Thermodynamics – Exam I

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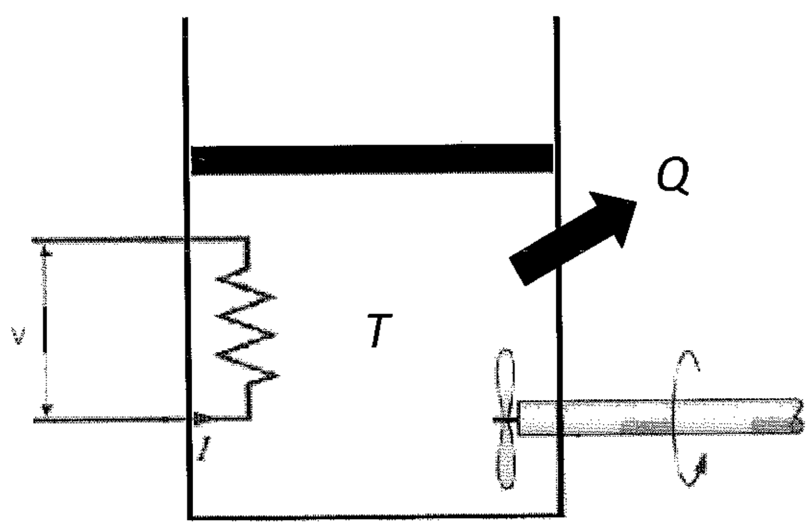
Date: Tuesday, November 17th 2009; 06:00 PM
Location: ENG attic
Instructor: Dr. Wassim HABCHI
Notes: No documents allowed
Value: 20% of Total Grade
Time: 120 Minutes

[____ / 100]

Problem I (30 points)

Part I: (10 points)

Consider a piston-cylinder device where the piston is moving freely. The cylinder contains water at a given temperature T and pressure P. An electric resistance heater is placed inside the tank. It passes a current I from a source of voltage V. The water is being stirred by a paddle wheel and the cylinder is losing heat to the surroundings.



0-1 / 2-3 / 4

a) Identify the different forms of heat and work exchange involved in this system (4pts)
b) If you were asked to determine the steady-state temperature inside the cylinder, what would be the missing parameters or data? (6pts)

0-2 / 2-4 / 5-6

Part II: (10 points)

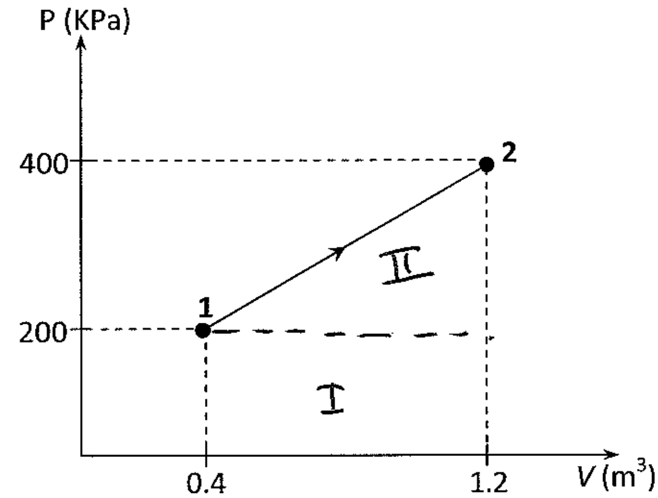
Consider a rigid tank that contains a given mass m of water that has a specific internal energy u_1. The system gains a given amount of work W and looses a given amount of heat Q. If you were asked to determine the new value for the specific internal energy u_2:

 0-1/2/3

a) What engineering principle would you need to apply in order to solve this problem? (3pts)
b) Determine a set of assumptions that would simplify this problem without changing the result. (3pts)
c) Formulate an appropriate equation to solve the problem (4pts)

Part III: (10 points)

Consider the compression process shown on the P-V diagram below:



The work associated with this process is defines as:

$$W = \int_1^2 P dV \quad (1)$$

0-1/2-3/4-5

a) Find an expression for P as a function of V if the pressure rise is linear with respect to V. (5pts)
b) Using equation (1), determine the work W associated with this process **(in J)**.Verify your answer using a simpler and more straightforward method. (5pts)

Solution:

Part I:

a) The system is exchanging energy by Heat & work:
- Heat: - Convection
  - Radiation
- Work: - Electrical
  - Shaft work

b) the missing parameters are:
- Convection coefficient h
- External surface area of cylinder A
- Temperature of the surrounding T_{surr}
- Emissivity of the cylinder ε
- Shaft work W_{shaft}

2nd method:
If we have any 2nd property at the final state beside P (v, h, u then we would have two independent properties of the system and 2 using the thermodynamics table, we can extract other properties ⇒ T

Part II :

a) the conservat° of energy principle (1st Law of thermodynamics)

b) Assumptions: $- \Delta KE \simeq 0$

$- \Delta PE \simeq 0$

c) the 1st Law of thermodynamics applied to this system reads:

$$E_{in} - E_{out} = \Delta E_{system}$$

$$(\cancel{Q_{in}}^{0} - Q_{out}) + (W_{in} - \cancel{W_{out}}^{0}) = \Delta U + \cancel{\Delta KE}^{0} + \cancel{\Delta PE}^{0}$$

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

or $\boxed{u_2 = u_1 + \frac{W - Q}{m}}$

Part III :

a) Since the pressure rise is linear with respect to V :

$$P = aV + b$$

@1: $200 = 0{,}4a + b$ ①

@2: $400 = 1{,}2a + b$ ②

② − ① $\Rightarrow$ $0{,}8a = 200 \longrightarrow a = \frac{200}{0{,}8} = 250$

And $b = 100$

$\Longrightarrow$ $\boxed{P = 250V + 100}$

b) $W = \int_{V_1}^{V_2} P\,dV = \int_{V_1}^{V_2} (250V + 100)\,dV = \left[\frac{250V^2}{2} + 100V\right]_{V_1}^{V_2}$

$$\Longrightarrow W = (125 \times 1{,}2^2 + 100 \times 1{,}2) - (125 \times 0{,}4^2 + 100 \times 0{,}4)$$

$$\boxed{W = 240\,KJ = 240\,000\,J}$$

2nd method:

W is nothing else but the area under the P-V curve:

$$W = \text{Area (I)} + \text{Area (II)}$$

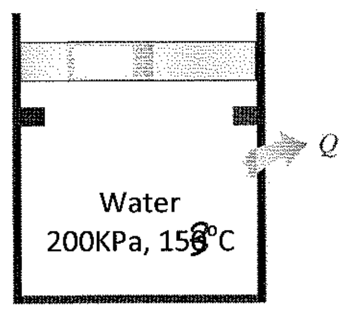
$$= 200 \times 0{,}8 + \frac{200 \times 0{,}8}{2}$$

$$= 240\ KJ$$

$$\Longrightarrow \boxed{W = 240\,000\,J}$$

Problem II (30 points)

A piston-cylinder device initially contains 2Kg of water at 200KPa and 153°C. The device is equipped with a set of stops as shown below:



a) Determine the water phase, ~~temperature~~ volume V_1, internal energy U_1, and enthalpy H_1 of water at the initial state. (7)

b) Now the cylinder looses heat and the piston falls down until it reaches the stops. At this position the volume V_2 is half the original volume V_1. Determine the new phase of water as well as T_2, U_2 and H_2. (10)

c) Now that the piston has reached the stops the cylinder keeps on loosing heat until its pressure reaches 50 KPa. Determine the new phase of water as well as T_3, U_3 and H_3. (10)

d) Make a rough sketch of the entire process 1→3 on a *P-v* diagram (3)

Solution:

a) $P_1 = 200\text{ KPa}$ & $T_1 = 153°C > T_{sat}$ @ 200KPa $= 120{,}21°C$ (Table A-5) $\Rightarrow$ $\boxed{\text{Superheated Vapor}}$

From Table A-6

@ P = 200 KPa & T = 153°C, by interpolation we get:

$u_1 = 2581{,}8\ \text{KJ/Kg} \longrightarrow U_1 = m u_1 = 2 \times 2581{,}8 = \boxed{5163{,}5\ \text{KJ}}$

$v_1 = 0{,}9671\ \text{m}^3/\text{Kg} \longrightarrow V_1 = m v_1 = 2 \times 0{,}9671 = \boxed{1{,}9342\ \text{m}^3}$

$h_1 = 2775{,}2\ \text{KJ/Kg} \longrightarrow H_1 = m h_1 = 2 \times 2775{,}2 = \boxed{5550{,}4\ \text{KJ}}$

b) $V_2 = \dfrac{V_1}{2} \Rightarrow v_2 = \dfrac{v_1}{2} = \dfrac{0{,}9671}{2} = 0{,}4835\ \text{m}^3/\text{Kg}$

and $P_2 = P_1$ since the piston is moving freely.

@ $P_2 = 200\text{ KPa} \longrightarrow v_f = 0{,}001061\ \text{m}^3/\text{Kg}$

$v_g = 0{,}88578\ \text{m}^3/\text{Kg}$

since $v_f < v_2 < v_g \longrightarrow$ $\boxed{\text{Sat. Liq.-vap. mixture}}$

$$x = \frac{v_2 - v_f}{v_g - v_f} = \frac{0{,}4835 - 0{,}001061}{0{,}88578 - 0{,}001061} = \boxed{0{,}5453}$$

- $T_2 = T_{sat} @ 200 KPa = \boxed{120,21°C}$
- $u_2 = u_f + x\, u_{fg} = 504,5 + 0,5453 \times 2024,6 = 1608,5\ KJ/Kg$

$\Rightarrow U_2 = 2 \times 1608,5 = \boxed{3217\ KJ}$

- $h_2 = h_f + x\, h_{fg} = 504,71 + 0,5453 \times 2201,6 = 1705,2\ KJ/Kg$

$\Rightarrow H_2 = 2 \times 1705,2 = \boxed{3410,5\ KJ}$

c) @ 3: $v_3 = v_2 = 0,4835\ m^3/Kg$ and $P_3 = 50 KPa$.

but for $P = 50 KPa \rightarrow v_f = 0,001030\ m^3/Kg$

$v_g = 3,2403\ m^3/Kg$

since $v_f < v_3 < v_g \Rightarrow$ **Sat. Liq.-vap. mixture**

$$x = \frac{v_3 - v_f}{v_g - v_f} = \frac{0,4835 - 0,001030}{3,2403 - 0,001030} = \boxed{0,1489}$$

And $T_3 = T_{sat} @ 50 KPa = \boxed{81,32°C}$

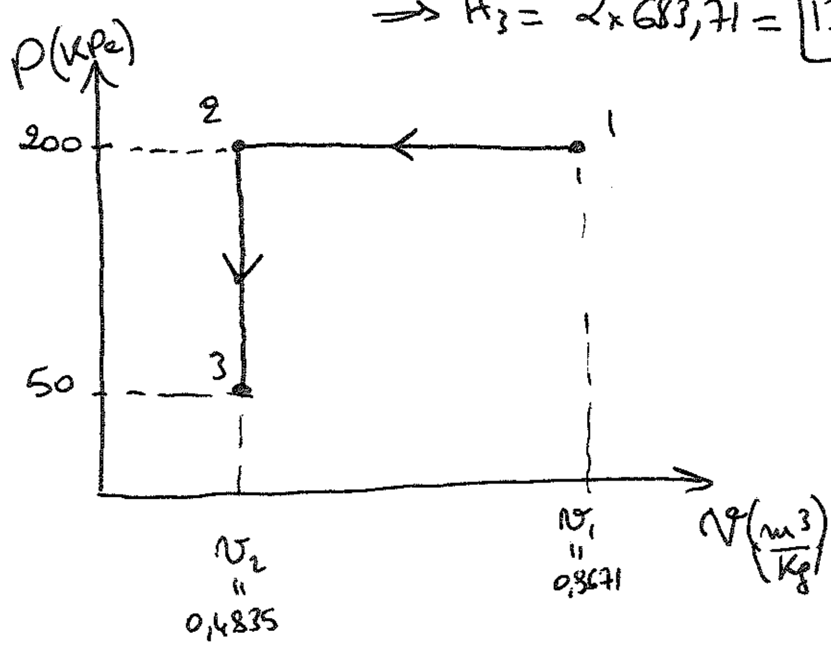
- $u_3 = u_f + x\, u_{fg} = 340,49 + 0,1488 \times 2142,7 = 659,54\ KJ/Kg$

$\Rightarrow U_3 = 2 \times 659,54 = \boxed{1319,1\ KJ}$

- $h_3 = h_f + x\, h_{fg} = 340,54 + 0,1488 \times 2304,7 = 683,71\ KJ/Kg$

$\Rightarrow H_3 = 2 \times 683,71 = \boxed{1367,4\ KJ}$

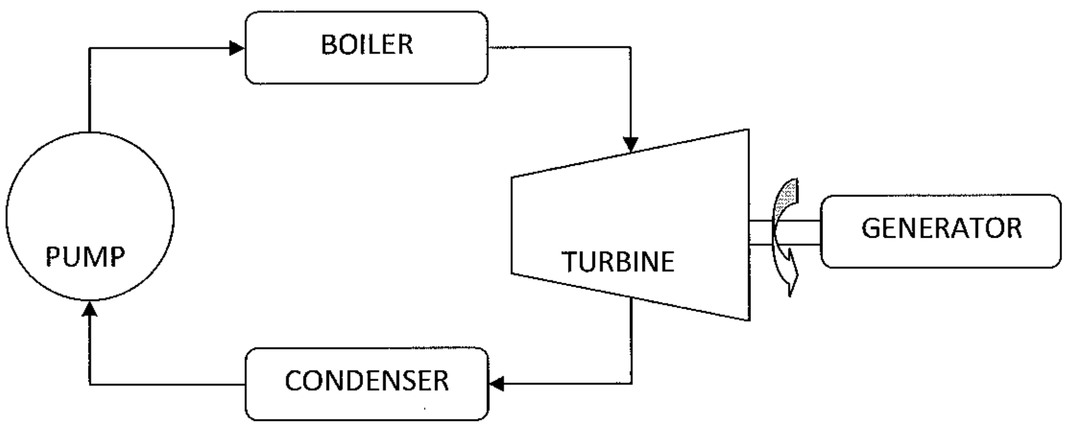
d)



Problem III (20 points)

A steam power plant is operating at full regime. Under this regime the rate amount of fuel burned in the boiler is 2.5 Kg/s and the combustion efficiency is 98%. The shaft of the turbine is rotating at a speed of 2000 rpm with a torque of 4500 N.m. The power supplied to the pump is 50 KW and the rate amount of heat generated by the boiler is 1,2 MW.

a) Determine the heating value of the fuel used
b) The thermal efficiency of the power plant
c) If the overall efficiency of the power plant is 65%, determine the efficiency of the generator.
d) Determine the electric power provided by the generator **(in MW)**



Solution:

a) $$\eta_{comb} = \frac{\dot{Q}_{boiler}}{\dot{m}_f \times Q_{HV}} \Longrightarrow Q_{HV} = \frac{\dot{Q}_{boiler}}{\dot{m}_f \times \eta_{comb}} = \frac{1,2}{2,5 \times 0,98}$$

$$\boxed{Q_{HV} = 0,4898 \text{ MJ/Kg}}$$

b) $$\eta_{th} = \frac{\dot{W}_{turb} - \dot{W}_{pump}}{\dot{Q}_{boiler}} = \frac{2\pi \dot{N} T - \dot{W}_{pump}}{\dot{Q}_{boiler}}$$

$$= \frac{2\pi \times (2000/60) \times 4500 - 50 \times 10^3}{1,2 \times 10^6} = \boxed{0,7437 \text{ or } 74,37\%}$$

c) $$\eta_{overall} = 0,65 = \eta_{comb} \times \eta_{th} \times \eta_{gen}$$

$$\Longrightarrow \eta_{gen} = \frac{0,65}{\eta_{comb} \times \eta_{th}} = \frac{0,65}{0,98 \times 0,7437} = \boxed{0,8918 \text{ or } 89,18\%}$$

d) $\eta_{gen} = \dfrac{\dot{W}_{elec,out}}{\dot{W}_{turb} - \dot{W}_{pump}}$

$$\Rightarrow \dot{W}_{elec,out} = \eta_{gen} \times (\dot{W}_{turb} - \dot{W}_{pump})$$

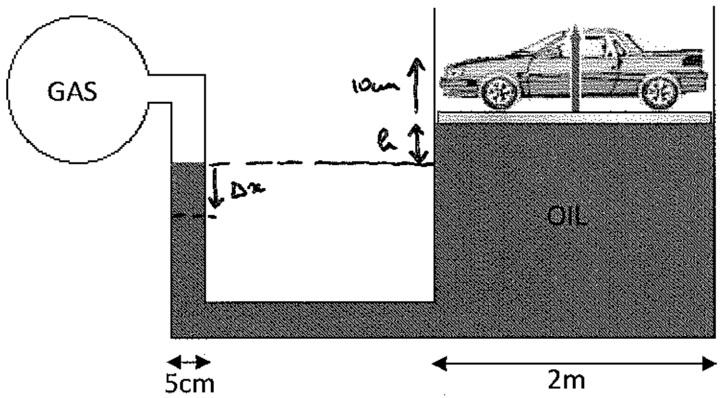
$$= 0{,}8918 \times \eta_{th} \times \dot{Q}_{boiler}$$

$$= 0{,}8918 \times 0{,}7437 \times 1{,}2$$

$$= \boxed{0{,}7959 \text{ MW}}$$

Problem IV (20 points)

Consider the hydraulic car lifter shown below. The tubes are of cylindrical shapes and their internal diameters are D_1=5cm and D_2=2m. The oil used has a density of 780 Kg/m^3.



a) Neglecting the piston's weight, determine the pressure difference ΔP inside the Gas tank if the car were to be lifted to a height of 10 cm from its original position shown above. What would this pressure become if the diameter D_1 was 10cm?

b) What would be the effect of using an oil of lower density?

Hint: the displaced volume of oil in one tube is the same that goes into the other tube

Solution:

a) Initially : $P_1 - \rho g h = \frac{mg}{A_2}$ ① where m is the mass of the vehicle

The increase in the level of oil (10 cm) corresponds to a decrease in the small tube Δx such that :

$$V = \frac{\pi D_1^2}{4} \times \Delta x = \frac{\pi D_2^2}{4} \times 0{,}1 \Rightarrow \boxed{\Delta x = 0{,}1\left(\frac{D_2}{D_1}\right)^2}$$

Since the displaced volume of oil in the 1st tube goes entirely into the second.

At the final position :

$$P_2 - \rho g(h + \Delta x + 0{,}1) = \frac{mg}{A_2} \quad ②$$

$$② - ① \Rightarrow P_2 - P_1 - \rho g(\Delta x + 0{,}1) = 0$$

$$\Rightarrow \Delta P = \rho g(\Delta x + 0{,}1) = \rho g\left[0{,}1\left(\frac{D_2}{D_1}\right)^2 + 0{,}1\right]$$

$$\Rightarrow \Delta P = 780 \times 10 \times \left[0{,}1\left(\frac{200}{5}\right)^2 + 0{,}1\right]$$

$$\Delta P = 1248780 \text{ Pa} \simeq \boxed{1{,}25 \text{ MPa}}$$

* If $D_1 = 10$ cm :

$$\Delta P = 780 \times 60 \times \left[0{,}1\left(\frac{200}{10}\right)^2 + 0{,}1\right]$$

$$= 312\,780 \text{ Pa} \simeq \boxed{0{,}31 \text{ MPa}}$$

b) If the oil was of lower density, then ΔP would be smaller and less effort would be needed to lift the car.

The END