Version EM2

EGT3
ENGINEERING TRIPOS PART IIB

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Friday 3 May 2024 14.00 to 15.40

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**Module 4A13**

**COMBUSTION AND 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.**

**You may not remove any stationery from the Examination Room.**

1 (a) Discuss the advantages and disadvantages of hydrogen as potential fuel for future gas turbines from a combustion perspective. What difficulties would you expect if a conventional combustor is run on hydrogen? [30%]

(b) In an effort to decrease NO emission from a gas turbine, the designer proposes the injection of water vapour upstream of the combustor. Discuss what effect this might have on the risk of autoignition in the injector vicinity and on flame position, and why would NO emission be affected. Justify your answers. [30%]

(c) A gas turbine combustor is designed so that the primary zone has equivalence ratio 1 and the secondary (or dilution) zone has equivalence ratio 0.5. Fuel is injected only in the primary zone. Due to a manufacturing mistake, the area of the air injection holes in the dilution zone is twice the design value. What effect does this have on the equivalence ratio in the primary and secondary zones relative to the design values? What might happen to the flame stability and emissions from the defective combustor? [40%]

2 A large marine engine has a premixed ammonia-air combustion system, with the ammonia-air flame ignited by an injection of a small amount of biodiesel. About 5% of the overall power comes from the biodiesel combustion.

(a) Discuss the expected emissions from this combustion system and suggest methods to reduce them, justifying your proposals. [50%]

(b) How do you expect the autoignition time and the soot emissions to vary relative to a conventional biodiesel-only engine? How do you expect the ammonia-air flame speed to vary if we increase the amount of injected biodiesel? Justify your answers. [50%]

3 (a) In hydrogen–air combustion, the following elementary reactions occur:

$$H + OH + M \longrightarrow H_2O + M \qquad (R1)$$

$$HO_2 + H \longrightarrow OH + OH \qquad (R2)$$

Classify reactions R1 and R2 as either 'chain-initiating', 'chain-branching', 'chain-propagating' or 'chain-terminating' and justify your answers. [20%]

(b) (i) Nitric oxide formation is also present in hydrogen–air combustion and the following reactions occur:

$$N_2 + O \underset{k_{3b}}{\overset{k_{3f}}{\rightleftharpoons}} NO + N \qquad (R3)$$

$$O_2 + N \underset{k_{4b}}{\overset{k_{4f}}{\rightleftharpoons}} NO + O \qquad (R4)$$

where $k_{3f}$, $k_{3b}$, $k_{4f}$ and $k_{4b}$ are the forward and backward reaction coefficients for the reactions R3 and R4. Derive an expression for the net formation rate of NO, $\mathrm{d[NO]}/\mathrm{d}t$. [10%]

(ii) Using reactions R3 and R4, your expression from part (b)(i) and stating any assumptions made, show that

$$\frac{\mathrm{d[NO]}}{\mathrm{d}t} = 2\,k_{3f}\,[N_2]\,[O]$$

[30%]

(c) (i) Describe the mechanisms of nitric oxide generation and discuss strategies used to mitigate nitric oxide emissions from combustion applications. [30%]

(ii) For a given equivalence ratio, pressure and reactant temperature, would nitric oxide formation be greater in hydrogen–air combustion or in methane–air combustion? Justify your answer. [10%]

4 (a) (i) A burner has been developed that uses a fuel mixture of 50% hydrogen with 50% methane by volume. The air and fuel are injected separately into a pre-mixing chamber with constant mass flow rates of $\dot{m}_a$ and $\dot{m}_f$, respectively. If $\dot{m}_a/\dot{m}_f = 30$, determine the fuel–air equivalence ratio $\phi$ of the mixture. [25%]

(ii) For the same fuel–air equivalence ratio, what is the percentage change in the $CO_2$ mole fraction in this burner compared to using a fuel with 100% methane? Assume the combustion products are typical of fuel-lean combustion. [40%]

(b) (i) Briefly describe *flame blow-off*. [10%]

(ii) Discuss, with the aid of a diagram, the characteristics of a bluff-body stabilised flame. [25%]

**END OF PAPER**

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