

# The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 3 MODULE, AUTUMN SEMESTER 2017-2018

## **ENERGY EFFICIENCY FOR SUSTAINABILITY 2**

Time allowed ONE Hour and THIRTY minutes

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*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 parts of QUESTION ONE and TWO OTHER questions**

*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 examination paper over until instructed to do so**

***In this examination candidates are required to answer QUESTION 1 and TWO of the remaining FOUR questions. 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:** 8 page answer booklet  
Tables of Thermodynamic and Transport Properties of Fluids  
Enthalpy/Entropy chart for steam  
Formula sheet

### **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.

1. This question is **COMPULSORY**.  
Answer each part of this question. Each part carries 3 marks.  
*It should not be necessary to write more than about two or three sentences in answer to any part of this question.*
- (a) List the two fuels that provide the most primary energy in the UK.
  - (b) List two pollutants that may occur due to incomplete combustion of a fuel.
  - (c) State the two principle ways in which solar energy can be collected.
  - (d) Describe with the aid of a diagram the processes involved in the combustion of a liquid fuel.
  - (e) Briefly describe the two main types of heat exchanger.
  - (f) What is the exergy in a flow of dry saturated steam of 2.5 kg/s at a pressure of 5 bar. The temperature of the environment is 17 °C. Assume that water is a liquid at the environmental temperature.
  - (g) Define exergy.
  - (h) In a warm country the temperature of the outside environment is 32°C. A warehouse is kept at an internal temperature of 21°C by an air conditioning system which removes heat at a rate of 14 kW. What is the rate of flow of exergy into the warehouse from the air conditioning system?
  - (i) A heat pump is used to supply heat to a building. Briefly explain why it is important to supply heating to the building at as low a temperature as possible.
  - (j) Give three examples of means by which an Energy Manager may reduce expenditure on energy.

[Total 30 marks]

2. By considering the purposes for which energy is used in the UK, discuss measures that may be taken at national level to reduce emissions of greenhouse gases resulting from the use of energy.

[35]

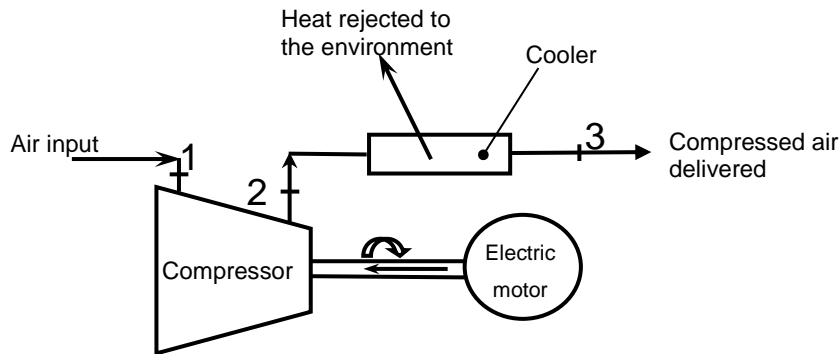
3. Hydrogen ( $H_2$ ) is burned in a central heating boiler with 25% excess air at a pressure of 1 bar. The products of combustion are cooled to a temperature of  $42^\circ C$  before leaving the boiler.
- Calculate the proportion of water vapour that has condensed from the products of combustion. [12]
  - Calculate the efficiency of the boiler (based on gross calorific value). [15]
  - Explain how the boiler efficiency would be affected by an increase in excess air. [8]

The heat losses from the boiler structure are 1.0% of the calorific value of the fuel. The fuel and air enter the boiler at a temperature of  $25^\circ C$ . Use mean specific heat capacity of dry products of combustion at temperature of 300K.

The gross calorific value of hydrogen is 143 MJ/kg.

Assume that condensate leaves the boiler at the same temperature as the gaseous products of combustion.

4. Air from the environment at 1 bar and  $10^\circ C$  enters an air compressor and is compressed to 8 bar in one stage. The air then passes through a cooler to reduce its temperature to  $10^\circ C$ . The air mass flow rate is 0.15 kg/s. The isentropic efficiency of the air compressor is 80%. The compressor is driven by an electric motor which has an efficiency of 90%.



Calculate:

- The rate of electricity consumption of the electric motor and the rate of heat rejection to the environment in the cooler. [15]
- The rate of exergy in the compressed air at outlet from the compressor and in the air delivered after the cooler. [10]
- The rate of irreversibility in the compressor, cooler and motor and the overall rational efficiency of the air compressor system. [10]

For dry air assume  $c_p = 1.005$  kJ/kgK, Specific gas constant  $R = 0.2871$  kJ/kgK  
 The ratio  $c_p/c_v = 1.4$ . The temperature of the environment is  $10^\circ C$ .  
 Assume atmospheric pressure is 1 bar.

5. An industrial site has installed a gas fuelled internal combustion engine combined heat and power (CHP) plant. Details of the engine are:

Electricity output	145 kW
Electrical generation efficiency	32.5%
Rate of useful heat output from the CHP plant	248 kW

The heat output from the engine is the combined useful heat that can be recovered from the engine exhaust gases and engine cooling system. The engine can only be operated at full output when running. When heat is needed that cannot be supplied by the CHP plant it is supplied by boilers which have an efficiency of 85%.

The electricity demand of the site is in excess of the output generated by the CHP plant at all times. The demand for heat at the site is 300 kW during weekdays (day and night) but reduces to 150 kW during weekends (day and night). There are 45 working weeks at the industrial site per year.

- (a) Calculate the annual cost savings for operating the CHP plant. [25]
- (b) Discuss the economic operation of the CHP system and suggest potential ways of improving the annual savings. [10]

Assume the following:

Purchase price of electricity during the day (17 hours) £35/GJ  
 Purchase price of electricity during the night (7 hours) £20/GJ  
 Price of fuel for CHP plant and alternative boilers £10/GJ  
 Maintenance cost of the CHP plant is 2.0p/kWh of electricity generated

All efficiencies and fuel prices are based on gross calorific value.  
 Electricity and fuel prices do not vary during the year.