GX802

OLLSCOIL NA hÉIREANN
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Semester I Examinations, 2002/03

Third Year (Mechanical, Biomedical) Engineering Examination

Applied Thermodynamics (ME306)

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Answer FIVE questions

Time allowed: 3 hours

The following tables and charts are available:
Tables A-1, A-2(a), A-4 to A-8, A-11 to A-13, A-26, A27 and Figures A-9, A-10, A-14 and A-33 from Cengel and Boles, "Thermodynamics: an Engineering Approach" (3rd ed.)
Hickson and Taylor, "Enthalpy-Entropy Diagram for Steam"

1

(a) Under what circumstances is the equation $ds = \dfrac{\delta q}{T}$ true for a thermodynamic process? **(2)**

(b) Is it possible for the entropy of a closed system to decrease? Explain your answer. **(3)**

(c) Starting with one of the equations $Tds = dh - vdp$ or $Tds = du + pdv$, prove that for an ideal gas with constant specific heat values, the entropy change is given by:

$$s_2 - s_1 = c_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{p_2}{p_1}\right)$$ **(7)**

(d) An insulated, rigid, tank of volume 4 m^3 contains air at 27°C, divided into two equal volumes by a barrier. Initially, pressure is 100 kPa on one side of the barrier and 1 MPa on the other. The barrier is suddenly ruptured, allowing the two bodies of air to mix, and after a time, the air in the tank comes to rest.

Carry out a First Law analysis to determine the final state of the air. Calculate the total entropy change of the air in the process and comment on the result. **(8)**

2 A steam power plant operates on the basic Rankine cycle with turbine isentropic efficiency of 84%. The condenser pressure is 30 kPa and saturated liquid water enters the pump, which can be regarded as isentropic. In the boiler, pressure drops from 15 MPa to 13.8 MPa and the boiler exit temperature is 450°C.

(a) Using the available information, sketch a T-s diagram for the cycle. **(3)**

Calculate the net power output per unit mass of steam, and the thermal efficiency of the cycle. **(9)**

(b) It is proposed that a reheat stage at 10 MPa be added to the cycle to boost efficiency without raising the maximum temperature. Sketch a T-s diagram for the modified cycle (or show the modifications clearly on the original sketch). Neglecting pressure drop in the reheater, and assuming that both turbine stages have the same efficiency as the original turbine, calculate the efficiency of the modified plant. **(6)**

(c) Is 10 MPa the best choice of reheat pressure? If not, would you recommend a higher or lower pressure? Explain your answer. **(2)**

3 A household freezer operates on a vapour-compression refrigeration cycle with R134a circulating at 0.014 kg/s. The evaporator pressure is 100 kPa and the condenser pressure is 800 kPa. Refrigerant exits the evaporator at –24°C and leaves the condenser as saturated liquid. The compressor is isentropic.

(a) Sketch the layout of the system and a *T-s* diagram for the cycle. **(4)**

(b) Calculate the refrigeration rate and the coefficient of performance. **(10)**

(c) The system is modified to provide a refrigerator compartment as well as a freezer. To accomplish this, the system is fitted with two expansion valves and two evaporators. Refrigerant is throttled to 0°C in the primary expansion valve, and then passes through an evaporator in the refrigerator chamber, where it receives heat at a rate of 0.3 kW. It is then throttled to the freezer evaporator (again at 100 kPa).

Sketch the system layout and a T-s diagram for the modified system (or show the modifications clearly on the original sketches). Calculate the coefficient of performance of the new cycle and the refrigeration rate in the freezer compartment. **(6)**

4 An air-conditioning unit delivers air at 100 kPa, 20°C, 30% relative humidity. The unit takes in air at 101.325 kPa, 30°C and 48% relative humidity, and first cools it to adjust the moisture content. The air is then reheated to the required room temperature. Condensed water is collected and discharged at the temperature to which the air is cooled.

(a) Sketch a schematic diagram of the system. **(2)**

(b) What is the relative humidity of air leaving the cooling/dehumidifying section ? **(2)**

(c) Based on information given about the state of air exiting the heater section, determine the specific humidity and temperature of the air leaving the cooling/dehumidifying section. **(4)**

(d) Find the heating and cooling rates per kg of dry air. **(12)**

5 A gas turbine engine operates on the Brayton cycle with a combustion pressure of 1.4 MPa, compressor isentropic efficiency of 86%, and turbine isentropic efficiency of 82%. The intake air mass flow rate is 15.2 kg/s and the turbine inlet temperature is 1180°C. Ambient conditions are 22°C, 102 kPa.

(a) Sketch the cycle on T-s and p-v diagrams. **(4)**

(b) Calculate the compressor exit temperature, exhaust temperature and efficiency of the engine. **(8)**

(c) Explain the principle of regeneration in a gas turbine engine and how it can raise efficiency. What criterion determines whether regeneration can be applied to a particular cycle? **(4)**

(d) Calculate the maximum engine efficiency which could be achieved by the use of regeneration in the engine described above. **(4)**

6

(a) A fuel for spark ignition engines consists of 35% (by mass) octane (C_8H_{18}) and 65% methanol (CH_3OH). The enthalpy of formation of these compounds at 25°C and 1 atm is –208450 kJ/kmol and –200670 kJ/kmol, respectively. Calculate the lower heating value (LHV) of the fuel at 25°C and 1 atm in J/kg. **(10)**

(b) A 6-cylinder 4-stroke spark ignition engine using the above fuel has a bore of 80 mm and a stroke length of 85 mm. In a test at 2500 rpm, indicated power is 34.45 kW and brake power is 28.81 kW. The fuel flow rate at this condition is 3.14 g/s. The effect of elevated temperature and pressure on the heating value of the fuel can be neglected.

Calculate the imep, bmep, mechanical efficiency, and overall efficiency of the engine. **(7)**

(c) Explain the meaning of mechanical efficiency, and list some factors which contribute to it. **(3)**

Note: the enthalpy of formation of gaseous H_2O and gaseous CO_2 at 25°C and 1 atm are –241820 kJ/kmol and –393520 kJ/kmol, respectively.

7 A patient of mass 88 kg is about to undergo general anaesthesia and a major surgical procedure. The mass of the core and periphery are estimated as 60% and 40% of the total, respectively. On the operating table immediately before anaesthetisation, the patient is in thermal steady state. Core temperature is 36.8°C, average peripheral temperature is 35.4°C, average skin temperature is 28.1°C, and the basal metabolic rate is measured as 124 W. 70% of the patient's skin surface area of 2.3 m^2 is exposed to the surroundings and air at 18°C, while the remainder is well insulated. Assume that the patient's skin is dry at all times and that the basal metabolic rate remains constant throughout the procedure. The emissivity (ε) of skin can be taken as 0.95 and the Stefan-Boltzmann constant (σ) is 5.67×10^{-8} W m^{-2} K^{-4}.

(a) Sketch a plot of core temperature as a function of time from the onset of anaesthesia. Label and explain the major features of the curve. **(4)**

(b) Sketch a thermal resistance network for heat flow from the patient's core to the surroundings and air, and where possible write expressions for each resistance. **(4)**

(c) Estimate the shell thermal resistance and the convection coefficient for heat transfer between the patient and ambient air. **(5)**

(d) Estimate the patient's temperature after core heat has been redistributed uniformly due to the suppression of vasoconstriction. If no precautions against hypothermia are taken, estimate the final steady-state temperature of the patient. **(7)**