ENGINEERING TRIPOS PART IIB

Thursday 29 April 2010 9:00 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 a 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

sas05

1 (a) Describe what is meant by "availability". How does the exergy of a material stream differ from its availability? [10%]

(b) A flow diagram for a power station utilising a steam cycle is shown in Fig. 1. After leaving the boiler, the steam passes through a high pressure turbine (HP), is then reheated and finally goes through a low pressure turbine (LP), before entering the condenser. The mass flow of steam through the boiler is 1 kg s^{-1}. Table 1 gives the properties of the steam at each point in the cycle. For the power station shown in Fig. 1 calculate,

i) the thermal efficiency, [10%]

ii) the increases in the exergy of the water as it passes through the boiler, and then the reheater, and hence the exergetic efficiency of the whole system (i.e. steam cycle + heat source). Assume that heat is supplied to the power station reversibly. [15%]

(c) The power station is to be altered so that 20% of the steam leaving the reheater is now diverted through an isenthalpic throttle valve, into a heat exchanger where it provides heat to an amine-based carbon capture system, before being returned to the main steam cycle, as shown in Fig. 2. The carbon capture system takes flue gas (21 mol.% CO_2 in N_2) at a rate of 0.01 kmol of flue gas per kg of steam through the boiler to produce pure CO_2 for sequestration.

i) What is the minimum amount work required to separate the flue gas into pure CO_2 and pure N_2? [15%]

ii) By performing an exergy balance over the entire carbon capture plant, determine how much exergy is lost to irreversibilities in the carbon capture plant. [10%]

iii) Identify and quantify all other losses in exergy due to irreversibility in the modified power station. You may assume that heat is transferred to the boiler and reheater reversibly. [30%]

iv) What is the new thermal efficiency of the power station with carbon capture added? Comment on your answer. [10%]

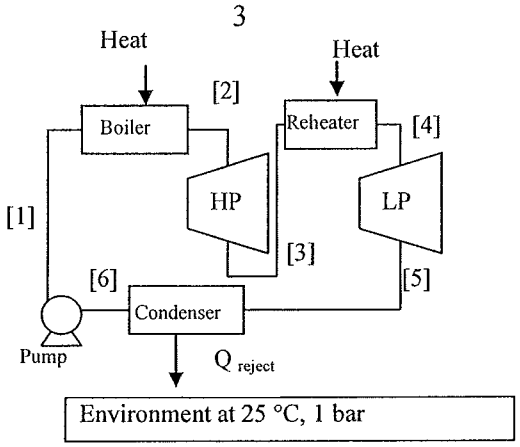

Fig. 1

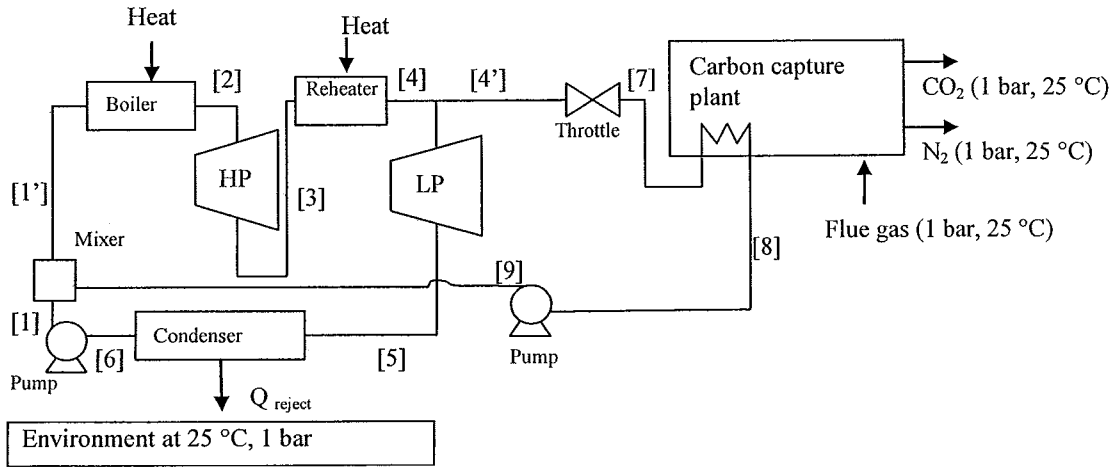

Fig. 2

Table 1. Temperature (T), Pressure (P), enthalpy (h) and entropy (s) at each point in the steam cycle

	[1]	[2]	[3]	[4]	[5]	[6]	[4']	[7]	[8]	[9]	[1']
T (°C)	25.2	500	422	721	25	25	721	716.3	100	100.4	40.3
P (bar)	100	100	20	20	0.032	0.032	20	1	1	100	100
h (kJ kg^{-1})	114.8	3375.1	3296.8	3966.5	2546.5	104.8	3966.5	3966.5	417.5	429.9	177.8
s (kJ kg^{-1} K^{-1})	0.367	6.599	7.200	8.000	8.557	0.367	8.000	9.380	1.303	1.303	0.573
State	l	v	v	v	v (sat)	l (sat)	v	v	l (sat)	l	l

l = liquid, v = vapour, sat = saturated

2 A company is proposing to place solar thermal systems in an isolated developing country, near the equator. The system will consist of parabolic troughs, each with a projected area of 1 m^2 focusing sunlight onto an absorber tube containing a heat transfer fluid.

(a) In the context of life cycle analysis, discuss the problems encountered when allocating environmental burdens. Also, describe the methods of allocating by price, and substitution, and their relative merits and limitations. [40%]

(b) Each parabolic trough (which has a reflectance of 1) is mounted on motors, which allow it to track the position of the sun, and keep its projected area perpendicular to the sun's rays during the day. Losses in energy as sunlight passes through the atmosphere can be neglected. The absorber tube consists of an outer sheath of glass (transmissivity = 0.9), an air gap and an inner tube which approximates a black body. The total heat loss from the absorber is $Q_{loss} = 0.5\Delta T + 0.0011\ \Delta T^2$, where ΔT is the temperature difference between the absorber and the surroundings (assumed to be at 25 °C).

i) What is the maximum possible temperature of the absorber tube? [10%]

ii) In practice, the absorber tube captures 850 W, what is the temperature of the absorber tube? [10%]

(c) The heat captured is used to drive a steam cycle in a power station which produces electricity (at a thermal efficiency of 30%), and heat. The heat is to be used in local industries, which would otherwise burn sustainably grown wood. The electricity is to be fed into the local grid. Using the data given below:

i) What is the saving in the global warming potential (GWP) per dish in a year? [10%]

ii) What is the CO_2 footprint of the electricity produced by the dish, if the heat is treated as a co-product, and burdens are allocated by substitution? [10%]

(d) Discuss how your answers to part (c) would change if the country were not isolated, but was instead connected to the British electricity grid via an ultra efficient DC link, and if the biomass used to provide heat was not sourced sustainably? What does this suggest about the validity of results from a life cycle analysis? [20%]

Data for question 2:

The solar constant is 1387 W m^{-2}.

The electricity in the country comes predominantly from coal. The GWP of 1 kWh of electricity from the country's electricity grid, and 1 kWh of heat from wood are 0.6 and 0.01 kg CO_2-equivalent, respectively.

The CO_2 footprint of the materials used in the construction of the solar collector is 50 kg CO_2-equivalent. The solar collector has a lifespan of 10 years, and at its present location can collect 850 W for 10 hours per day on average over the year.

The CO_2 footprint of all the material in the power station is 10 kg CO_2-equivalent for each 1 m^2 solar collector.

3 (a) One scheme for downsizing the engine of a car is to be considered. The new car is to be produced with a smaller engine, but contains a cylinder of compressed air, which is topped up by a compressor when surplus power is available. When starting the engine or when the power demand is high, compressed air from the tank is supplied to the cylinder (via a special valve arrangement) in place of air directly from the atmosphere.

Explain in detail with reference to the performance characteristics of an internal combustion engine why downsizing is advantageous. What are the disadvantages of downsizing and how does the proposed scheme overcome them? [65%]

(b) Suggest two ways of producing cars which run using stored renewable solar power in the UK. Comment on the issues regarding the sustainability and feasibility of each of these two schemes. [35%]

END OF PAPER

Answers

1 b. i) 0.38, ii) boiler 1402.2 kJ/kg, reheater 431.18 kJ/kg,, exergetic efficiency = 0.81
c. i) 12.7 kJ/kg of steam through the boiler.
ii) Carbon capture plant, 215.4 kJ/kg (per kg of steam through boiler)
ii) HP turbine, 179.19 kJ/kg; LP turbine: 132.86 kJ/kg; mixer, 5.605 kJ/kg, Throttle, 82.29 kJ/kg. All answers are per kg of steam through the boiler.
iii) 0.314.

2. b. i) 887 °C ii) 441 °C
c. i) 565 kg CO_2 eq per dish per year.
ii) -0.0073 kg CO_2 equivalent per kWh

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