ENGINEERING TRIPOS PART IIB

Friday 3 May 2013 2 to 3.30

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 A small-scale hydrogen generator is used to produce hydrogen from a fossil fuel. This generator is assumed to be a partial oxidation combustor operating at 1800 K and an equivalence ratio of 2.0 with $C_{10}H_{20}$ as fuel and atmospheric air as oxidiser. The products leaving the combustion chamber are in thermodynamic equilibrium.

(a) Would you expect thermodynamic equilibrium everywhere inside the combustion chamber? Explain your answer. [15%]

(b) Calculate the mole fractions of gases leaving the combustor, assuming that the only species present are N_2, CO_2, CO, H_2, H_2O. [60%]

(c) It is suggested that the conversion efficiency will increase if steam is added to the reactants. Is this qualitatively correct? Explain your answer. [10%]

(d) Does the pressure affect the composition of the products in either of the above cases? Explain your answer. [15%]

2 In a gas turbine combustor with premixed combustion, hot air from the compressor at 1000 K and 10 bar flows at a mass flow rate of $0.25\ \mathrm{kg\,s^{-1}}$ through a straight circular duct of diameter $D = 0.05$ m. The liquid fuel $C_{10}H_{22}$ 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 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? [30%]

(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 $B = 1 \times 10^{-6}\ \mathrm{m^2\,s^{-1}}$. [40%]

(c) During tests, it is found that autoignition occurs half-way along the duct which is unsafe and a designer proposes to lower the air temperature to 950 K. The activation temperature for the fuel is 15000 K. Estimate the autoignition length for the proposed air temperature if all other parameters are kept the same. [30%]

3 This question concerns a concept for an air-powered vehicle. A reciprocating expander is used to extract mechanical work from an air reservoir and propel the vehicle. The expander consists of a single piston-in-cylinder arrangement and the cycle is as follows:-

i) starting from a cylinder volume $V_1 = 0$, the inlet valve opens which admits compressed air at a pressure p_c into the cylinder.

ii) when the piston has moved so that the cylinder volume is αV_{max}, (V_{max} being the maximum cylinder volume), the inlet valve is closed, and the expansion, which may be assumed reversible and adiabatic, continues to V_{max}, at which point the pressure is p_i.

iii) the exhaust valve opens, and the piston returns to its starting position, and all the cylinder contents are ejected to the environment, which is at a pressure p_a and temperature T_a.

iv) the exhaust valve closes, and the cycle begins again.

You may assume that the reservoir temperature remains constant at T_a, and that the maximum cylinder volume is much smaller than the reservoir volume V_{res}.

(a) Sketch the cycle on a p-V diagram. [10%]

(b) Show that the maximum work extraction occurs when α is chosen such that $p_i = p_a$, and that then $\alpha = r^{-1/\gamma}$, where $r = p_c/p_a$. Explain why this result would be expected? [30%]

For the remainder of this question, assume that this optimal valve timing is used.

(c) Determine the mass flow rate of air through the engine at an engine speed of N revolutions per second and hence by differentiating the equation of state for the air in the reservoir with respect to time, find an expression for the rate of change of reservoir pressure at this condition. [30%]

(d) By use of a CVT transmission, the engine speed is adjusted to deliver the power demanded – i.e. as the reservoir pressure drops, higher values of N and increasing values of α are required to meet the same power demand, since the work per cycle is reducing. The reservoir is considered to be “empty” when a threshold power of P_t can be reached only at the maximum engine speed, $N_{\max}$. Find an expression for the reservoir pressure $p_{c,\min}$ at this condition, and hence find an expression for the total work delivered, assuming a reservoir of volume V_{res} with an initial pressure of $p_{c,\max}$. [30%]

4 (a) For gasoline engines, describe the origin of unburnt hydrocarbons, carbon monoxide and oxides of nitrogen emissions in the exhaust. How does the concentration of each pollutant vary with the engine operating variables – speed, AFR, spark advance, manifold pressure and EGR rate? [50%]

(b) For Diesel engines, describe the origin of oxides of nitrogen and particulate emissions in the exhaust. How does the concentration of each pollutant vary with the engine operating variables – speed, AFR, start of injection and EGR rate? [50%]

Use carefully proportioned qualitative graphs as necessary.

END OF PAPER