Assignment 2

1 (i) Determine the heat generated during the stoichiometric combustion of kerosene with nitric acid when the initial temperature of kerosene and nitric acid is 25°C. You can assume the following. Kerosene can be approximated as do-decane with a chemical formula $C_{12}H_{26}$. Nitric acid is pure and anhydrous with a chemical formula HNO_3. The standard heats of formation are given below:

$\Delta H^0{}_f\big|_{CO_2} = -390\ kJ/mole$, $\Delta H^0{}_f\big|_{H_2O} = -286\ kJ/mole$, $\Delta H^0{}_f\big|_{CO} = -112\ kJ/mole$,

$\Delta H^0{}_f\big|_{HNO_3} = -171.8\ kJ/mole$, $\Delta H^0{}_f\big|_{kerosene} = -159\ kJ/mole$.

(ii) What is the mixture ratio corresponding to the stoichiometric composition?

(iii) If the molar specific heat of the gases could be assumed constant in the temperature range of interest and are given by the following:

$CO_2 = 63\ \frac{J}{mole\ K}$, $CO = 37\frac{J}{mole\ K}$, $H_2O(g) = 58\frac{J}{mole\ K}$, $H_2O(l) = 90\frac{J}{mole\ K}$,

$N_2 = 37\frac{J}{mole\ K}$,

determine the final temperature of the gases. You can assume the combustion process to be adiabatic. The boiling temperature of water can be assumed as 100°C and the latent heat of vaporization as 40 kJ/mole.

(iv) What is the molecular mass of the combustion products?

(v) Given that the specific heat ratio of CO_2, CO, $H_2O(g)$ and N_2 are 1.32, 1.35. 1.33 and 1.4 respectively, determine the value of C* for the stoichiometric propellant combination of kerosene and nitric acid. The universal gas constant is $8.314\ \frac{kJ}{kmole\ K}$.

2. In order to get the advantage of lower molecular mass for improving the specific impulse, a mixture ratio of 4.5 is used for the combustion of kerosene and nitric acid in the rocket. The standard heat of formation of nitric acid is -172 $kJ/mole$. Using the data for the standard heats of formation, specific heats and latent heat given in the previous problem, determine:

a. Molecular mass of the combustion products by the simple procedure that hydrogen is most reactive and all nitrogen in the propellant is converted to N_2.

b. Energy released from the combustion of 1 kg of kerosene

c. Adiabatic flame temperature

d. Sea-level specific impulse ($I_{sp,SL}$) assuming chamber pressure as 7 MPa and the gases to be expanded in the nozzle to the ambient pressure of 0.1 MPa.

3. A fuel-rich mixture of kerosene and oxygen at a mixture ratio of 2.5 is burnt in a gas generator to produce hot combustion products for driving a turbine. If the molecular formula for kerosene is given by $C_{12}H_{24}$, determine:

a) Temperature of the combustion products

b) Molecular mass of combustion products.

The heat of formation ΔH_f^o in kJ/mole for kerosene = - 159, CO_2= - 390, CO= -112, and $H_2O(l)$= -286. The specific heats in J/(mole K) of CO_2 = 63, CO= 37 , $H_2O(l)$= 90 and $H_2O(g)$ = 58. The boiling temperature of water is 100°C and the latent heat of vaporization is 40 kJ/mole at 100 °C.

4. RDX having molecular formula $(CH_2NNO_2)_3$ and a standard heat of formation of +75 $kJ/mole$ decomposes to form CO_2, CO and H_2O. Determine the energy release in kJ per kg of RDX and the adiabatic flame temperature of the combustion products. You can use the data of heat of formation and specific heats given in Exercise 4.1.

5. Most of the geosynchronous satellites use the propellant combination of mono-methyl hydrazine (MMH with molecular formula $CH_3N_2H_3$) and mixed oxides of nitrogen MON-3. The chemical formula for MON-3 can be approximated to be N_2O_4. The mixture ratio used is 1.65. The standard heats of formation of MMH and N_2O_4 are +54.8 and +9.63 $kJ/mole$ respectively. Determine the following:

a. Is the mixture fuel-rich, stiochiometric or fuel-rich?

b. Determine the temperature of the combustion products using the data of standard heats of formation and specific heat given in Exercise 4.1. You can assume the initial temperature of the propellants as 25°C.

a. If the pressure in the rocket combustion chamber is 1.4 MPa, the exit pressure in the nozzle is 0.01 MPa and the pressure at the geosynchronous altitude at which the spacecraft orbits is perfect vacuum, determine the specific impulse. The ratio of the exit area of the nozzle to the throat area is 100. You can assume the C* efficiency η_{C*} =0.98 and the thrust coefficient C_F = 1.2.

6. Determine the temperature and the molecular mass of the combustion products in a cryogenic liquid propellant rocket using sub-cooled liquid hydrogen and liquid oxygen at temperatures of 18 K and 80 K respectively at a mixture ratio of 5. The standard heat of formation of H_2O is – 286 kJ/mole. The following are the thermo-physical properties of LH_2 and LOX:

Boiling temperature of LH_2: 22K

Specific heat of LH_2: 16 $\frac{kJ}{kmole\ K}$

Specific heat at constant pressure of GH_2: 30 $\frac{kJ}{kmole\ K}$

Latent heat of LH_2: 892 $\frac{kJ}{kmole}$

Boiling temperature of LOX: 90K

Specific heat of LOX: 54 $\frac{kJ}{kmole\ K}$

Specific heat at constant pressure of gaseous oxygen : 29 $\frac{kJ}{kmole\ K}$

Latent heat of LOX: 6800 $\frac{kJ}{kmole}$.

Determine the specific heat ratio of the combustion products and the characteristic velocity C* of this cryogenic propellant combination.

7. A double base propellant can be assumed to consist of 40% NG and 60% NC by mass. The other substances in the propellant such as plasticizers, curators and burn rate modifiers are in small quantities and can be neglected. Determine the number of moles of NG per mole of NC in the propellant. The chemical formula for NC can be taken as $C_6H_7O_4(NO_3)_2$ and the chemical formula for NG is $C_3H_5(ONO_2)_3$.

Is the double base propellant oxidizer-rich or fuel-rich?

8. A composite modified double base propellant is formed by adding 10% AP by mass to the double base propellant consisting of 40% NG and 60% NC by mass. Determine the ratio of moles of NC, NG and AP in the composite modified double base propellant.

9. Aniline (C_6H_7N) is used with nitric acid (HNO_3) in a liquid propellant rocket at stoichiometric mixture ratio. Determine:

a. The mixture ratio

b. If the standard heats of formation of aniline and nitric acid are 30.7 and -172 kJ/mole respectively, determine the temperature of the combustion products. You can use the values of the standard heats of formation and specific heats for the products given in this chapter. The temperature at which aniline and nitric acid are injected can be assumed as 25°C.

c. If 3% aluminium powder is added to the above propellant and if all aluminium is converted to Al_2O_3 at the cost of some carbon in the propellant not getting oxidized to CO_2, determine the heat release per unit mass of propellant. Assume there is no dissociation. The atomic mass of aluminium is 27 and the heat of formation of Al_2O_3 is -1670 kJ/mole.

10. A liquid propellant rocket, used for transferring a satellite from low earth orbit to geosynchronous orbit, uses a propellant combination comprising mono-methyl hydrazine (MMH- $CH_3N_2H_3$) and di-nitrogen tetroxide (N_2O_4). Equal volumetric flow rates of MMH and N_2O_4 are supplied to the thrust chamber. Given that the density of MMH is 865 kg/m^3 and the density of N_2O_4 is 1400 kg/m^3, determine the mixture ratio of the propellant combination used.

11. A stoichiometric mixture of hydrogen and oxygen is burnt in a rocket chamber at a chamber pressure of 3 MPa. Both hydrogen and oxygen are admitted as gas at a temperature of 25°C. Determine:

a. The heat release from combustion and the temperature of combustion products when there is no dissociation of the products of combustion.

b. The heat release from combustion and the composition and temperature of combustion products when dissociation occurs and the products comprise of H_2, H, OH and O_2 in addition to H_2O. The standard Gibbs Free Energy for H_2O, OH and H in kJ/kmole is given in the Table below at 3000, 3200, 3400, 3600, 3800 and 4000 K. The standard values of Gibbs Free energy for H_2 and O_2 is zero at all temperatures

Species	H_2O	OH	H
3000 K	-77,326	-4245	46,182
3200 K	-65,604	-6862	33,928
3400 K	-53,865	-9457	21,650
3600 K	-42,110	-12,028	9350
3800 K	-30,338	-14,576	-2967
4000 K	-18,458	-17,110	-15,229

12. A hybrid rocket is proposed to be developed using solid hydrogen at a temperature of 8 K and liquid oxygen at a temperature of 80 K. Determine the heat release from combustion of solid hydrogen and liquid oxygen at a mixture ratio of 6 and atmospheric pressure in the absence of dissociation. The freezing and boiling temperatures of hydrogen may be assumed as 14 K and 20 K and the boiling temperature of oxygen as 90 K at one atmosphere. The heat of vaporization of liquid hydrogen is 0.89 kJ/mole and the heat of melting of solid hydrogen is 1.004 kJ/mole. The heat of vaporization of liquid oxygen is 6.8 kJ/mole. The specific heats of solid hydrogen, liquid hydrogen and gaseous hydrogen may be assumed as constant and equal to 5, 20, and 30 J/ (mole K) respectively. Similarly the specific heats of liquid oxygen and gaseous oxygen could also be assumed constant at 29 and 35 J/ (mole K) respectively.

The standard heat of formation of water is -286 kJ/mole. The boiling temperature of water at 1 atmosphere is $100^{o}C$ and the specific heat of water is 90 J/ (mole K). The specific heat of steam at constant pressure could be assumed to be constant and equal to 58 J/ (mole K).