EGT3
ENGINEERING TRIPOS PART IIB

Wednesday 27 April 2016 9.30 to 11

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.*

Write your candidate number ***not*** *your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book
Attachment: None

10 minutes reading time is allowed for this paper.

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

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

$$\mathrm{A} + \mathrm{A} \underset{k_2}{\overset{k_1}{\rightleftharpoons}} \mathrm{A} + \mathrm{A}^* \qquad \text{(R1)}$$

$$\mathrm{A}^* \xrightarrow{k_3} \mathrm{P} \qquad \text{(R2)}$$

where k_i are specific rate constants, A is a reactant and A^* is activated A which decays to a product P.

(i) Deduce an expression for the rate of formation of P if A^* is taken to be in steady state; [25%]

(ii) show that the rate of formation of P is first order in the high pressure limit and is second order in the low pressure limit. [25%]

(b) The products of methane-air combustion at an equivalence ratio of 2.0 are in chemical equilibrium at 5 bar and 1200 K. Calculate their volumetric composition, assuming that the only species present are CO_2, CO, H_2O, H_2 and N_2. Would a change in pressure affect this composition? [50%]

2 In a gas turbine combustor with premixed combustion, hot air from the compressor at 1100 K and 10 bar flows at a mass flow rate of $0.21\ \mathrm{kg\,s^{-1}}$ through a straight circular duct of diameter $D = 0.055$ m. The liquid fuel $C_{12}H_{26}$ with density $\rho_f = 800\ \mathrm{kg\,m^{-3}}$ is mixed with air inside this tube by injecting the fuel parallel to the air stream uniformly across the duct. The activation temperature for the fuel is $T_a = 15000$ K. The initial droplet diameter is 60 microns and the fuel mass flow rate is $0.01\ \mathrm{kg\,s^{-1}}$. The fuel droplets evaporate as they flow along the duct and it may be assumed that this process is isothermal at the air inlet temperature.

(a) If no combustion occurs in the duct, what is the equivalence ratio of the mixture after complete evaporation? [25%]

(b) Derive an expression for the variation of droplet diameter with time and hence calculate the length, L, of the duct required for complete evaporation. Take the mass flux of fuel to be $\dot{m}'' = \rho_f B/(4d)$ at the surface of an evaporating droplet of diameter d. Take the mass transfer number as $B = 8 \times 10^{-7}\ \mathrm{m^2\,s^{-1}}$. [40%]

(c) It is proposed that a biofuel having an activation temperature of about 10% larger than T_a is to be used in the gas turbine which has a combustor of length $2L$. Estimate the autoignition length for the biofuel if all other parameters are kept the same. Would there be any practical implications? Explain your answer. [35%]

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3 During the last year, there has been more interest in light-duty diesel vehicle emissions than normal. The press have talked about the shift from gasoline- to diesel-engined vehicles, and the effect on emissions. Discuss the issues involved, carefully highlighting the reasons for the changing popularity of gasoline vs diesels (and increasing market penetration of electric vehicles), and the exhaust aftertreatment technologies and challenges for each engine type. [100%]

4 Certain internal combustion engine cycles have been proposed that allow the expansion ratio to be greater than the compression ratio. Such a cycle can be modelled using an air standard cycle as follows: (i) isentropic compression, with a compression ratio of r_c, from state 1 to state 2; (ii) constant volume heat addition to state 3 resulting in a temperature rise of θT_1; (iii) isentropic expansion, with an expansion ratio of r_e, to state 4; and (iv) constant volume heat rejection to state 5.

(a) Draw a p-V diagram of the cycle. [20%]

(b) Assuming the clearance volume is V_c, derive an expression for the cycle efficiency in terms of r_c, r_e, and θT_1 [40%]

(c) For an Atkinson cycle, state 4 becomes state 5, i.e. a complete expansion occurs. Derive an expression for the cycle efficiency in this case. Assuming $\theta = 11$ and $r_c = 10$, compare the efficiency of the Otto (i.e. with $r_e = r_c$) and the Atkinson cycles. [40%]

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Numerical Answers - 2016

1. (b) x_{CO2} = 0.0426, x_{CO} = 0.1053, x_{H2O} = 0.1053, x_{H2} = 0.1905, x_{N2} = 0.5563

2. (a) equivalence ratio is 0.7118

   (b) Evaporation time is 4.5 ms, Evaporation length is 0.127 m

   (c) $L_{ign, bio} = 3.9 L_{ign,fuel}$

4. (c) η_{otto} = 60.2% $\eta_{Atkinson}$ = 70.4%