Version SS/6

EGT3
ENGINEERING TRIPOS PART IIB

Tuesday 25 April 2017 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

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) Describe the difference between exergy and availability. Where are the main exergy losses in a conventional thermal power station? [20%]

(b) A fuel cell is used as part of a combined heat and power system as shown in Fig. 1. The high temperature fuel cell takes methane as a fuel and produces electricity. The fuel cell operates with an outlet temperature of 1000 °C, and all the heat from the fuel cell is produced at this temperature. Air and fuel don't mix, instead oxygen is transferred through a high temperature membrane to the fuel, producing two separate product streams. The rate of entropy generation in the fuel cell is 500 kJ K^{-1} s^{-1}. Using the data in Table 1 determine:

(i) the overall changes in enthalpy and availability; [15%]

(ii) the work output. [15%]

(c) The hot exhaust gases are cooled to 100 °C and the heat (including that from the fuel cell) is used to raise dry saturated steam at 1 atm. The water for the steam generator is taken from the environment at ambient temperature. The total enthalpy flow of all the products leaving the fuel cell when cooled to 100 °C is −852734 kJ s^{-1} with respect to the same standard state as in Table 1.

(i) Sketch the hot and cold composite curves (assuming heat capacities are constant), and determine the maximum amount of steam that can be produced. [25%]

(ii) What is the overall exergetic efficiency of the system if the useful products are steam and electricity? The exergies of pure $O_2(g)$ and $CO_2(g)$ are 19400 and 3900 kJ $kmol^{-1}$, respectively. [25%]

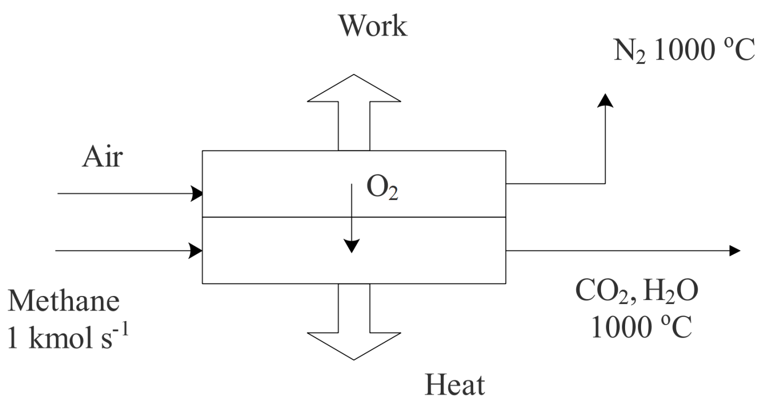


Fig. 1

Data:

Table 1

Enthalpy and entropy with respect to self consistent reference states

	Enthalpy (kJ $kmol^{-1}$)		Entropy (kJ $kmol^{-1}K^{-1}$)	
T (°C)	25	1000	25	1000
$CH_{4(g)}$	−74600		186.4	
$H_2O_{(g)}$	−241826	−204068	188.8	243.1
$CO_{2(g)}$	−393510	−344889	213.8	282.7
$N_{2(g)}$	0	30587	191.6	236.2
$O_{2(g)}$	0		205.1	
$H_2O_{(l)}$	−285830		69.9	

The environment is at 298.15 K and 1 atm., and consists of 21 mol.% O_2, 79 mol.% N_2, 400 ppm CO_2 and saturated liquid water.

 (TURN OVER

2 A photovoltaic (PV) surface is mounted inside a planar solar thermal collector as shown in Fig. 2. The transmissitivity and reflectivity of the glass are 90% and 10% respectively, and are constant for all wavelengths. The area is 1 m^2. The band-gap for the semi-conductor is 1.24 eV. The spectral response of the PV surface is such that a photon with energy above the band-gap converts 1.24 eV to electricity and dissipates the remainder as heat. All photons hitting the collector are absorbed. The heat loss from the panel can be described by $Q_{loss}(Wm^{-2}) = 200 + (T - 25)$, where T is the temperature of the panel in celcius.

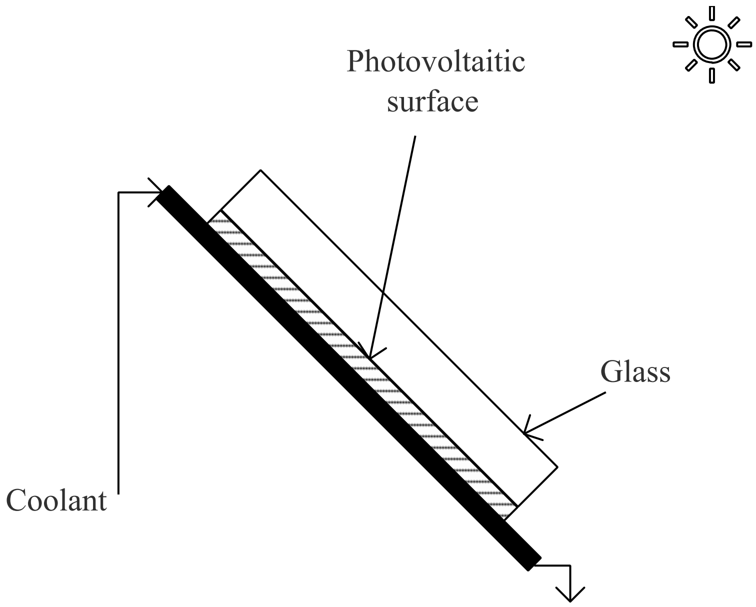


Fig. 2

(a) Describe how a photovoltaic panel generates electricity. [20%]

(b) Using the data opposite **estimate** the electrical and heating power produced if coolant is supplied to the panel to maintain it at 70 °C. [30%]

(c) The CO_2 footprint for the manufacture and installation of the panel is 2000 kg CO_2 and its lifetime is 10 years. Using suitable average values, estimate the amount of CO_2 saved for each 1 kWh of electricity produced, if the heat from the panel is used for domestic heating. [20%]

(d) Discuss whether the estimate of CO_2 saving calculated previously is likely to reflect reality. [30%]

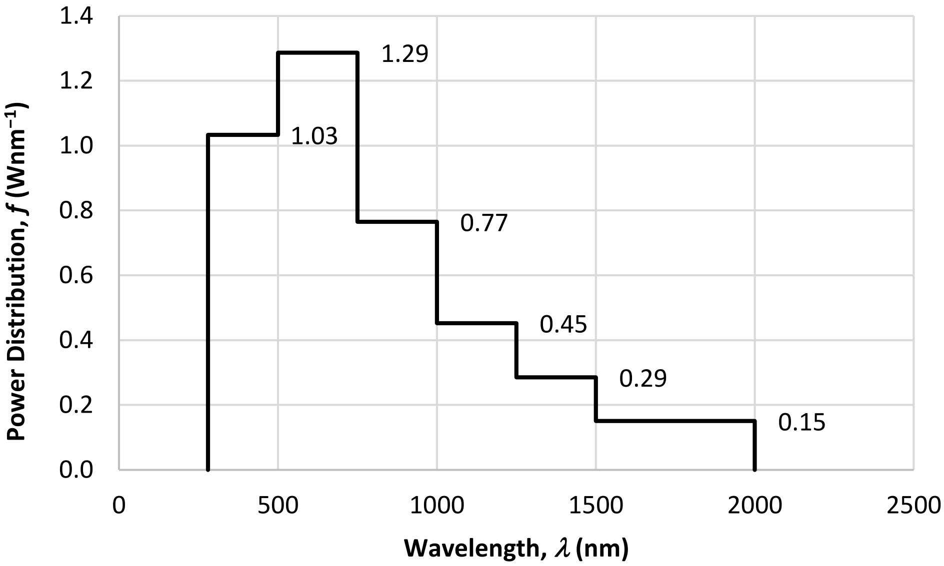
Data:

Domestic heating typically uses a gas boiler with a thermal efficiency of 90%. The calorific value of natural gas is 40 MJ kg^{-1} and natural gas can be assumed to be pure methane (CH_4). The electricity grid has an average CO_2 footprint of 0.4 kg of CO_2 equivalent per kWh delivered. The panel can be moved to face the sun, but can only do this on average 8 hours per day, throughout the year.

Planck's constant is 6.62×10^{-34} J s.

The speed of light is 3×10^8 m s^{-1}.

The charge on an electron is 1.6×10^{-19} C.



Approximate distribution of power in the solar flux. The power hitting a 1 m^2 surface normal to the sun between wavelengths λ and $\lambda + d\lambda$ is $f d\lambda$

Fig. 3

3 Cars are responsible for around 12% of total EU emissions of carbon dioxide (CO_2). The average emission level of a new car sold in 2014 was 123.4 grams of CO_2 per kilometre (gCO_2/km). By 2021, the fleet average for all new cars is required to be less than 95 gCO_2/km.

This emissions intensity can be disaggregated into three terms using the following multiplicative identity:

$$\frac{CO_2}{\text{km}} = \frac{CO_2}{\text{fuel}} \times \frac{\text{fuel}}{\text{tractive work}} \times \frac{\text{tractive work}}{\text{km}} \tag{1}$$

(a) Briefly describe each of the three terms and the impact of each term on the carbon emissions from a car. Estimate values for each ratio. [15%]

(b) Describe what limits the efficiency of an internal combustion engine, making reference to both petrol and diesel engines. How does turbocharging improve the efficiency of car engines? [25%]

(c) Describe options for improving the value of the final term, $\frac{\text{tractive work}}{\text{km}}$. [30%]

(d) How could Equation (1) be modified to allow the carbon intensity of electric vehicles to be investigated? What new options for reducing the carbon intensity of cars does this introduce? Discuss the impact of the electric car battery on the whole lifecycle energy use. [30%]

END OF PAPER