ENGINEERING TRIPOS PART IIB

Tuesday 10 May 2011 9 to 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
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

Sas06

1 (a) Starting from the change in availability flow, ΔB, caused by heat transfer,

$$\Delta B = \int_{T_1}^{T_2} \left(1 - \frac{T_0}{T}\right) d\dot{Q}$$

show that the irreversible loss in availability ($T_0 S_{irrev}$) caused by transferring heat between the hot and cold streams in a heat exchanger is given by;

$$T_0 S_{irrev} = T_0 F_h \ln\left(\frac{T_{2h}}{T_{1h}}\right) + T_0 F_c \ln\left(\frac{T_{2c}}{T_{1c}}\right)$$

where F is the heat capacity flow rate, T_1 and T_2 are the initial and final temperatures of the material passing through the heat exchanger and T_0 is the temperature of the environment. The subscripts h and c refer to the hot stream and the cold stream, respectively. [15%]

(b) A petroleum processing plant has an energy recovery system; the plant is old and the heat integration is not optimal. Fig. 1 shows the arrangement of heat exchangers used to recover heat from streams two hot streams (labelled as [1] and [2]), into two cold streams (labelled as [3] and [4]). The initial temperature for each stream, and the temperatures at the exit of each heat exchanger are also shown. The heat capacity flow rate for each stream is 1 kW °C^{-1}.

(i) How much heating and cooling are required by the scheme shown in Fig. 1? Calculate the minimum amount of exergy which must be supplied by the heating utility, and the maximum which can be recovered into the cooling utility. [15%]

(ii) Assuming all the material flows are reversible, and the hot and cold utilities are supplied reversibly, how much availability is lost in the current design through irreversibility? [20%]

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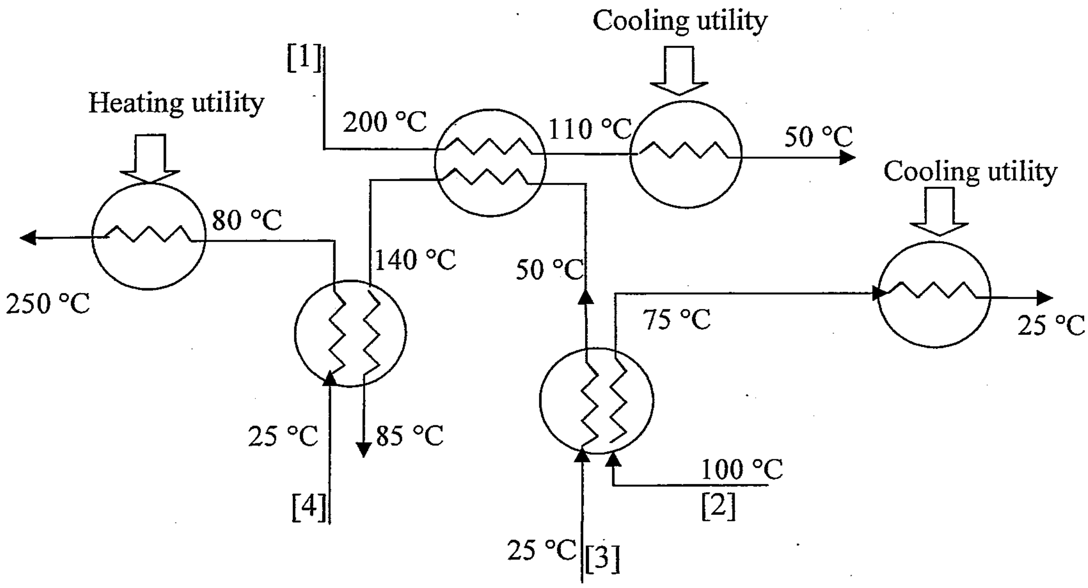


Fig. 1

(c) The heat energy recovery is to be optimised, such that the initial and final temperature of each stream is the same as that in Fig. 1.

(i) What are the minimum amounts of heating and cooling utility required? [20%]

(ii) What is the minimum amount of exergy which must be supplied by the heating utility in the optimised scheme? [10%]

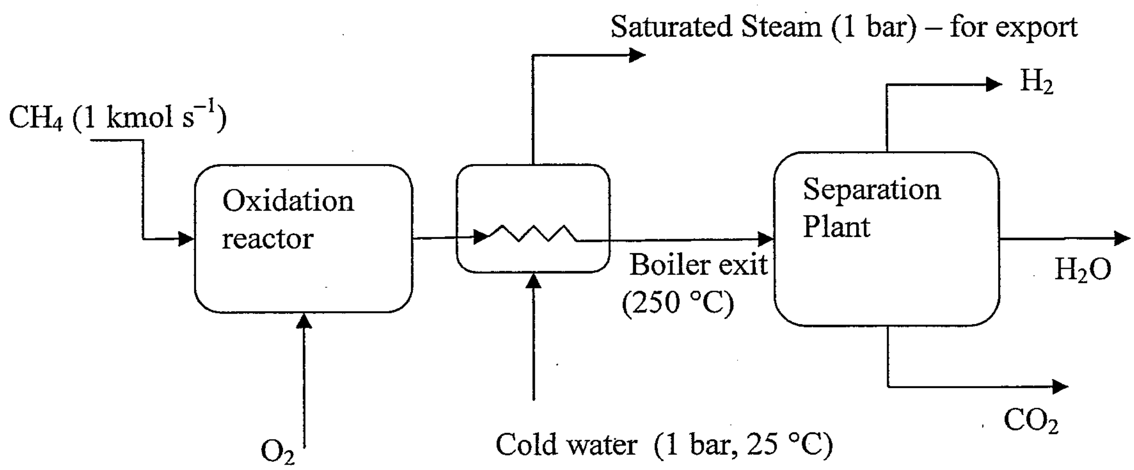
(iii) For this new heat integration scheme, what is the loss in the availability caused by irreversibility? Why would the heat integrated design result in the lowest possible availability loss? [20%]

2 (a) In the context of life cycle analysis, discuss three methods of allocating burdens between co-products, and their relative advantages and disadvantages. [25%]

(b) A methane partial oxidation plant consumes 1 kmol s^{-1} of methane and operates with an oxygen inflow of 62.5% of that required for stoichiometric combustion. A diagram showing the plant is given in Fig. 2. All the products from the reactor are cooled to 250 °C, raising steam at 1 bar in the boiler. As the syngas passes through the heat exchanger tubes in the boiler, its composition changes via the water-gas shift reaction, leaving only H_2O, H_2 and CO_2 at the boiler exit. No reaction takes place in the separation plant. The steam raised in the boiler is a co-product which is exported to other users. Some additional data about the plant is given overleaf.

(i) How much hydrogen is produced by the plant? [15%]

(ii) How much steam can be exported? [15%]



All material streams at 25 °C and 1 bar unless otherwise stated

Fig. 2

(c) (i) What is the combined global warming potential of the hydrogen AND the steam produced by the plant? [20%]

(ii) What is the global warming potential of the hydrogen if allocation by substitution is used to account for the co-product of steam? You may assume that the steam would otherwise have to be provided by a steam boiler, which burns methane stochiometrically in air producing only CO_2 and H_2O, and would otherwise be identical to the plant shown in Fig. 2, but without the separation plant. [25%]

(cont.

Additional data for Q2

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

Species	Enthalpy at 25 °C	Enthalpy at 250 °C
CH_4	-74600	-65280
H_2	0	6560
O_2	0	6808
H_2O	-241826	-234083
CO_2	-393510	-384162
N_2	0	6597

Table 2. Emissions to atmosphere associated with the delivery of natural gas and oxygen to the plant, obtained from a life cycle analysis up to the point of delivery.

Emission	Natural gas per kmol of CH_4 delivered (kg $kmol^{-1}$)	Oxygen delivery (kg $kmol^{-1}$)
CH_4	1.4×10^{-1}	7.4×10^{-2}
CO_2	4.7	6.9
CO	1.8×10^{-2}	1.7×10^{-3}
NO_x	3.3×10^{-2}	1.6×10^{-2}
N_2O	4.5×10^{-5}	5.6×10^{-5}

Table 3. Global warming potential potency factor (relative to 1 kg CO_2) for emissions to atmosphere.

Species	Potency factor
CH_4	21
CO_2	1
CO	3
NO_x	40
N_2O	310

3 (a) What is meant by *Natural Capital*? Give an example of an *external cost* and discuss why a business or individual may behave in an unsustainable manner. [35%]

(b) Briefly discuss the factors which influence the design of a wind turbine and the choice of materials used in the blades. [35%]

(c) Bio-fuels are one potential way of decarbonising road transport. What are the issues associated with biofuels and could biofuels be expected to have a major impact on the transport sector? [30%]

END OF PAPER