Exam Number:

Department of Mechanical Engineering

Michigan State University

Thermodynamics

Ph.D. Qualifying Examination

January 2004

Instructions:

- **Four Questions**
- **One Open Book, Open Notes**
- **All Problems Carry Equal Weight**

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1. (25%) A liquid (say water) has temperature $T_w(0) = T_{w0}$ in a perfectly insulated vessel. The liquid has total specific heat $C_{Vw} = m_w c_{vw}$ where m_l is the mass of water (*kg*) and c_{vw} is the per-mass specific heat (*kJ/kg-K*). At time time $t = 0$ a block of metal of temperature $T_m(0) = T_{m0}$ and total specific heat C_{Vm} is plunged into the water. Let's consider that the temperature of the metal is greater than that of the water (we are water-quenching a hot metal block). There is no work of expansion by either material. We perform two calculations. *(i)* First, by writing the first law for each material and by considering only the initial and final states, calculate the final temperature of the water and metal: call this T_∞. (ii) Second, by writing the *transient* first law for each material with a heat exchange law *of the form* $h(T-T_\infty)$ for each material (you must pick the signs correctly, but h is the *same* for both materials), we obtain two differential equations, which we solve with the given initial conditions for the temperature throughout the process. Do both materials approach T_∞ at the same rate? Why or why not?

2. (25%) In a combustor, incoming air at $T = 298K$ and incoming fuel (octane) also at $298K$ mix and combust, forming CO_2, H_2O. There is some leftover O_2 in the product gases, viz., $C_8H_{18} + \alpha(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O(v) + \beta O_2 + 3.76\alpha N_2$. Note that the H_2O is vapor, so we are looking at the Low Heating Value (LHV). For the remainder of the problem we use $\alpha = 13.5$. Determine: *(i)* the value of α, call this value α_s when the reaction is purely stoichiometric (i.e., when there is no O_2 in the products); *(ii)* Determine the value of β when $\alpha = 13.5$ (our off-stoichiometric case); *(iii)* Determine the incoming ratio of *(mass air)/(mass fuel)*; *(iv)* Determine the heat release of the chemical reaction [kJ per kg of fuel (C_8H_{18}) and kJ per kg of oxidizer (O_2)]; *(v)* Determine the adiabatic flame temperature of the product gases.

   Draw a picture representing the overall thermodynamics of you flame temperature calculations, showing the nature of the combustor (is it insulating or not, etc.) and the exact form of the first law that is used as the basis for calculating the flame temperature.

   Name *two* real-world uses for these hot gases.

   TABLE: Heats of formation of the compounds in the combustion reaction.

$\Delta h_f^0(298K)_{C8H18}$	$\Delta h_f^0(298K)_{CO2}$	$\Delta h_f^0(298K)_{H2O}$	$\Delta h_f^0(298K)_{N2}$	$\Delta h_f^0(298K)_{O2}$
-208,447 kJ/kmole	-393,546 kJ/kmole	-241,845 kJ/kmole	0	0

   NOTE: See attached property data.

1. A room of dimensions 12 ft. x 15 ft. x 8 ft. contains an air-water vapor mixture of 70^0 F, 14.7lb_f/ in^2 with a relative humidity of 20%. Calculate the mass of water vapor in the room.

2. A turbo-supercharger is to be utilized to boost the inlet air pressure to an automobile engine. This device consists of an exhaust gas-driven turbine directly connected to an air compressor as shown in the figure. Assume that the turbine and the compressor are reversible and adiabatic. Calculate the turbine exit temperature and power output.

   If the isentropic efficiency of the turbine is 85%, calculate the exit temperature and the power output of the turbine.