ENGINEERING TRIPOS PART IIB

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Monday 7th May 2007 2:30 to 4:00

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Module 4M15

SUSTAINABLE ENERGY

*Answer not more than **three** 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.

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 (a) (i) State briefly why hydrogen cannot be regarded as an energy source. In what form is energy stored in hydrogen? [5%]

(ii) Describe three ways in which hydrogen can be produced from fossil fuels. [35%]

(b) A chemical plant (shown in Fig. 1) is to produce $H_2$ from methane.

(i) How much energy needs to be supplied to the plant?

(ii) What is the change in availability of per kmol of methane used?

(iii) How much work could be extracted by diluting the $CO_2$ to the atmospheric concentration (i.e. the exergy of the $CO_2$ stream leaving the plant)?

(iv) The exergy flow of methane entering the plant is 829.8 MJ/kmol. What is the ratio of the exergy in the $H_2$ to the exergy in the methane feed stock? Comment on the thermodynamic feasibility of the process in light of your answer. [60%]

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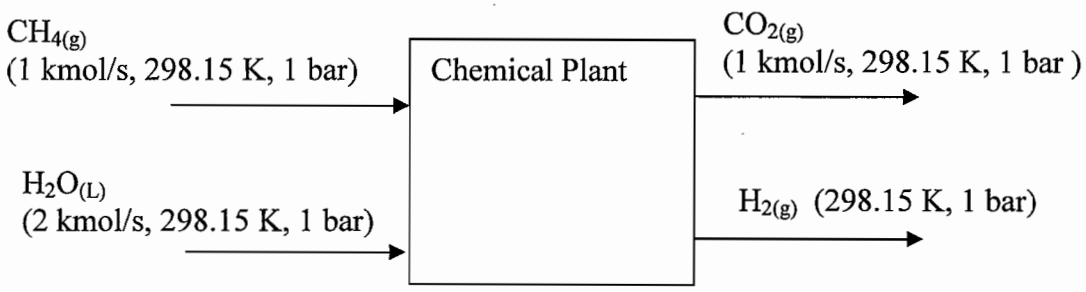


Fig. 1

**Data**

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 is present in the environment as a pure liquid.

| Enthalpy and entropy of pure components at 298.15 K and 1 bar (consistent reference state) | | |
|---|---|---|
| Species | Enthalpy (kJ/kmol) | Entropy (kJ/kmol/K) |
| $CH_{4(g)}$ | -74600 | 186 |
| $O_{2(g)}$ | 0 | 205 |
| $N_{2(g)}$ | 0 | 192 |
| $CO_{2(g)}$ | -393510 | 214 |
| $H_{2(g)}$ | 0 | 131 |
| $H_2O_{(L)}$ | -285830 | 70 |

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2 (a) Describe briefly the principle of lifecycle analysis. Your answer should describe what is meant by the product system, the system boundary and elementary flows (both inputs and outputs). [20%]

(b) Define the embodied energy and $CO_2$ foot-print of a product/substance. [15%]

(c) A company is considering converting its cars from petrol to a mixture of 85% petrol, 15% bioethanol. The bioethanol is to be produced from corn.

(i) For a functional unit of 1 L of ethanol, draw a flow diagram and perform a simplified life cycle analysis to work out the "field to tank" energy input.

(ii) The net energy benefit is defined as the amount of energy in the fuel divided by the energy required to make the fuel. Comment on the net energy benefit for corn ethanol.

(iii) Can the $CO_2$ foot-print associated with the ethanol be calculated? [45%]

(d) The company's cars are typically driven 10,000 km per year. When running on petrol they have a fuel economy of 15 km/L. Assuming the efficiency of the car when expressed in km/GJ remains constant, how much fossil fuel energy will be saved per car by switching to the petrol/ethanol blend? Express your answer as a percentage of energy used if driving on 100% petrol and comment on what action the company should take? [20%]

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**Data**

*Farm data*

The corn crop yield is 10,000 kg /hectare/year.

The embodied energy in fertilizer etc. and labour used in farming is 18.4 GJ/hectare/year.

On average the farm uses 600 kg of machinery/equipment per hectare. This equipment has a service life of 15 years. The equipment is produced from steel, and requires 50 % of the embodied energy of the material to assemble.

The embodied energy of steel is 24 MJ/kg.

*Transport*

Transportation of the corn to a processing facility requires 0.3 MJ/kg of corn.

*Processing*

Each kg of corn processed requires an input 3.9 MJ of energy and will produce 0.3 L of ethanol.

All energy inputs can be assumed to be fossil-derived (non-renewable).

The calorific value ethanol is 21.3 MJ/L.

The calorific value of petrol is 31.6 MJ/L.

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3 Define "sustainability" and discuss what is meant by sustainable energy. Can the free market and improved technology alone deliver sustainable energy? Justify your answer. [100%]

4 (a) With the aid of an appropriate diagram, show how the maximum torque from a gasoline engine varies with engine speed. Explain the shape of the curve you have drawn. [25%]

(b) On the same figure show how the "road load" torque varies with engine speed, explaining the trend you have suggested. [25%]

(c) Add to this figure contours of constant specific fuel consumption, justifying what you have sketched. [25 %]

(d) Add constant power curves to the figure, then discuss how the fuel economy of gasoline powered vehicles might be improved, with minimum sacrifices in performance. [25 %]

**END OF PAPER**