Introduction to Combustion MCL 343

Minor Test I

Problem 1

This problem relates to oxy-fuel combustion – when a hydrocarbon fuel is burned in pure oxygen and the products consist of only carbon dioxide and water. The water is removed by condensation, leaving a stream of pure CO_2. Consider an oxy-fuel spark-ignition engine operating according to the ideal Otto cycle. We will only look at the constant volume combustion step of the cycle. To limit the maximum temperature of the cycle, pure carbon dioxide from the exhaust is cooled down to the ambient air temperature and used to dilute the fresh fuel-oxygen mixture.

The fuel is liquid iso-octane (C_8H_{18}) and the engine operates at equivalence ratio of 0.9. The fuel-O_2-CO_2 mixture enters the engine at ambient conditions and is compressed adiabatically to 18 atm and 530K. Assume that the reactants and products behave as ideal gases.

The following species enthalpies are provided

	$\hat{h}_i$ at T=530K (KJ/mol)	$\hat{h}_i$ at T=3100K (KJ/mol)
C_8H_{18}	-167.1	---
CO_2	-383.9	-234.4
H_2O	-250.1	-109.7
O_2	7.0	102.0

(A) Assuming complete combustion, what should the mole fraction of CO_2 in the reactants be to limit the post-combustion temperature to 3100 K? What is the post-combustion pressure? **(4)**

(B) Close to 3100K, CO is not completely converted to CO_2 but is instead governed by the following reversible reaction:

$CO_2 \leftrightarrow CO + 0.5\ O_2$

which has an equilibrium constant: $\ln K_P = 10.34 - 33973/T$. Assuming this reaction to be in equilibrium at the end of the combustion step, the final temperature will shift away from 3100K. Take the degree of dissociation of CO_2 to be α, and the temperature and pressure to be P_3 and T_3 post combustion. Develop three simultaneous equations that can be solved to obtain α, T_3 ,P_3. You are not required to simplify the equations **(7)**

Assume the following thermodynamic properties to be valid near T = 3100 K:

	u[J/mol] at T=3100K	c_v [J/mol K] (constant)
CO	u_{CO}	$c_{v,CO}$
CO_2	u_{CO2}	$c_{v,CO2}$
H_2O	u_{H2O}	$c_{v,H2O}$
O_2	u_{O2}	$c_{v,O2}$

Problem 2

Choose the correct option(s) and give a physical reasoning for your choice(s).

(A) The K_P of a particular reaction is observed to increase with temperature. The reaction should be **(2)**

(I) exothermic

(II) endothermic

(B) A reaction occurring at constant T and P goes to equilibrium. Which of the following two quantities of the mixture goes to a minimum **(2)**

(I) Total Gibbs free energy, G(T,P)

(II) Standard Gibbs free energy, $G^0(T)$

Note: Standard Gibbs free energy is evaluated at the reference pressure P^0.

(C) Consider the enthalpy of formation $\widehat{h_{f,C}(T)}$ and the total enthalpy $\widehat{h_C}(T)$ of a chemical compound C. These two values are identical at **(2)**

(I) All temperatures

(II) Only the reference Temperature T^0

Note: The enthalpy of formation is the enthalpy of the formation reaction.