Name: SID: Discussion Section:

Chemical Engineering Thermodynamics 141 – Spring 2011
Tuesday, February 22, 2011
Midterm I – 70 minutes – 100 total points
One one-sided 8.5"x 11" equation sheet allowed

(20 points) 1. Consider an ideal gas.

i) (2 points) On the P-V diagram shown below, draw an isothermal curve at T_1.

ii) (3 points) Show graphically the reversible work for compression from $2V_1$ to V_1 at constant temperature T_1.

iii) (6 points) Show mathematically that the reversible work done on the system at T_1 is greater than at T_2 where $T_1 > T_2$. Begin from the definition of work.

iv) (3 points) Which one of the following expressions does not remain constant in the reversible and adiabatic expansion of an ideal gas?

a) $T V^{R/Cv}$ b) $T V^{\gamma-1}$ c) $T V^{\gamma}$ d) $P V^{\gamma}$

v) (6 points) Prove that all the other expressions remain constant. Begin from the 1st Law.

(20 points) 2. Consider you are working as an engineer in an oil refinery. A new dock is added to the refinery port. The dock will service tanker ships which have capacities of 4.5×10^7 kg. The refinery tank farm is situated at a distance of 2 km from the dock at an elevation of 50 m. Your task is to size the pump located on the dock. The station must be able to empty the tanker ships in one 8-hour shift. The density of oil is 900 kg/m^3.

ii) (5 points) If there is no pressure drop due to friction, what is the absolute discharge pressure of the pump?

iii) (15 points) What is the power output of the pump (in kW)?

(40 points) 3. A 2 kg copper block is taken out of a furnace at 250°C and quenched in a 10 L oil bath at an initial temperature of 40°C. The specific heat ($C_P = C_V$) for oil and copper are 1.7 kJ kg^{-1} K^{-1} and 0.39 kJ kg^{-1} K^{-1} respectively. The density of oil is 0.9 g/cm^3.

i) (5 points) What is the final temperature of the system?

ii) (5 points) How much heat does the copper transfer to the bath?

iii) (15 points) What is the change in entropy of the copper block, oil bath, and universe (in kJ/K)?

iv) (15 points) How long does it take to cool the oil bath back to 40°C if the ambient temperature, T_o, is equal to 20 °C? The oil loses heat at a rate of:

$$\dot{Q} = U \cdot A(T - T_o) = B(T - T_o)$$

where B = 5 J K^{-1} s^{-1}.

(20 points) 4. The thermal expansion coefficient, α, and the isothermal compressibility, κ, of a gas are given by the following expressions:

$$\alpha = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P = k_1 \frac{C_P}{C_V} T^{(C_P - C_V)/C_V}$$

$$\kappa = \frac{-1}{V}\left(\frac{\partial V}{\partial P}\right)_T = \frac{k_2}{P}$$

where k_1 and k_2 are constants. C_P and C_V may assumed to be independent of temperature.

i) (14 points) Derive a volume explicit equation of state, i.e. V = f(T,P).

ii) (6 points) Does this fluid have a critical point? Why?

Table A.1: Conversion Factors

Quantity	Conversion
Length	$1\ \text{m} = 100\ \text{cm}$ $= 3.28084(\text{ft}) = 39.3701(\text{in})$
Mass	$1\ \text{kg} = 10^3\ \text{g}$ $= 2.20462(\text{lb}_\text{m})$
Force	$1\ \text{N} = 1\ \text{kg m s}^{-2}$ $= 10^5(\text{dyne})$ $= 0.224809(\text{lb}_\text{f})$
Pressure	$1\ \text{bar} = 10^5\ \text{kg m}^{-1}\ \text{s}^{-2} = 10^5\ \text{N m}^{-2}$ $= 10^5\ \text{Pa} = 10^2\ \text{kPa}$ $= 10^6(\text{dyne})\ \text{cm}^{-2}$ $= 0.986923(\text{atm})$ $= 14.5038(\text{psia})$ $= 750.061(\text{torr})$
Volume	$1\ \text{m}^3 = 10^6\ \text{cm}^3$ $= 35.3147(\text{ft})^3$ $= 264.172(\text{gal})$
Density	$1\ \text{g cm}^{-3} = 10^3\ \text{kg m}^{-3}$ $= 62.4278(\text{lb}_\text{m})(\text{ft})^{-3}$
Energy	$1\ \text{J} = 1\ \text{kg m}^2\ \text{s}^{-2} = 1\ \text{N m}$ $= 1\ \text{m}^3\ \text{Pa} = 10^{-5}\ \text{m}^3\ \text{bar} = 10\ \text{cm}^3\ \text{bar}$ $= 9.86923\ \text{cm}^3(\text{atm})$ $= 10^7(\text{dyne})\ \text{cm} = 10^7(\text{erg})$ $= 0.239006(\text{cal})$ $= 5.12197 \times 10^{-3}(\text{ft})^3(\text{psia}) = 0.737562(\text{ft})(\text{lb}_\text{f})$ $= 9.47831 \times 10^{-4}(\text{Btu})$
Power	$1\ \text{kW} = 10^3\ \text{W} = 10^3\ \text{kg m}^2\ \text{s}^{-3} = 10^3\ \text{J s}^{-1}$ $= 239.006(\text{cal})\ \text{s}^{-1}$ $= 737.562(\text{ft})(\text{lb}_\text{f})\ \text{s}^{-1}$ $= 0.947831(\text{Btu})\ \text{s}^{-1}$ $= 1.34102(\text{hp})$

Table A.2: Values of the Universal Gas Constant

$$
\begin{aligned}
R &= 8.314\ \text{J mol}^{-1}\ \text{K}^{-1} = 8.314\ \text{m}^3\ \text{Pa mol}^{-1}\ \text{K}^{-1}\\
&= 83.14\ \text{cm}^3\ \text{bar mol}^{-1}\ \text{K}^{-1} = 8{,}314\ \text{cm}^3\ \text{kPa mol}^{-1}\ \text{K}^{-1}\\
&= 82.06\ \text{cm}^3(\text{atm})\ \text{mol}^{-1}\ \text{K}^{-1} = 62{,}356\ \text{cm}^3(\text{torr})\ \text{mol}^{-1}\ \text{K}^{-1}\\
&= 1.987(\text{cal})\ \text{mol}^{-1}\ \text{K}^{-1} = 1.986(\text{Btu})(\text{lb mole})^{-1}(\text{R})^{-1}\\
&= 0.7302(\text{ft})^3(\text{atm})(\text{lb mol})^{-1}(\text{R})^{-1} = 10.73(\text{ft})^3(\text{psia})(\text{lb mol})^{-1}(\text{R})^{-1}\\
&= 1{,}545(\text{ft})(\text{lb}_\text{f})(\text{lb mol})^{-1}(\text{R})^{-1}
\end{aligned}
$$