Version SAS/4

EGT3
ENGINEERING TRIPOS PART IIB

Tuesday 3 May 2016 9.30 to 11

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 a question is indicated in the right margin.*

*Write your candidate number **not** your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper
Single-sided graph paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book

10 minutes reading time is allowed for this paper.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

1 A factory requires material streams to be heated and cooled as shown in Table 1.

Table 1

Stream	Mass flow ($kg\ s^{-1}$)	Heat capacity ($kJ\ kg^{-1}\ K^{-1}$)	Inlet Temperature (°C)	Outlet Temperature (°C)
A	1.0	2.0	70	110
B	2.0	0.5	70	90
C	1.0	1.0	140	40
D	1.0	1.0	85	70

(a) By using an energy cascade, determine the requirements for external heating and cooling, and the pinch temperature (assuming zero temperature difference at the pinch). [30%]

(b) Sketch the grand composite curve and determine:

(i) the minimum exergy of the heat required to meet the external heat demand; [15%]

(ii) the maximum amount of work that could be generated at 100% marginal efficiency if a new combined heat and power system were to be built by the factory owner and the temperature of the heat source is 1000 K. [15%]

(c) The heat from the factory is to come from a nearby power station. The power station normally rejects heat at 25 °C. To supply the heat for the factory, the power station will divert a fraction of steam (which has a temperature of 300 °C and pressure of 1 bar) that would otherwise go through the (isentropic) low pressure turbine. The steam is returned to the power station as a saturated liquid at 1 bar. The fluid leaving the low pressure turbine has a pressure of 0.02 bar. The factory owner claims the heat should be free as it is waste heat. Discuss ways of setting a fair price for the heat, given the additional data below. Comment on the viability and sustainability of combined heat and power in this case. [40%]

Additional Data:
The temperature of the environment is 25 °C.
The price of electricity is 20 pence per kWh. The price of gas is 3 pence per kWh.

2 Briefly discuss the following with reference to the characteristics of internal combustion engines. You may wish to illustrate your answer with sketches.

(a) Describe what limits the efficiency of a traditional car or truck engine, and why large static engines can operate at much higher thermal efficiencies (e.g. as used in the marine industry). [40%]

(b) How supercharging and turbocharging can improve efficiency of engines used in cars. [35%]

(c) The pros and cons of fully electric vehicles *vs.* hybrid designs. [25%]

3 A new factory produces two products, A and B. The factory consumes $0.1 \times n_A \times n_B$ GJ of primary fossil fuel energy to run, where n_A and n_B are the number of units of A and B produced. The embodied energy of the materials required to make A and B are 1 and 2 GJ per unit produced, respectively. There is an additional input of 100 GJ of energy per production run, and the factory is constrained so that a total production run must consist of 100 units of A and B combined. In addition, for each unit of B produced, 0.5 GJ of waste heat is generated.

(a) In the context of life-cycle analysis, briefly discuss:

(i) allocation by substitution *vs.* using reference systems to avoid allocation, and when these methods are appropriate; [20%]

(ii) marginal allocation, and why it cannot be used to determine the burden associated with the heat produced for the factory described above. [10%]

(b) Calculate the embodied energy of product B, per unit produced, if the waste heat can be utilised elsewhere and if:

(i) the factory only produces A, and marginal allocation is used; [25%]

(ii) the factory produces equal amounts of A and B, and the case where the factory produces only A is used as the reference system. [15%]

(c) If the factory was in the UK (connected to the UK electricity grid) and was fitted with solar panels so that on average it needed no primary fossil fuel to run, **discuss** how your analysis and answers might change. You may neglect the embodied energy of the solar panels. [30%]

END OF PAPER

1) a) 15 kW of external heat needed, cooling of 30 kW, pinch at 70 °C
   b) i) 2.24 kW ii) 27.8 kW
   c) –

2) –
3) a) –
   b) i) depends on exact assumption (see crib) 12.4 GJ ii) 7.5 GJ
   c) -