University of Manitoba
Department of Mechanical and Manufacturing Engineering

ENG 1460 Introduction to Thermal Sciences (W11)

A01, A02, A03 (Profs. D. Kuhn, B.-C. Wang, and S. Ormiston)

Term Test # 1 15 February 2011 Duration: 90 minutes

1. You are permitted to use the textbook for the course, a one-page double-sided aide sheet, and a calculator.
2. Ask for clarification if any problem statement is unclear.
3. Clear, systematic solutions are required. **Show your work.** Marks will not be assigned for problems that require unreasonable (in the opinion of the instructor(s)) effort for the marker to decipher.
4. Use linear interpolation in the property tables as necessary.
5. Keep 5 significant figures in intermediate calculations, and use 4 or 5 significant figures in final answers. For temperature, keep two decimal places in your final answer.
6. There are **three** problems on this test. The weight of each problem is indicated. The test will be marked out of **60**.

Values

9 1. A water pipe is connected to the manometer system shown in Figure 1. The local atmospheric pressure, P_o, is 101.3 kPa and the gravitational acceleration is 9.81 m/s^2. The densities of the water, oil, and mercury are 1000.0, 800.0, and 13,600.0 kg/m^3, respectively. The heights of the liquid levels in the manometer system are given in the figure. Determine the absolute pressure at the centre of the water pipe, P_w, in kPa.

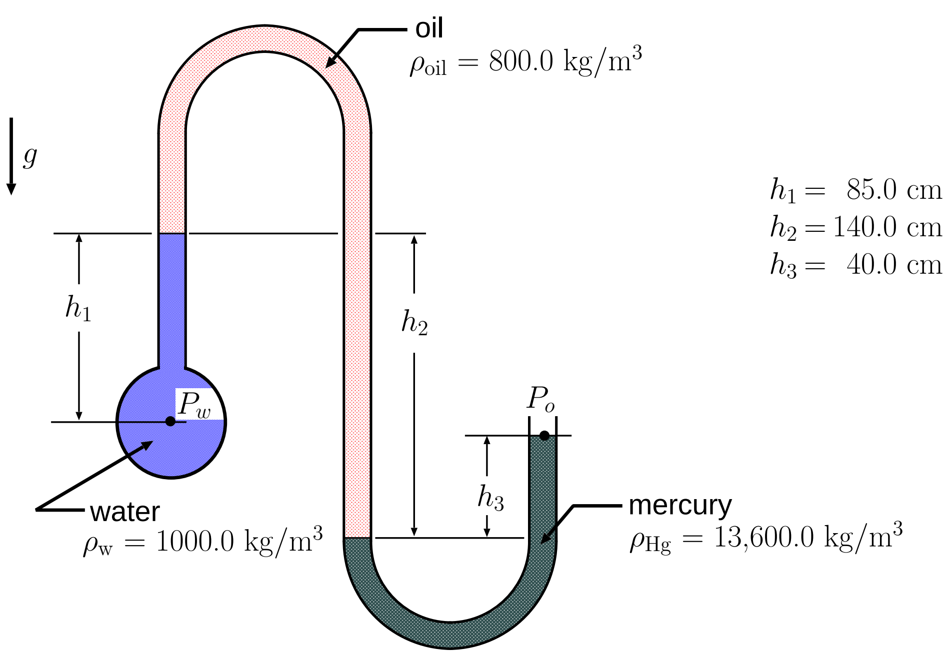

Figure 1: Schematic for Problem 1

2. A rigid tank is initially separated into Chamber A and Chamber B by a very thin plate, as shown in Figure 2. Initially, both chambers contain water under different conditions. The volume of Chamber A is $V_A = 0.203$ m^3, and the mass of the water in Chamber B is $m_{B1} =$ 0.2 kg initially. At the initial state (State 1), the temperature and pressure of the water in Chambers A and B are T_{A1}=55°C and $P_{A1} =$ 200 kPa and $T_{B1} =$ 150°C and $P_{B1} =$ 20 kPa, respectively. Then, the plate is suddenly removed and the water in the two chambers combines. The combined water in the rigid tank is then heated until the final equilibrium state (State 2)
$\boxed{29}$ is reached, with a final temperature $T_2 =$ 175°C. The volume of the plate can be ignored.

7 (a) Determine the mass of the water in Chamber A at the initial state, m_{A1}, in kg.

6 (b) Determine the volume of Chamber B, V_B, in m^3.

3 (c) Determine the specific volume of the water at the final state, v_2, in m^3/kg.

4 (d) Determine the pressure of the water at the final state, P_2, in kPa.

(e) Show the three state points (the initial states of the water in Chamber A and Chamber B, and the final state of the water) on a T–v diagram. Write out your justification for the location (region) of each state. Also show the isobaric curves/lines corresponding to P_{A1},
9 P_{B1} and P_2 on the T–v diagram. You do not need to show any process paths on the diagram.

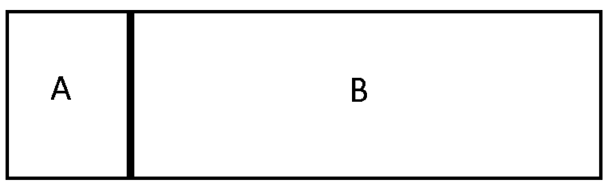

Figure 2: Schematic for Problem 2

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3. Carbon Monoxide is enclosed in the piston/cylinder system shown in Figure 3 with the piston initially fixed in position by a pin enclosing a volume of $V_1 = 200$ L (State 1). The pin is released and the piston reaches its equilibrium position (State 2) at its floating pressure P_2 and a volume $V_2 = 150$ L. The Carbon Monoxide is then cooled, coming to rest with an enclosed volume of $V_3 = 100$ L (State 3). The initial pressure of the Carbon Monoxide is $P_1 = 175$ kPa, the temperature at State 2 is $T_2 = 200°$C, and the pressure at State 3 is $P_3 = 125$ kPa. Treat Carbon Monoxide as an ideal gas.

4 (a) Calculate the mass of the Carbon Monoxide in the piston/cylinder system, m, in kg.

4 (b) Calculate the initial temperature, T_1, in °C.

3 (c) Calculate the temperature of the Carbon Monoxide at State 3, T_3, in °C.

3 (d) Calculate the mass of piston if the area of the piston is 0.002 m^2, the atmospheric pressure is $P_o = 100$ kPa, and the acceleration due to gravity is 9.81 m/s^2.

3 (e) Calculate the work done by the system in process 2 to 3, ${}_2W_3$, in kJ.

5 (f) Sketch a P–V (pressure versus volume) diagram showing all state points, temperature lines, the line for the process from State 2 to State 3, and the area representing the work done by the Carbon Monoxide during the process from State 2 to State 3. Label temperature, pressure and volume values.

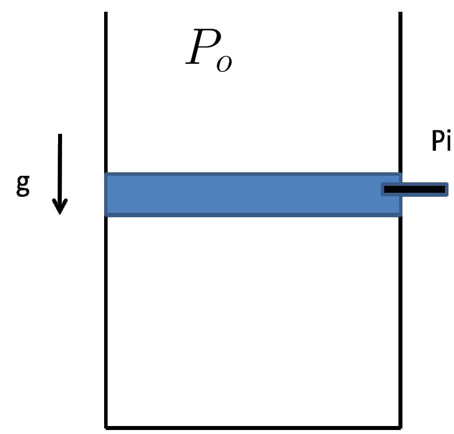
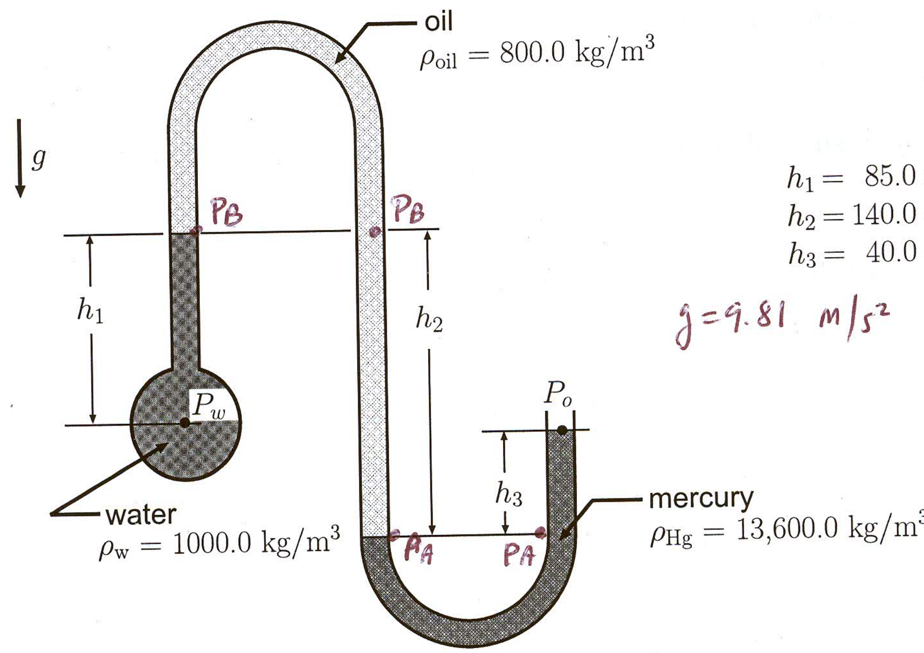


Figure 3: Schematic for Problem 3

ENG 1460 (W11) Term Test 1 Solution

1.



$h_1 = 85.0$ cm
$h_2 = 140.0$ cm
$h_3 = 40.0$ cm

$g = 9.81\ m/s^2$

$P_A = P_o + \rho_{Hg}\, g\, h_3$

$P_B = P_A - \rho_{oil}\, g\, h_2$

$P_w = P_B + \rho_w\, g\, h_1$

Combining the equations above yields

$$P_w = P_o + \rho_{Hg}\, g\, h_3 - \rho_{oil}\, g\, h_2 + \rho_w\, g\, h_1$$

$P_o = 101.3\ [kPa] = 101{,}300\ [Pa]$

$$P_w = 101{,}300 + 13600(9.81)(0.40) - 800(9.81)(1.40) + 1000(9.81)(0.85)$$

$$P_w = 101300 + 53366 - 10987 + 8339 = 152108\ [Pa]$$

$$P_w = 152.1\ [kPa]$$

Problem 2

(a) Table B.1.1

At $T_{A1} = 55°C$, $P_{sat} = 15.758$ kPa

$P_{A1} = 200$ kPa $> P_{sat}$

∴ Compressed Liquid

[Second Method:

Table B.1.2

At $P = 200$ kPa, $T_{sat} = 120.23°C$

$T_{A1} = 55°C < T_{sat}$

∴ Compressed Liquid]

At $T_{A1} = 55°C$, $v_f = 0.001015\ m^3/kg$

$v_{A1} \approx v_f|_{55°C} = 0.001015\ m^3/kg$ (method of Approximation)

$$m_{A1} = V_A / v_{A1} = 0.203/0.001015 = 200\ (kg)$$

(b) Table B.1.1

At $T_{B1} = 150°C$, $P_{sat} = 475.9$ kPa

$P_{B1} = 200$ kPa $< P_{sat}$

∴ Superheated Vapour

[Second method:

Table B.1.2

At $P_{B1} = 200$ kPa, $T_{sat} = 60.06°C$

$T_{B1} = 150°C > T_{sat}$

∴ Superheated Vapour]

Table B.1.3 At $T_{B1} = 150°C$, Interpolation:

v [m^3/kg]	P [kPa]
19.51251	10
$v_{B1} = ?$	20
3.88937	50

$$v_{B1} = 19.51251 + \frac{20-10}{50-10}(3.88937 - 19.51251)$$

$$= 15.60673\ \left(\frac{m^3}{kg}\right)$$

$$V_B = m_{B1} \cdot v_{B1} = 0.2 \times 15.60673 = 3.12135\ (m^3)$$

(C) Final state

$$V_{tot} = V_A + V_B = 0.203 + 3.12135 = 3.32435\ (m^3)$$

$$m_{tot} = m_{A1} + m_{B1} = 200 + 0.2 = 200.2\ (kg)$$

$$v_2 = \frac{V_{tot}}{m_{tot}} = \frac{3.32435}{200.2} = 0.016605\ (m^3/kg)$$

2-2

(d) Table B.1.1

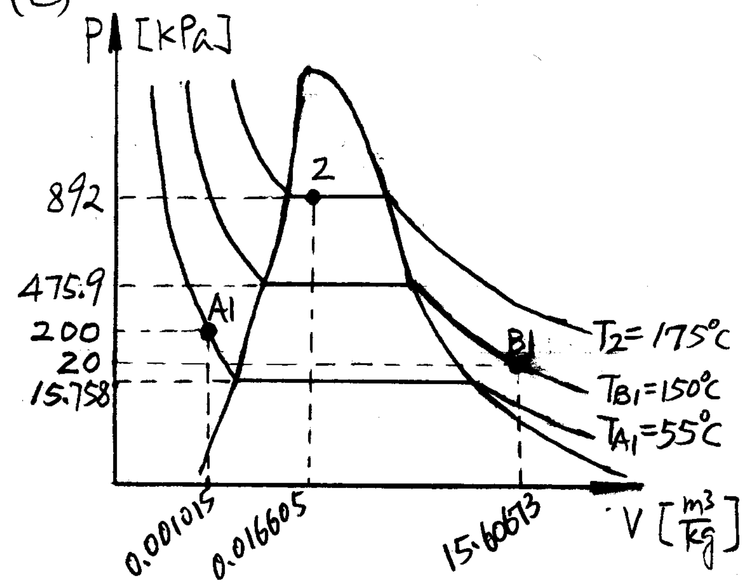
At $T_2 = 175°C$, $V_f = 0.001121 \frac{m^3}{kg}$, $V_g = 0.21680 \frac{m^3}{kg}$

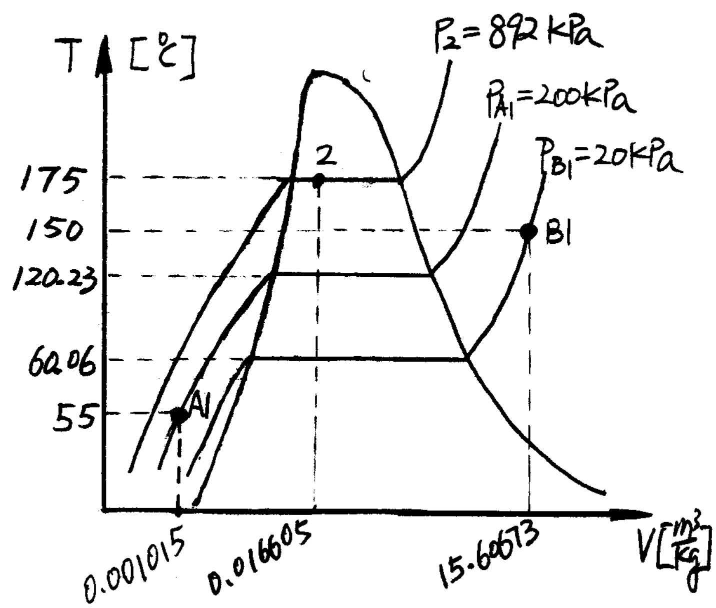
$V_f < V_2 < V_g$

$\therefore$ Saturated mixture

$P_2 = P_{sat}|_{175°C} = 892\ (kPa)$

(e)





Note that only the T-v diagram is required.

#3. a)

$$P_2 V_2 = m R T_2 \qquad \text{IDEAL GAS}$$

$$P_2 = P_3 = 125 \text{ kPa} \qquad \text{FLOATING PISTON}$$

$$V_2 = 0.150 \text{ m}^3 \qquad \text{GIVEN}$$

$$R = 0.2968 \frac{\text{kJ}}{\text{kg K}} \qquad \text{TABLE A.5}$$

$$T_2 = 200\,°C = 473.15\text{K} \qquad \text{GIVEN}$$

$$m = \frac{P_2 V_2}{R T_2}$$

$$= \frac{125[\text{kPa}] \times 0.150[\text{m}^3]}{0.2968[\frac{\text{kJ}}{\text{kg}\cdot\text{K}}] \times 473.15[\text{K}]}$$

$$= 0.13352 \text{ kg}$$

b)

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}; \qquad P_1 = 175 \text{ kPa} \quad \text{GIVEN} \qquad V_1 = 0.200 \text{ m}^3 \quad \text{GIVEN}$$

$$T_1 = \frac{P_1 V_1 T_2}{P_2 V_2}$$

$$= \frac{175[\text{kPa}] \times 0.200[\text{m}^3] \times 473.15[\text{K}]}{125[\text{kPa}] \times 0.150[\text{m}^3]}$$

$$= 883.21 \text{ K}$$

$$= 610.06\,°C$$

c) $$\frac{P_3 V_3}{T_3} = \frac{P_2 V_2}{T_2}$$

$V_3 = 0.100 \text{ m}^3$ Given.
$P_2 = P_3$

$$T_3 = \frac{\cancel{P_3} V_3 T_2}{\cancel{P_2} V_2}$$

$$= \frac{0.100\,[\text{m}^3]\,473.15\,[\text{K}]}{0.150\,[\text{m}^3]}$$

$$= 315.43 \text{ K}$$

$$= 42.28 \text{ K}$$

d) $$P_2 A = P_0 A + m_p g$$

Force Balance
$P_0 = 100$ kPa Given
$g = 9.81$ m/s² Given
$A = 0.002$ m² Given

$$m_p = \frac{(P_2 - P_0)\,A}{g}$$

$$= \frac{(125 - 100) \times 0.002 \times 1000 \left[\frac{\text{N}}{\text{kN}}\right]}{9.81}$$

$$= 5.1020 \text{ kg}$$

e) $$_2W_3 = P_2\,(V_3 - V_2)$$

$$= 125\,(0.100 - 0.150)$$

$$= -6.250 \text{ kJ}$$

f)