EGT3
ENGINEERING TRIPOS PART IIB

Monday 29 April 2019 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 partial oxidation reactor operating at 1600 K and an equivalence ratio of 2.0 with a biofuel and atmospheric air is used to produce hydrogen. The biofuel molecule is $C_{17}H_{32}O_4$. The products leaving the reactor are in thermodynamic equilibrium.

(a) Would you expect thermodynamic equilibrium everywhere inside the reactor? Explain your answer. [5%]

(b) Calculate the mole fractions of gases leaving the reactor, assuming that the only species present are CO_2, CO, H_2, H_2O and N_2. [65%]

(c) Does the pressure in the reactor affect the product composition? Explain your answer. [5%]

(d) How would you increase the hydrogen yield? Explain your answer. [25%]

2 A LPP (lean premixed, prevaporised) gas turbine combustor has the following arrangement. The hot air at 1050 K and 10 bar coming from the compressor flows through a straight circular duct of diameter $D = 0.05$ m and length L before entering the combustion chamber. The mass flow rate of air is $0.214\ \mathrm{kg\,s^{-1}}$. A liquid fuel $C_{11}H_{24}$ with density of $\rho_f = 800\ \mathrm{kg\,m^{-3}}$ is mixed with air inside the duct by injecting the fuel parallel to the air stream uniformly across the duct. The initial droplet diameter is 30 μm 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 and no combustion is desired in the duct.

(a) What is the equivalence ratio of the mixture after complete evaporation of the liquid fuel? [25%]

(b) Derive an expression for the variation of droplet diameter with time and hence calculate the length 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 $B = 3 \times 10^{-7}\ \mathrm{m^2\,s^{-1}}$. [45%]

(c) Experimental tests showed that autoignition occurs half-way along the duct and a designer proposes to lower the air temperature to 980 K so that the autoignition occurs outside the duct for the same mass flow rates. Would this be a sensible proposition? Justify your answer. Take the activation temperature for the fuel to be 15000 K for your analysis. [30%]

3 (a) Why do modern Spark Ignition (SI) engines work at stoichiometric conditions? [5%]

(b) A single cylinder, four stroke SI engine with a compression ratio of 10.5, bore of 86 mm and a stroke of 86 mm is running with fully opened throttle at 2000 rpm. The gasoline fuel has a lower calorific value of 43.1 $\mathrm{MJ\,kg^{-1}}$. The torque produced by the engine is measured to be 39.5 N m and the air flow rate is 35.4 $\mathrm{kg\,h^{-1}}$. The indicated mean effective pressure is 11.1 bar. Assume that the ratio of specific heat capacities is $\gamma = 1.4$, ambient air density is 1.23 $\mathrm{kg\,m^{-3}}$ and the engine is running at stoichiometric air-fuel ratio of 14.56. Calculate the following quantities for this engine:

(i) ideal Otto cycle efficiency;

(ii) volumetric efficiency;

(iii) fuel flow rate per cycle;

(iv) brake specific fuel consumption in gram per kW h;

(v) brake mean effective pressure in bar;

(vi) brake fuel efficiency;

(vii) mechanical efficiency. [60%]

(c) Explain why Compression Ignition (CI) engines are more efficient than SI engines. [15%]

(d) Carefully sketch the islands for NO_x and soot formation in the equivalence ratio versus temperature space. Discuss salient features of these variations. Also, carefully mark the operating regimes of SI, CI and homogenous charge CI engines on this diagram. [20%]

4 (a) What is knock in spark ignition engines and why is it important? [5%]

(b) How are RON (Research Octane Number) and MON (Motor Octane Number) defined? [5%]

(c) What is fuel octane sensitivity and does it depend on fuel components? Explain your answer. [10%]

(d) Five fuels are listed in Table 1 with their RON and MON. The parameter K and Octane requirement (OR) are listed in Table 2 for three operating conditions. Arrange the five fuels in increasing order of Octane Index (OI) for each of the operating conditions. Which fuels provide adequate anti-knock quality for each of the operating conditions? [40%]

Fuel	RON	MON
A	95	85
B	98	88
C	92	84
D	98	95
Iso-Octane	100	100

Table 1

Operating condition	K	OR
1	-0.6	101
2	-0.1	93
3	0.5	85

Table 2

(e) What is preignition? What are the necessary conditions for it to occur? What property of fuel-air mixture is related to the probability of preignition and why? [20%]

(f) What is superknock? Why is it more likely to occur in turbocharged engines? Can it occur in every cycle? Explain your answer. [20%]

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Numerical Answers - 2019

1. (b) $x_{CO2} = 0.0434, x_{CO} = 0.1795, x_{H2O} = 0.0878, x_{H2} = 0.1220, x_{N2} = 0.5673.$

2. (a) Equivalence ratio is 0.6995 ≈ 0.7, (b) t_{evap} = 3 ms, L_{evap} = 0.1 m

   (c) $L_{ign}(980) = 2.585 L_{ign}(1050)$

3. (b) (i) $\eta_{otto} = 60.96\%$, (ii) $\eta_{vol} = 96\%$, (iii) 0.04052 g/cycle

   (iv) 293.877 g/kWh, (v) 9.94 bar, (vi) $\eta_{BF} = 28.42\%$,

   (vii) $\eta_{mech} = 89.55\%$

4. (d) OI for OC 1: A = 101, B = 104, C = 96.8, D = 99.8, Iso-Oct. = 100

   OI for OC 2: A = 96, B = 99, C = 92.8, D = 98.3, Iso-Oct. = 100

   OI for OC 3: A = 90, B = 93, C = 88, D = 96.5, Iso-Oct. = 100