ENGINEERING TRIPOS PART IIB

Wednesday 9 May 2012 9-10.30

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

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) Define "availability". How does "exergy" differ from "availability"? [15%]

(b) A power station (shown schematically in Fig.1.) is to be fitted with a post-combustion carbon capture system. The power station burns methane with 20% excess air and the flue gases are cooled to 523 K before being vented to the atmosphere (or when the capture plant is fitted, sent to the capture plant). The heat released from the combustion process is transferred to the power cycle (based on a steam cycle), which can be approximated here by two heat engines, the first, with a thermal efficiency η_1 =0.3, takes heat from the combustion process, and rejects heat at T_1 to the second heat engine. The second heat engine can be approximated by a Carnot engine, which rejects heat at the temperature of the environment T_e. Considering the case without the carbon capture plant,

(i) Using data from table 1, calculate the heat absorbed by the power cycle per kmole of CO_2 released. [20%]

(ii) How much work is generated per kmole of CO_2 released? [10%]

(c) The capture plant is driven by a supply of heat, absorbing heat at T_1, and rejecting it at T_2. The heat required to drive the plant is taken from the heat rejected from the first heat engine in the power cycle as shown in Fig.1.

(i) If work, rather than heat were to be used to drive the capture plant, show that the minimum amount of work per kmole of CO_2 (W_{min}) needed to separate the flue gases, as shown in Fig.1, is about 8600 kJ kmol^{-1}. [15%]

(ii) Show that, if the capture process is assumed to be reversible, the heat which must be diverted from the power cycle, Q_{cc}, is given by

$$Q_{cc} = \frac{T_2 W_{min}}{T_e\left(1 - \frac{T_2}{T_1}\right)}$$

and calculate the loss in electrical work output caused by the addition of the carbon capture plant. [20%]

(iii) If the heat rejected by the carbon capture plant could be recovered and used to generate work, what is the minimum energy penalty possible for the system shown? Comment on your answer in light of your answer to (c) (ii). [20%]

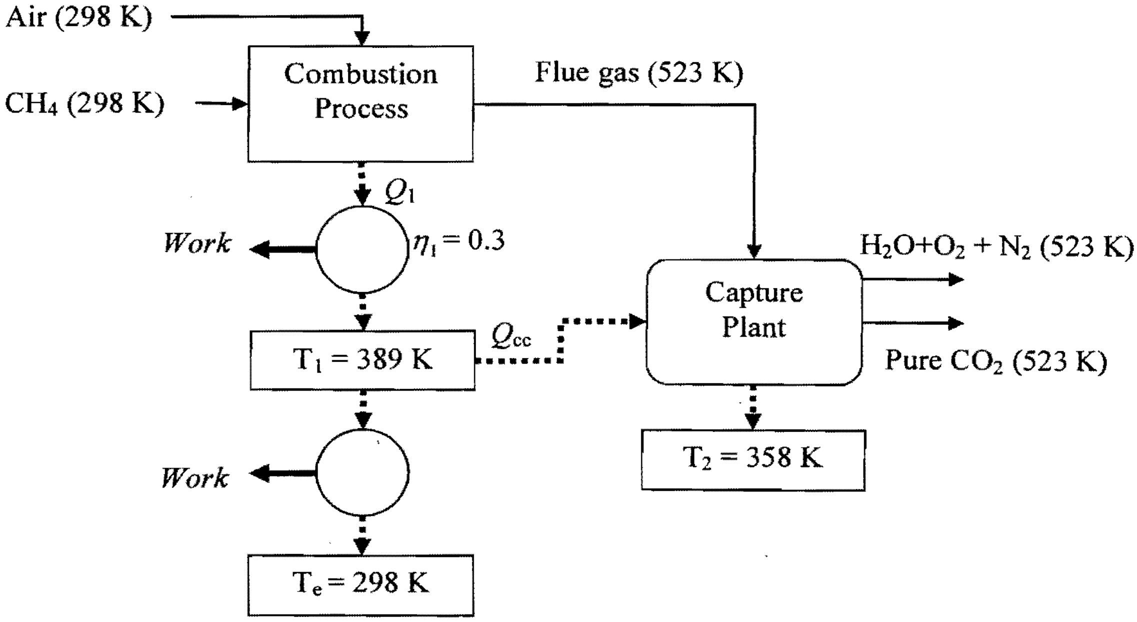

Fig 1.

Additional data for Q1

Table 1. Enthalpy (kJ $kmol^{-1}$) with respect to a mutually consistent reference state.

Species	Enthalpy at 298 K	Enthalpy at 523 K
CH_4	-74600	-65280
H_2	0	6560
O_2	0	6808
H_2O	-241826	-234083
CO_2	-393510	-384162
N_2	0	6597

Air can be assumed to be 21 mol.% O_2, 79 % N_2.
All gases can be assumed to behave ideally.

2 (a) (i) When performing a lifecycle assessment (LCA), why are reference systems used? [10%]

(ii) Briefly describe the problem of allocation in the context of LCA, and the method of allocation by substitution. [20%]

(b) A business proposes to reduce its environmental burden by using biodiesel produced from rapeseed (with a calorific value of 30 MJ kg^{-1}) to fire the existing boiler in its premises (which currently runs on natural gas). Taking a functional unit as 1 GJ of heat delivered to the premises (and using the data below) calculate:

(i) The overall saving in global warming potential (GWP). [20%]

(ii) The overall saving in fossil energy. [10%]

(c) In light of your answers to (b) provide a critical assessment of the proposal and suggest whether or not the proposal should go ahead. You should also consider the wider issues that arise when using biofuels, and suggest how, if the aim was simply to reduce global warming potential, the proposal could be modified. [40%]

Additional data for Q2

Over the lifecycle of biodiesel the direct input of energy and embodied energy used to make the biodiesel is 20 MJ per kg of biodiesel (including agricultural inputs, machinery, processing etc.). The GWP associated with the production of the biofuel is 3 kg CO_2equivalent per kg of biodiesel.

The co-products associated with the biodiesel are to be combusted in a nearby coal fired power station, and have an equivalent energy (i.e. heating) value of 30 MJ per kg of biodiesel produced.

0.8 hectares of land are required to produce enough rapeseed for 1000 kg of biodiesel in a year. Half of the rapeseed is to be grown on virgin land, which when converted to agricultural use results in a large release of CO_2 (taken here to be equivalent to 6000 kg per hectare per year). Half is to be produced on existing, but unused, arable land, resulting in no additional CO_2 when it is brought into use. However, the unused arable land requires some maintenance requiring an energy input of 6 GJ per hectare per year.

The local power station burns coal. The combustion of the coal produces 4 MJ of heat for every kg of CO_2 released.

When burning natural gas, the boiler can deliver heat with a CO_2 footprint of 0.06 kg CO_2equivalent per MJ of heat. The boiler can be assumed to be 100% efficient.

3. (a) Describe the principles which govern the operation of a solar photovoltaic panel, and with reference to the characteristics of a suitable equivalent circuit explain the function of a Maximum Power Point Tracker. [25%]

(b) Write brief notes to explain the following points to an engineering colleague who is unfamiliar with internal combustion engine technology. You may wish to illustrate your arguments with diagrams where appropriate

(i) Why the crank angle over which combustion takes place is roughly independent of engine speed in a spark ignition engine. [10%]

(ii) Why a throttle is needed to vary the load of a spark ignition engine. [15%]

(iii) Why the compression ratio of a spark ignition engine is limited, and the effect this has on the typical engine configurations. [15%]

(iv) With reference to your answers to (ii) and (iii), the factors which affect the relative efficiency of diesel vs. spark ignition engines. [15%]

(v) How turbo-charging an internal combustion engine can improve the specific fuel consumption, but may introduce other problems. [20%]

END OF PAPER