ENGINEERING TRIPOS PART IIB

Monday 4 May 2009 2:30 to 4

Module 4M15

SUSTAINABLE ENERGY

*Answer not more than **two** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of the question is indicated in the right margin.*

There are no attachments.

STATIONERY REQUIREMENTS
Single-sided script paper
Single-sided graph 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

1 Bio-diesel can be produced by esterification of vegetable oil using methanol as shown in fig. 1. The process also produces two waste products, the husk from the oil-containing seeds, and glycerol.

(a) i) What is meant by lifecycle analysis? Why are reference systems sometimes used to allocate environmental burdens? [10%]

ii) For the system shown in fig. 1, calculate the total energy input required to produce 1 kg of bio-diesel. The waste husks and glycerol are incinerated (without recovering any energy). The land used to grow the crop would otherwise have been set-aside fallow land. Only the agriculture, oil extraction and esterification contribute significantly to the environmental burden. The embodied energy associated with machinery and process equipment etc. can be neglected. [15%]

(b) Two schemes for dealing with the waste products are to be evaluated: Case A, the husks and glycerol are combusted in a small local power station which has a thermal efficiency of 30%; Case B, the husks and glycerol are burned in a combined heat and power plant (CHP) with a thermal efficiency of 20%. The heat produced from the CHP displaces heat produced by natural gas. What is the new embodied energy of the bio-diesel in **both** case A and case B if:

i) Environmental burdens are allocated by price, and the bio-diesel can be sold for £1000 per tonne? [15%]

ii) Environmental burdens are allocated by substitution? [20%]

(c) In the light of your answers to (a) and (b), do bio-fuels for transportation make sense from a sustainability point of view? What other issues need to be considered? [40%]

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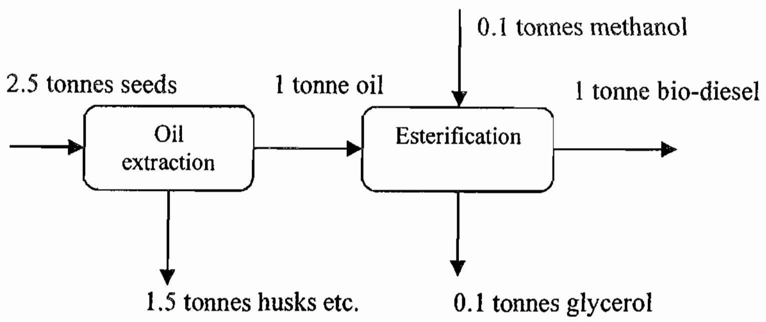

Fig. 1

Data:

Agriculture

Rapeseed can be grown with a seed yield of 3 tonnes ha^{-1} yr^{-1} (tonnes per hectare per year), requiring 50 L ha^{-1} yr^{-1} of diesel to power farm machinery and 0.3 tonnes ha^{-1} yr^{-1} of nitrate fertiliser (n.b. 1 tonne = 1000 kg). The fertiliser has an embodied energy of 42 GJ per tonne.

Fallow land requires cultivation less frequently and so requires only 10 L ha^{-1} yr^{-1} of diesel to power farm machinery.

The calorific value of diesel is 42 MJ L^{-1}.

Oil extraction

The extraction process uses 3 GJ per tonne of oil produced. The calorific value of the husks is 17 GJ per tonne.

Esterification

Esterification requires 4 GJ per tonne of bio-diesel to run the process. The embodied energy of methanol is 45 GJ per tonne. The calorific value of the glycerol is 17 GJ per tonne.

Co-products

The heat from the CHP can be sold for the same price per unit energy as natural gas, which is £20 GJ^{-1}. Electricity is worth £70 GJ^{-1} and (on average in the UK) 2 GJ of fossil fuel energy are needed to generate 1 GJ of electricity. The calorific value of bio-diesel is 40 GJ per tonne.

(TURN OVER

2 A partial oxidation plant, shown in fig. 2, is to be used to make hydrogen from methane. The partial oxidation reactor produces a large amount of heat (all released at the same temperature as the outlet of the reactor), which can be used to drive the rest of the process.

(a) (i) The separation process produces streams of pure H_2, CO_2 and water. What are the molar flows of the streams leaving the process? [10%]

(ii) If the molar ratio of CO to CO_2 in the outlet of the partial oxidation reactor is 1.2, how much heat is released by the partial oxidation reactor for a feed of 1 kmol s^{-1} of methane? [20%]

(b) The shift reactor produces an additional 100 MJ of heat per kmol of CH_4 at a temperature of 600 °C. The separation process requires a heat input of 250 MJ per kmol of CH_4 at a temperature of 200 °C and rejects 268 MJ of heat per kmol of CH_4 at a constant temperature of 25 °C. The CH_4 feed is to be preheated to 600 °C, and can be assumed to have a constant heat capacity of 51.7 kJ $kmol^{-1}$ K^{-1}.

(i) By interval analysis, or otherwise, determine the maximum amount of heat which can be recovered, and hence the net heating and cooling requirements for this process. [20%]

(ii) Plot the grand composite curve for this process. If all the waste heat were to be used, what is the maximum amount of work which could be generated? [20%]

(iii) In practice, the waste heat from the process is used in a steam turbine cycle (which absorbs heat at a constant temperature of 350 °C, and rejects heat at 25 °C) with a thermal efficiency of 30%. What is the exergetic efficiency of the overall process, given that the exergy of the methane entering the plant is 830 MJ $kmol^{-1}$? You may neglect the exergy flows associated with the O_2 entering and CO_2 leaving the plant. [30%]

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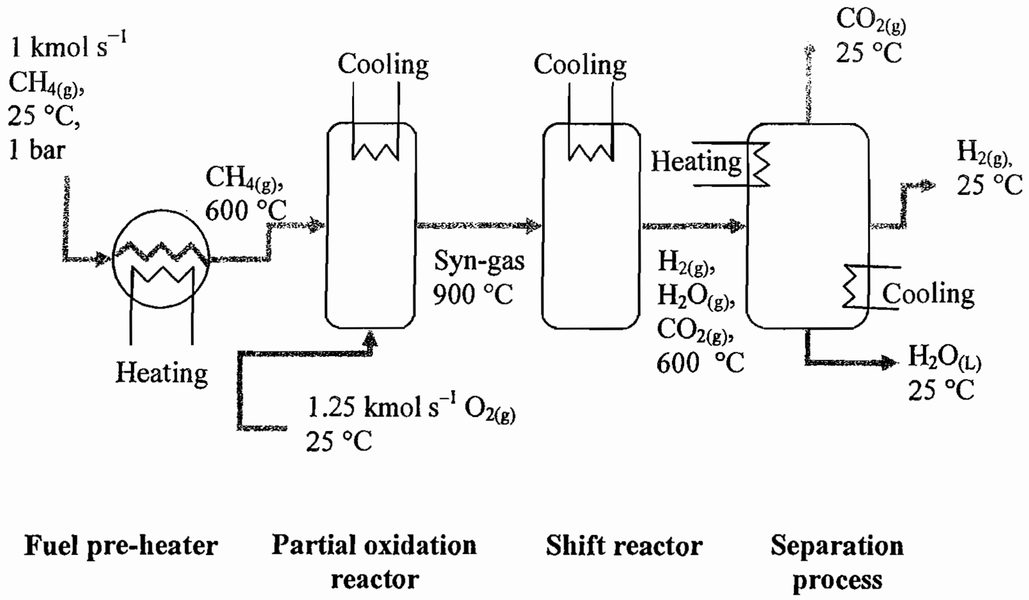

Fig. 2 (n.b. all streams at 1 bar)

Data:

Enthalpy and entropy of pure components at 1 bar (consistent reference state)

	Enthalpy ($kJ\ kmol^{-1}$)			**Entropy ($kJ\ kmol^{-1}\ K^{-1}$)**		
	25 °C	**600 °C**	**900 °C**	**25 °C**	**600 °C**	**900 °C**
$CH_{4(g)}$	-74600	-44893	-22537	186.4	238.7	260.7
$CO_{(g)}$	-110535	-93008	-83024	197.7	230.1	239.9
$CO_{2(g)}$	-393510	-366895	-350542	213.8	262.0	278.1
$H_2O_{(g)}$	-241826	-220956	-208481	188.8	227.2	239.5
$H_{2\,(g)}$	0	16875	25964	130.7	162.1	171.1
$O_{2(g)}$	0	18324	28814	205.1	238.9	249.2
$H_2O_{(L)}$	-285830			69.9		

The environment is defined to be: T_o = 25 °C (298.15 K), P_o = 1 bar. The atmosphere may be assumed to consist of 79% N_2, 21% O_2, 0.04% CO_2 (molar composition). Water may be assumed to be a pure liquid in the environment.

(TURN OVER

3 A battery manufacturer is trying to persuade the UK government to force all car makers to start manufacturing plug-in electric vehicles, as an alternative to petrol and diesel fuelled vehicles. They also claim that no further increases in the efficiency of petrol or diesel fuelled vehicles are possible, and that the change to battery powered vehicles will drastically reduce the impact of vehicle emissions on the environment.

(a) Are the battery manufacturers correct when they say that petrol and diesel engines already operate at their maximum efficiency? If not, how can cars powered by internal combustion engines be made more efficient? Explain your reasoning. [33%]

(b) The battery manufacturer claims that if customers buy the electricity to charge the electric cars using the "*Green-Nuclear*" tariff offered by *Electricity R' Us plc.*, the cars are CO_2-neutral. In their product literature, *Electricity R' Us plc.* state that they will purchase the same number of units of electricity from nuclear power generators, as a customer of the "*Green-Nuclear*" tariff uses in a year. What are the arguments for, and against the claim of CO_2-neutrality, if the electricity for the electric cars is supplied via the "*Green Nuclear*" tariff? [33%]

(c) Does nuclear power meet the definition of a sustainable energy technology? How do the proposed future nuclear fission power stations address the concerns of the public? [33%]

END OF PAPER