ENGINEERING TRIPOS PART IIB

Monday 23 April 2012 9 to 10.30

Module 4A13

COMBUSTION AND IC ENGINES

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

There are no attachments.

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

ns03

1 Consider the following set of reactions occurring inside a closed vessel:

$$A \xrightarrow{k_1} C \qquad \text{(R1)}$$

$$A + C \xrightarrow{k_2} \alpha C + \text{product} \qquad \text{(R2)}$$

$$C \xrightarrow{k_w} \text{product} \qquad \text{(R3)}$$

$$C + M \xrightarrow{k_g} M + \text{product} \qquad \text{(R4)}$$

where k_i are specific rate constants, M is a third body, A is a reactant and C is a radical.

(a) Describe what type of reactions (R1) to (R4) are, and explain the difference between (R3) and (R4). [20%]

(b) Write an equation for the rate of change of radical concentration, $[C]$, for the above set of reactions. [10%]

(c) Using your equation for (b), show that $[C]$ is finite when

$$\alpha < 1 + \frac{k_g[M] + k_w}{k_2[A]}$$

under the steady state condition for the radical concentration. [30%]

(d) The situation under which the radical concentration becomes very large is known as a chemical explosion. Deduce a criterion involving k_2, k_w, k_g, $[A]$, $[M]$ and α for the chemical explosion using the steady state expression for the radical concentration. [30%]

(e) Show that the criterion in (d) becomes

$$\alpha \geq 1 + \frac{k_g[M]}{k_2[A]}$$

when $k_w \ll k_g[M]$. [10%]

2 A simple model for a one-dimensional planar laminar premixed flame is shown in Fig. 1. The reactant mixture at temperature T_R, having density ρ_R is flowing into the flame at a constant velocity s_l. The thermal conductivity of the reactant mixture is λ and the specific heat capacity at constant pressure is c_p. The flame zone has a thickness δ_f and the fuel consumption rate per unit volume inside the flame is $\dot{\omega}$. The combustion is assumed to be adiabatic with product temperature T_P. The gas mixture obeys the ideal gas law.

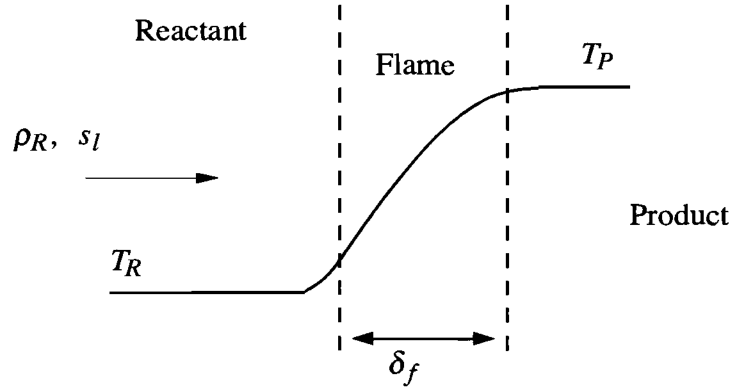

Fig. 1

(a) Deduce that $\delta_f^2 \approx \lambda / (c_p \dot{\omega})$ [20%]

(b) Deduce that $s_l \approx (1/\rho_R)\sqrt{\lambda\,\dot{\omega}/c_p}$ [20%]

(c) Consider that $\dot{\omega} \approx p^n Y_R A_f \exp(-T_a/T_P)$, where p is the pressure, n is the overall order of combustion reaction, Y_R is the fuel mass fraction in the reactant mixture and A_f is the pre-exponential factor for the reaction kinetics with activation temperature T_a. Substituting for $\dot{\omega}$ in s_l given in (b), discuss the variation of s_l with p, T_R and the equivalence ratio of the reactant mixture using carefully drawn diagrams. [40%]

(d) Using the overall mass balance across the flame, show that the velocity of the product can be written as $u_P = (1+\tau)s_l$, where $\tau = (T_P - T_R)/T_R$. Clearly state any assumptions you make. [20%]

3 (a) For a naturally aspirated port injected gasoline engine draw a carefully proportioned graph, showing how the maximum torque varies with engine speed. Also sketch on this graph a top gear road load characteristic, and representative constant power curves. Make notes to justify all the characteristics of the sketch you have produced. [40%]

(b) Comment on the differences that might be expected between the sketch you have produced for part (a) and that for a diesel engine producing the same maximum power. [10%]

(c) In the context of your answers to (a) and (b) above, describe, with appropriate explanations and sketches, how a vehicle's fuel economy might be improved by the use of

(i) continuously variable transmissions, both fully mechanical and hybrid; [15%]

(ii) turbochargers. [15%]

(d) Discuss briefly the pros and cons of electric vehicles. [20%]

4 A series hybrid powertrain has only an electrical connection between the gasoline IC engine and the transmission. With a battery, such a system allows for the possibility of improving fuel economy by running the IC engine in "start/stop" mode. To attempt an initial estimate of the possible fuel economy improvement, we wish to compare two vehicles, A and B, operated in an urban environment. Vehicle A has a conventional powertrain, and the average inlet manifold pressure is estimated to be 0.3 bar absolute. Vehicle B uses the same engine but runs in start/stop mode, and while running, is unthrottled.

The engine is assumed to run on the ideal Otto cycle with air as the working fluid with properties as at ambient conditions. The compression ratio is 10:1. The ambient conditions are 1 bar absolute and 300 K. The engine speed and AFR are fixed, and the temperature rise due to combustion at all engine running conditions is 2000 K.

(a) Assuming that there are no losses in either powertrain, determine the percentage of the time that the start/stop engine is running, and the fuel economy benefit. [60%]

(b) Discuss the practical issues that will affect the viability of such a start/stop vehicle. [40%]

You may assume without proof that the work done during the isentropic compression of a perfect gas between states 1 and 2 is given by

$$W_{12} = p_1 V_1 \left[1 - \left(\frac{V_1}{V_2} \right)^{\gamma - 1} \right] = p_1 V_1 \left[1 - \left(\frac{p_2}{p_1} \right)^{\frac{\gamma - 1}{\gamma}} \right]$$

in the usual notation.

END OF PAPER