Exam Number:

Department of Mechanical Engineering

Michigan State University

Thermodynamics

Ph.D. Qualifying Examination

December 2009

Instructions:

- Six Questions
- Open Book, Open Notes
- All Problems Carry Equal Weight
- Solve five of the six questions

Examination Prepared By

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NOTE: Figures have not yet been provided!

1. Water (H_2O) is contained in a perfectly insulated and perfectly rigid vessel on both sides of an impermeable membrane. On one side the initial conditions are $p = 3.0$ *MPa*, $T = 700$ ºC, $m = 1kg$, while on the other side the initial conditions are $T = 100$ ºC, $x = 0$, $m = 2$ *kg*. The membrane is ruptured and the system achieves the final temperature *210ºC*.

Using conservation of mass, the first law and the second law determine:

(a) (25) The specific internal energy u_2 in the final state.
(b) (10) The volume V and the specific volume v of the vessel.
(c) (15) Whether or not this process can occur.

2. A saturated air-water vapor mixture at *20℃* and *100 kPa* is contained in a closed *5* m^3 tank in equilibrium with *1 kg* of water. The tank is then heated to *80℃*. Is there any liquid water in the tank?

3. A spark ignites a mixture of methane gas (CH_4) and air ($O_2 + 3.76N_2$) according to the stoichiometric reaction $CH_4 + 2(O_2 + 3.76N_2) \rightarrow CO_2 + 2H_2O + 7.52N_2$. For a volume ΔV of gas with radius ½ mm and initially at 300K ($\rho = 1.1$ kg/m^3) calculate:

1. The flame temperature.
2. The heat released to the gas in the volume ΔV: use $\Delta h_C = 50{,}000$ $kJ/kgCH_4$ as the overall heat release for this reaction. Note that Δh_C is written per kg of the *fuel*.
3. The heating rate, given that the heat release occurs in 10^{-2} *sec*.

4. An amount of ideal gas m (with known gas constants R, c_v) is confined by a rigid diathermal diaphragm and a floating piston in two compartments, see **Figure**. Each compartment contains ½ of the mass of ideal gas. The pressure differs in each compartment, being p_{1A} in (A) and p_{1B} in (b). The temperatures are constant and identical in both compartments, $T = T_1$.

An adiabatic process $1 \rightarrow 2$ is initiated by rupturing the diaphragm. In the end state (2) the ideal gas has unique pressure p_2 and temperature T_2. Determine the final temperature T_2, writing your solution in the form

$$\frac{T_2}{T_1} = f\left(\frac{R}{c_v}, \frac{p_{1A}}{p_{1B}}\right)$$

5. A power plant operates under the conditions shown in the **Figure** below.

(a) Calculate η_{cycle}. Also calculate η_{carnot}, *disregarding* the transfer of heat from the condenser to the water reservoir. Compare the two results and comment.

(b) What percentage of $W_{turbine}$ is W_{pump}?

(c) Plot the cycle in the *T-s* plane and include as much information as possible. Show what the *equivalent Carnot cycle* would look like using dashed lines.

(d) Calculate the mass flow of cooling water required from the water reservoir if the water reservoir inlet temperature is *15ºC* while its outlet temperature is *30ºC*. Use c_{H2O} = *4.184 kJ/kg-K*. Note that the counterflow heat exchanger consisting of condenser and water reservoir line is perfectly insulated. See the **Figure** below.

6. A 50-50 mass percent mixture of petroleum (T_{boil} = *210 ºC*) and jet fuel (T_{boil} = *163 ºC*) is injected into the combustion chamber of a jet engine at a pressure of *1 atm* and a temperature of *500 ºC*. At what temperature does the fuel mixture boil?