MEL 343 *Fuels, Combustion and Pollution*

Department of Mechanical Engineering

Indian Institute of Technology, Delhi

II Semester 2006-2007

Major examination

1. *This examination is closed book and closed notes. You may use data from tables, though.*
2. *Make suitable assumptions as and when required and provide a brief explanation for such.*

Duration: 2 hours | Full marks: 40

1. The length of a laminar diffusion flame (in metre) on a circular burner port is given by the following relation:

   $L_f = 1330 \dfrac{Q_{tot}(T_\infty / T_F)}{\ln(1+1/S)}$, symbols having their usual meaning. Recall that Q_{tot} (m^3/s) is the total flow rate of the nozzle fluid.

   Suppose there is primary aeration. a) Derive an expression for S in terms of S_{pure} and percentage primary aeration, ψ_{pri}. b) Consider flow of propane (Mol. Wt. 44.096) in the nozzle with 40% primary aeration (Mol Wt of air is 28.85). The temperatures of the ambient and the nozzle fluid are both 300 K. The volume flow rate of the propane-air mixture through the nozzle is 7.5 cm^3/s. The pressure is 1 atm. Determine the length of the flame. The burner diameter is 1 cm.

   c) Explain how you can calculate the length of the flame if all the stoichiometric requirement of air is supplied with the fuel stream. Write down the steps in your calculation only, you need not carry out the calculation.
   [8 marks]

2. Consider an n-heptane droplet when its diameter is 100 μm. The temperature profile in the inner zone, i.e., between the droplet and the flame is given by:

   $T(r) = (2 \times 10^{-5})r^3 - (0.0289)r^2 + (14.411)r - 232.69$ (Temperature is in K),

   where r, the radial coordinate, is expressed in μm. Determine the droplet-burning rate. The gas phase thermal conductivity has a value of 0.0926 W/mK. Assume the enthalpy of vaporization to be 316 kJ/kg. Also, P = 1 atm and $T_\infty = 300$ K. The droplet can be assumed to be at its boiling point. [5 marks]

3. For methane, the maximum laminar burning velocity in pure oxygen is 11 m/s, whereas in air the maximum burning velocity is 0.45 m/s. Explain what causes this increase in burning velocity. [2 marks]

4. Consider the reaction $CH_4 + O_2 \rightarrow CH_3 + HO_2$. Although a CH_4 molecule may collide with an O_2 molecule, a chemical reaction may not necessarily occur. List two factors important in determining whether or not a reaction occurs during a collision.
   [2 marks]

5. We considered three mass-average velocities in our discussion of species conservation: the bulk flow velocity, the individual species velocities, and the individual species diffusion velocities. How do the various velocities relate to each other? Give reasons. [2 marks]

6. The expression for minimum ignition energy is $E_{ign} = 61.6P(\frac{c_P}{R_b})(\frac{T_b - T_u}{T_b})(\frac{\alpha}{S_L})^3$ with the symbols having their usual meaning. From this expression, determine the pressure dependency of E_{ign}. [2 marks]

7. Consider a premixed flame stabilized above a circular tube. For the flame to be perfectly conical (constant angle α), what is the shape of the velocity profile at the tube exit? Explain. [2 marks]

8. Briefly explain the idea of rich-lean combustion to reduce NO_x production. [3 marks]

9. Recall mixture fraction f in connection with the discussion that we had on laminar jet diffusion flame with infinite reaction rate. The mixture fraction is given by the following equation:

   $f = Y_F + (\frac{1}{\nu+1})Y_{Pr}$, the symbols having their usual meanings.

   (a) What is the value of f at the flame? Write this value in terms of ν. Start your work from the expression for f given above.
   (b) Inside the flame, what is the possible range of f values? Justify adequately.
   (c) Outside the flame, what is the possible range of f values? Justify adequately.

   [6 marks]

10. Consider the hypothetical reaction:

    $O + CO_2 + H_2O \Leftrightarrow OH + CO + O + O + H$

    Calculate the net production rate of the oxygen atom and water in moles per unit volume per unit time. Consider both forward and reverse reactions. [3 marks]

11. A laminar flame propagates through a propane-air mixture with an equivalence ratio of 0.9, a pressure of 5 atm, and a temperature of 300 K. The flame velocity is 22 cm/s. For the unburned gases, ρ_1 = 5.97 kg/m^3 and the molecular weight is M_1 = 28.318 kg/kmol. It is also known that for the burned gas, T_2 = 2200 K, ρ_2 = 0.784 kg/m^3 and the molecular weight of the burned gases is M_2 = 28.23 kg/kmol. Find a) the velocity and b) the pressure behind the flame. Do the results conform to your expectations vis-à-vis a laminar flame? [5 marks]