The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 4 MODULE, SPRING SEMESTER 2015-2016

ADVANCED THERMAL POWER SYSTEMS

Time allowed ONE Hour and THIRTY Minutes

Candidates may complete the front cover of their answer book and sign their desk card but must NOT write anything else until the start of the examination period is announced

Answer ALL questions in Section A and TWO questions in Section B

Only silent, self-contained calculators with a Single-Line Display or Dual-Line Display are permitted in this examination.

Dictionaries are not allowed with one exception. Those whose first language is not English may use a standard translation dictionary to translate between that language and English provided that neither language is the subject of this examination. Subject specific translation dictionaries are not permitted.

No electronic devices capable of storing and retrieving text, including electronic dictionaries, may be used.

DO NOT turn the examination paper over until instructed to do so

In this examination candidates are required to answer ALL questions in Section A and TWO out of FOUR questions in Section B. If a candidate answers more than the required number of questions, all questions will be marked and the highest marks will be used in the final examination mark.

ADDITIONAL MATERIAL: Formula sheet
Tables of Thermodynamic Properties of Fluids
Enthalpy-entropy chart for Steam

INFORMATION FOR INVIGILATORS:

Question papers should be collected in at the end of the exam – do not allow candidates to take copies from the exam room.

Turn Over

SECTION A

ANSWER ALL QUESTIONS IN THIS SECTION

It should not be necessary to write more than about two or three sentences in answer to any part of this question. All parts carry equal marks.

1. Evaluate the molar Gibbs Function of nitrogen gas at a temperature of 800K and a pressure of 30 bar (absolute).

2. Write the equation for the equilibrium constant for the following reaction in terms of partial pressures:

$$H_2O \Leftrightarrow \tfrac{1}{2} H_2 + OH$$

3. State the meaning of pinch temperature for a heat recovery steam generator and state why small pinch can be achieved with solar thermal using molten salt.

4. Use the non-steady flow energy equation to derive an expression for the flow of superheated steam into an initially evacuated closed vessel.

5. Briefly describe the operation of combustion carbon capture by amine absorption.

6. What is the rate of specific irreversibility in a steam turbine with steam entering at 160 bar and 500°C and exhausting adiabatically at 40 bar with enthalpy of 3050 kJ/kg and entropy 6.52 kJ/kgK? Take the ambient condition as water at 15°C.

7. State two advantages of an Integrated Coal Gasification Combined Cycle Power Plant over a conventional coal-fired power plant.

8. ^{135}Xe has a half-life of 9.2 hours. 'Decay' is by neutron absorption to the stable ^{136}Xe. What is the decay constant?

9. Describe the water-steam cycles of BWR and PWR nuclear reactors.

10. Calculate the speed of a neutron with a kinetic energy of 0.8 MeV.

SECTION B

ANSWER TWO OUT OF FOUR QUESTIONS IN THIS SECTION

11. A steady flow of pure carbon dioxide gas at a constant pressure of 8 bar (absolute) is heated from 25°C to a certain temperature. At this temperature the gas has dissociated and has the following composition by volume:

39.43% CO_2
40.38% CO
20.19% O_2

(a) Calculate the final temperature of the gas. [15]

(b) If the mass flow rate of the carbon dioxide is 0.03 kg/s, calculate the heat input required to raise the gas (at 8 bar) to the final temperature calculated above. Given that the enthalpy of each gas is:

$$\tilde{h}_i = \tilde{h}_{fi} + \Delta\tilde{h}_i$$

where the terms are in order: absolute enthalpy at temperature T, formation enthalpy at 25°C and enthalpy above the reference temperature 25°C.

[18]

12. An open cycle gas turbine has an air inlet temperature of 15°C, a pressure ratio of 8 across the compressor and a turbine entry temperature of 1127 °C. If the compressor and turbine both have a polytropic efficiency of 92%:

(a) Calculate the specific work output and thermal efficiency of the gas turbine.

[13]

(b) If a recuperator with an effectiveness of 75% is added to the gas turbine, calculate the improved thermal efficiency.

[10]

(c) Explain why recuperative gas turbines are rarely used in practice.

[10]

Assume that the working fluid is air throughout the gas turbine with a specific heat capacity of 1.005 kJ/kgK. Ignore pressure losses in the gas turbine combustion chamber and inlet and outlet ducts.

Turn over

13. Exhaust gases from a gas turbine set are used to power a heat recovery steam generator. The hot gases enter at 713K and at a mass flow rate of 30 kg/s. The steam pressure in the HRSG is 85 bar and the final steam temperature at the outlet from the superheater is 380°C. Feedwater is supplied to the economiser at 30°C. The pinch temperature difference is 30K.

 (a) Calculate the mass flow rate of steam and the temperature at which the gases leave the heat exchanger.
 [15]

 (b) Calculate the total rate of irreversibility in the heat recovery boiler.
 [18]

 Assume a specific heat capacity c_p of the exhaust gases of 1.13 kJ/kgK.
 Assume an environmental temperature of 15°C.

14. (a) Describe the terms in the four factor formula and what the formula is used for.
 [10]

 (b) What is the effective multiplication factor for a neutron lifecycle if the four factor formula is sufficient since the reactor is large? Given that fast fission factor, 1.06, resonance escape probability, 0.5, thermal utilisation factor, 0.95, and thermal fission factor, 1.95. What is the likely state of this reactor?
 [5]

 (c) What is the meaning of binding energy of a nucleus with regard to energy release by nuclear reactions?
 [5]

 (d) Describe, with the aid of a schematic binding energy diagram, why it is that fusion produces significantly more energy than fission.
 [8]

 (e) For a fission of ${}^{235}_{92}U$ (235.043 923 1 amu) into ${}^{132}_{53}I$ (131.907 995 amu) and ${}^{101}_{39}Y$ (101.930 310 amu) with the release of 1 neutron, calculate the energy released from the reaction.
 [5]

END