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CEM

Q4001 Thermodynamics of Materials **August, 2019**
Homework 1

1. Determine which of the following systems are in equilibrium.
   (a) A rigid insulated cylinder is divided by an insulated piston into two equal parts. One part contains oxygen at 50 °C and 300 kPa, and the other part contains nitrogen at 30 °C and 100 kPa. The piston is held in place by a stop.
   (b) Same as part a, but the stop is removed.
   (c) A rigid insulated cylinder is divided by a copper piston into two equal parts. One part contains oxygen at 50 °C and 300 kPa, and the other part contains nitrogen at 30 °C and 100 kPa.
   (d) A rigid insulated cylinder is divided by a copper piston into two equal parts. One part contains oxygen at 30 °C and 100 kPa, and the other part contains nitrogen at 50 1C and 100 kPa.
   (e) A rigid insulated cylinder is divided by a copper piston into two equal parts. One part contains oxygen at 30 °C and 100 kPa, and the other part contains nitrogen at 30 °C and 100 kPa. A small hole is made in the piston.
   (f) Twenty grams of salt crystals are put in a container together with 1000 cm^3 of water.
   (g) Twenty grams of salt crystals are put in a container together with 1000 cm^3 of saturated saline solution.

2. A perpetual motion machine of the first kind (PMM1) is defined as an *adiabatic* system for which the work in a cycle is not zero. Is the first law equivalent to the statement that a PMM1 is impossible? Explain.

3. The solar energy can be harnessed to produce electric work. A PV solar panel produces 100 kW of electric power per day in summer, which is used to charge a storage battery. The battery loses heat to the environment at a rate of 3 kW. How much energy is stored in the battery after 6 h of operation?

4. The envelope of an elastic balloon exerts a pressure on its contents proportional to its area. The balloon is inflated from a volume of 10 L and a pressure of 200 kPa to a volume of 25 L.
   (a) Calculate the final pressure in the balloon.
   (b) Calculate the work of the balloon envelope.

5. For a simple compressible system, indicate whether the following statements are true, sometimes true, or false:
   (a) The work done by a system when changes from states 1 to 2 depends on its volume.
   (b) When a gas expands, its energy increases.
   (c) The work of an adiabatic cycle is equal to 0.
   (d) The work in a cycle is equal to 0.
   (e) The energy change from states 1 to 2 depends on the work of the system.
   (f) When a gas is compressed in a cylinder, its energy does not change.

6. The specific energy of a certain substance is given by $U = A + BPV$, where $A = 60\,\mathrm{kJ/kg}$, $B = 8$, P units are kPa, and V is expressed in in m^3/kg. Find the work done by a system of this substance when its volume increases adiabatically from 1.5 MPa and 60 to 150 L.

Due date: Tuesday, august 20th.

- the internal energy of the ideal gas can't change.

$\Delta U = Q - W = 0$ therefore $Q = W$

- adiabatic processes → no heat is allowed to flow in or out of the system, but the gas can be expanded or be compressed.

$\Delta U = -W$

↳ work done by the system

↳ internal energy of a closed system

▷ 2nd Law of Thermodynamics

Heat will spontaneously flow from something hotter to something colder, but it won't flow from something colder to something hotter.

↳ because of entropy → which is the ~~[illegible]~~ inherent disorder of a system. The more disordered the system, the higher its entropy.

- If the entropy in a system decreasses, that means ~~[illegible]~~ the entropy of the environment around the system must increase enough to compensate

↳ there's an overall increase in entropy of the universe.

- when the molecules are different tempreratures → orderly arrangement
- when their temperatures become equal → the neat organization is gone hence the increase of entropy.

Homework 1

$\boxed{1}$ (a), (e) & (g) are in equilibrium.

(a) There is no mass or heat transfer through the piston; hence each part is in equilibrium within their respective subsystem.

(e) The pressure & temperature of the system are the same.

(g) There is no change in the rate of dissolution.

$\boxed{2}$ Yes, as the conservation of energy (a.k.a. 1st Law of thermodynamics) does not allow systems to produce work without any energy.

3 $E_{in} = 100\,kW$; $E_{lost} = 3\,kW$

$$E_{stored} = E_{in} - E_{lost}$$
$$= 97\,kW \quad \text{where: } kW = \frac{kJ}{s}$$

$$t = 6\,hr = 21\,600\,s$$

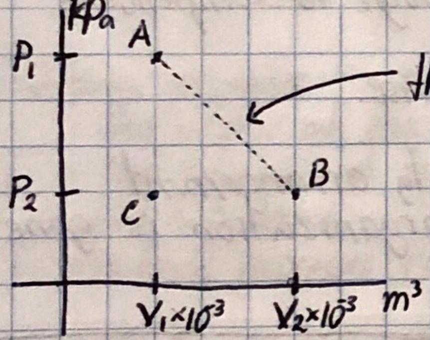
$$e_{stored} = E_{stored} \cdot t$$
$$= 2\,095\,200\,kJ$$

After 6hr of operation, 2 095 200 kJ of energy have been stored.

4 $P_1V_1 = P_2V_2$, @constant temperature

$$200\,kPa\,(10\,L) = P_2\,(25\,L)$$
$$P_2 = 80\,kPa$$

(a) The pressure in the balloon is 80 kPa when its volume is 25 L.



the process. work done = area under ABCD

$1\,m^3 = 0.001\,L$

$$Work = \left[\frac{1}{2}(P_1 - P_2\,kPa)(V_2 - V_1\,m^3) + (P_2\,kPa)(V_2 - V_1\,m^3)\right] \times 10^{-3}$$
$$= \left[\frac{1}{2}(120\,kPa)(15\,m^3) + (80\,kPa)(15\,m^3)\right] \times 10^{-3}$$
$$= \left[2100\,kPa\,m^3\right] \times 10^{-3} \qquad Pa = \frac{kg}{m\,s^2} \;\; \& \;\; J = \frac{kg\,m^2}{s^2}$$
$$= 2.1\,kJ$$

(b) The work done by the balloon envelope is 2.1 kJ.

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(a) True. The gas volume decreases with an increase in gas compression.

(b) False. When the gas expands (higher pressure to a lower pressure) the system's energy decreases.

(c) ~~[illegible]~~ Sometimes True. the work is zero for reversible ~~[illegible]~~ adiabatic cycles. Irreversible adiabatic cycles will produce some kind of work

(d) Sometimes True. the work is zero for reversible adiabatic cycles. For any other form of cycle, it will not be zero.

(e) True. The change in pressure depends on the work; and the change in energy depends on the ~~[illegible]~~ change in pressure.

(f) False. Same explanation as (e). The container's shape is not germane.

6 $U = A + BPV$; where U = specific energy

$A = 60\ kJ/Kg$ 78 kJ/Kg

$B = 8$

$P = kPa$

$V = m^3/Kg$ $\longrightarrow$ also...

$P_1 = 1.5\ MPa$

$V_1 = 60\ L$

$V_2 = 150\ L$

For ~~[illegible]~~ adiabatic processes, $\Delta U = -W$; also from $U = A + BPV$ we can determine:

$\Delta U = B(P_2V_2 - P_1V_1)$ ~~[illegible]~~ ; and ~~[illegible]~~

$W = \dfrac{P_2V_2 - P_1V_1}{\gamma - 1}$, where: W = work done & γ = heat capacity ratio.

So: $+B(P_2V_2 - P_1V_1) = \dfrac{P_2V_2 - P_1V_1}{\gamma - 1}$

$\gamma = 1.125$

For adiabatic processes,

$$W = \int_{V_1}^{V_2} P\,dV = \int_{V_1}^{V_2} \frac{k}{V^\gamma}\,dV = k\left[\frac{V^{(1-\gamma)}}{1-\gamma}\right]_{V_1}^{V_2}$$

$$W = P_1 V_1^{\gamma}\left[\frac{V^{(1-\gamma)}}{1-\gamma}\right]_{V_1}^{V_2}$$

$$W = \frac{P_1 V_1^{\gamma}}{1-\gamma}\left[V_2^{(1-\gamma)} - V_1^{(1-\gamma)}\right]$$

$$W = \frac{(1.5\times10^6)(60\times10^{-3})^{1.125}}{1-1.125}\left[150\times10^{-3\,(1-1.125)} - 60\times10^{-3\,(1-1.125)}\right]\ Pa\,m^3$$

$W = 77\,918{,}739\ J$
is the work done by the system

$$\Big/\ Pa = \frac{Kg}{ms^2}\ \&\ J = \frac{Kg\,m^2}{s^2}$$