{\,0}$$

$$U_2 - U_1 = {}_1Q_2 = m(u_2 - u_1)$$

Find u_1, need x_1 $\quad x_1 = \frac{m_g}{m} \quad m = m_f + m_g$

$$m_f = \frac{\forall_f}{v_f} = \frac{0.05\ m^3}{0.001043\ m^3/kg} = 47.94\ kg$$

$$m_g = \frac{\forall_g}{v_g} = \frac{4.95\ m^3}{1.694\ m^3/kg} = 2.922\ kg$$

$$m = 50.86\ kg, \quad x_1 = \frac{2.922}{50.86} = 0.0575$$

$$u_1 = u_f + x_1(u_g - u_f) = [417.33 + x_1(2506.1 - 417.36)]\left[\frac{kJ}{kg}\right]$$

$$= 537.33\ kJ/kg$$

@ 2 $\quad v_2 = v_1 = \frac{\forall_1}{m} = \frac{5\ m^3}{50.86\ kg} = 0.0983\ m^3/kg$

$x_2 =$ interpolate between P = 20 kPa + 25 kPa

P	v_g	u_g
20	0.09963	2600.3
25	0.07998	2603.1

$$\frac{u_2 - 2600.3}{2603.1 - 2600.3} = \frac{0.0983 - 0.09963}{0.07998 - 0.09963}$$

$$u_2 = 2600.49\ kJ/kg$$

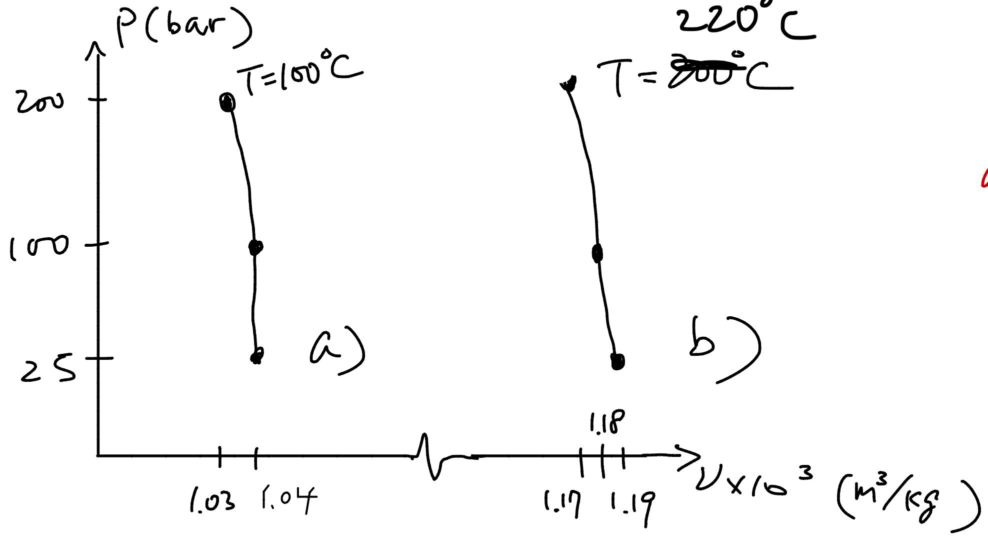
$${}_1Q_2 = 50.86(2600.49 - 537.33)\ kg\left(\frac{kJ}{kg}\right) = \boxed{104,932\ kJ}$$

6) For Compressed Liquid Water.

a) (2) Draw the *P*-*v* diagram for an isothermal process where $T = 100\ °C$, $P = 25$, 100, and 200 bar. Labeled the diagram accurate to 2nd decimal point.

b) (2) On the same graph, draw another isothermal process for $T = 220\ °C$ at the same 3 pressures as a).

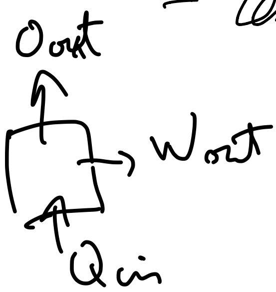
c) (6) What conclusions can be drawn from these 2 lines (processes)



axis w/ labels
axis w/ units
T=100 + 200°C

c) for liquid
volume is a function of temperature only
only, not pressure

- Pressure change order of magnitude (up to 200 atm!), volume change ~1%
- temp change of 100° causes ~15% volume change



7)

a) T / F For a power cycle, the thermo efficiency cannot be > 1

b) T / F For refrigeration cycle, the Coefficient of performance cannot be > 1

c) T / F For a heat pump cycle, the Coefficient of performance cannot be > 1