EGT3
ENGINEERING TRIPOS PART IIB

Thursday 26 April 2018 2 to 3.40

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

10 minutes reading time is allowed for this paper at the start of the exam.

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

1 (a) Discuss briefly the chemistry of formation of the key pollutants (other than CO_2) from natural gas combustion and describe the main methods used to minimise their emission. [40%]

(b) A laminar premixed flame sits at the top of a round pipe of radius $R = 10$ mm and has a conical shape (ignore tip curvature and wall effects). The apex of the cone is at a distance L from the exit of the pipe. The laminar burning velocity of the mixture is $S_L = 0.4$ m s^{-1} and the flow velocity of the mixture at the pipe exit is uniform across the pipe and equal to $V = V_0\,[1 + A\cos(\omega t)]$, where $V_0 = 0.8$ m s^{-1}, $A = 0.1$, t is time, and ω is a constant. Derive an expression for the time variation of L and hence, or otherwise, calculate the minimum and maximum distance of the flame's apex from the pipe exit. [30%]

(c) What do we mean by the term *quenching distance*? Discuss the physical and chemical origins of quenching at a solid wall. [30%]

2 The autoignition time, τ_{ign}, of an adiabatic, stagnant, homogeneous, flammable mixture at constant pressure with initial mass fractions $Y_{f,0}$ and $Y_{ox,0}$, temperature T_0, density ρ, and assuming negligible reactant consumption and a simple one-step chemical model characterised by an activation temperature T_{act} and pre-exponential factor A is given by

$$\tau_{ign} = \frac{1}{A\,\rho\,Y_{f,0}\,Y_{ox,0}} \frac{T_0^2}{T_{act}} \exp\left(\frac{T_{act}}{T_0}\right)$$

(a) Derive this expression, stating clearly your assumptions and the connection between fuel and oxidiser mass fractions with the temperature and their initial values. [40%]

(b) What happens qualitatively to the autoignition time if there are heat losses? Discuss separately the situations for small heat losses and very large heat losses. [30%]

(c) The autoignition process in a sequential gas turbine combustor, where cold gaseous fuel at temperature $T_{f,0}$ is injected into a hot oxidiser at temperature $T_{ox,0}$, can be modelled as the independent evolution of individual fluid particles of varying $Y_{f,0}$, spanning the range 0 (i.e. 100% oxidiser) to 1 (i.e. 100% fuel). Each fluid particle's temperature varies linearly between $T_{f,0}$ and $T_{ox,0}$ and its autoignition time is governed by the above equation. Will all fluid particles autoignite at the same time? Justify your answer. [30%]

3 (a) Discuss the differences between an ideal air-standard Otto cycle and a real cycle in a spark-ignition engine and include the corresponding $p-v$ diagrams. [35%]

(b) Discuss the advantages and limitations of *turbocharging* for a spark-ignition engine. Sketch the $p-v$ diagram of the cycle, taken to be ideal, with turbocharging. [35%]

(c) A diesel engine manufacturer proposes to replace their single-hole injection nozzles with multi-hole ones, based on a claim that such a change will reduce particulate and nitrogen oxide emissions for the same engine power. Is this claim correct? Justify your answer. [30%]

4 Consider the gas exchange processes for a typical throttled, four-stroke spark-ignition engine.

(a) Define the volumetric efficiency, and explain the relevance of volumetric efficiency to the mean effective pressure and mean power, using any necessary equations. [20%]

(b) Explain the difference between residual gas and exhaust gas recirculation, and discuss what controls the amount of either type of recirculation and their relevance. [20%]

(c) Explain the gas exchange process in a spark-ignition engine, including the range of the relevant valve timings for intake and exhaust, the expected pressures inside and outside of the cylinder, and valve overlap and its relationship with volumetric efficiency and residual gases. Use any necessary diagrams, clearly annotated. [40%]

(d) Explain any differences between the gas exchange processes for a compression-ignition engine relative to those for a spark-ignition one. Use diagrams and equations as necessary. [20%]

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Numerical answers

Q1b. Minimum length: 14.4mm; maximum length: 20.2mm