MACHAKOS UNIVERSITY

University Examinations 2018/2019

SCHOOL OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF MECHANICAL AND MANUFACTURING ENGINEERING

SECOND YEAR SPECIAL/SUPPLEMENTARY EXAMINATION FOR

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

EEE 209 ENGINEERING THERMODYNAMICS

DATE: 31/7/2019 **TIME: 2.00-4.00 PM**

INSTRUCTIONS:

1. This paper contains FIVE questions. Question ONE carries **30 marks** while each of the Questions TWO - FIVE carries **20 marks**.
2. Answer question ONE and ANY other TWO questions.
3. Tables of thermodynamic properties (Steam Tables) and a Mollier chart for steam are provided for your use.

QUESTION ONE (30 MARKS)

a) (i) Define the terms: System, process, state and working fluid, as they are used in thermodynamics (2 marks)

(ii) Distinguish between a closed system and an open system with regard to the first law of thermodynamics. Give the corresponding equations (4 marks)

b) (i) State the second law of Thermodynamics for a cycle (2 marks)

ii Steam is supplied dry saturated at 42 bar to a turbine. After expansion, the exhaust steam is condensed at 0.04 bar in a water-cooled condenser before being pumped back into the boiler. If the steam cycle is Rankine in which the isentropic efficiency in the expansion process is 80%, while the pumping process is considered ideal, sketch a T-s diagram for the cycle and use the tables of thermodynamic properties of steam to determine,

A. the enthalpy of the steam at entry to the condenser (7 marks)

B. the heat rejected in the condenser (2 marks)

(c) (i) State the three distinct modes of heat transfer (3 marks)

(ii) With the aid of an equation, describe Fourier's Law (3 marks)

(iii) With respect to radiative heat transfer, define the terms reflectivity, absorptivity and transmissivity, and explain how the three are related (4 marks)

(iv) A 1.4 m-long, 0.2 cm-diameter electrical wire extends across a room that is maintained at 20^{0}C. Heat is generated in the wire as a result of resistance heating, and the surface temperature of the wire is measured to be 240^{0}C in steady operation. Also, the voltage drop and electric current through the wire are measured to be 110 V and 3 A, respectively. Disregarding any heat transfer by radiation, determine the convective heat transfer coefficient for heat transfer between the outer surface of the wire and the air in the room (3 marks)

QUESTION TWO (20 MARKS)

(a) (i) Define what a property is, in the context of thermodynamics, and further distinguish between an extensive property and an intensive property, giving an example for each (5 marks)

(ii) With the aid of either a $T - s$ or $p - v$ diagram, define the following processes: Isothermal, isobaric, isochoric (3 marks)

(b) Derive the expression for the specific volume of wet vapour, based on the definition of the dryness fraction (5 marks)

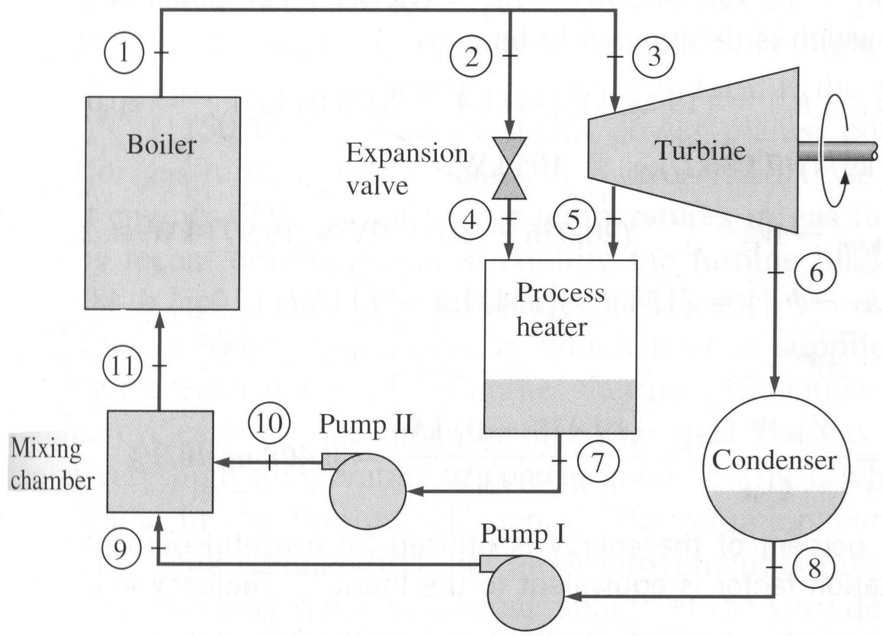
(c) (i) Taking the work done by a system on its surroundings as positive, derive the general expression for the work done by a gas that expands polytropically in a well-insulated cylinder according to the law $pV^{n} = K$, where n is the index of expansion while K is a constant (3 marks)

(ii) Carbon dioxide contained in a piston-cylinder device is compressed from 0.3 to 0.1 m^3. During the process, the pressure and volume are related by $p = \alpha \cdot V^{-2}$, where α= 8 kPa·m^6. Calculate the work done on the carbon dioxide during this process (4 marks)

QUESTION THREE (20 MARKS)

a) What is co-generation and what is its significance in industrial practice? **(2 marks)**

b) Consider the steam cogeneration plant shown in Fig. Qn. 3. Steam enters the turbine at 6



MPa and 600^0C. Some steam is extracted from the turbine at 600 kPa for process heating. The remaining steam continues to expand to 6 kPa. The exhaust steam from the turbine is subsequently condensed at constant pressure and pumped to the boiler pressure of 6 MPa. At times of high demand for process heat, some heat leaving the boiler is throttled to 600 kPa and then routed to the process heater. The extraction fractions are such that the steam leaving the process heater is a saturated liquid at 600 kPa, which is subsequently pumped to 6 MPa. The mass flow of steam through the boiler is 16 kg/s. Neglecting the changes in potential and kinetic energies, and disregarding the pressure drops and heat losses in the piping, and assuming the turbine and pump work to be isentropic:

(i) Represent the steam plant on a T-s diagram (2 marks)

Hence determine:

(ii) The specific enthalpy of the steam at each of the states 1 through to 10 (12 marks)

(iii) The maximum rate at which process heat can be supplied (2 marks)

(iv) The power produced when no process heat is supplied (2 marks)

QUESTION FOUR (20 MARKS)

(a) (i) Why is the Carnot cycle not used as the ideal model for steam power plants? (2 marks)

(ii) Why is high moisture content in steam detrimental to steam turbines? (1 mark)

(b) (i) Sketch the T-s diagram for an ideal Rankine cycle with superheat for steam, with the following notation:

- Point 1 denotes entry to the boiler
- Point 2 denotes entry to the turbine
- Point 3 denotes entry to the condenser (in the wet region)
- Point 4 denotes the end of condensation at the liquid saturation line (3 marks)

(ii) A steam power plant operates on a Rankine cycle in which the boiler pressure is 50 bar. If the steam enters the turbine having a specific enthalpy of 3100 kJ/kg, and expands isentropically to the condenser pressure of 0.1 bar, use the provided Mollier chart and adopt the notation in b(i) above to determine,

A. the dryness fraction of the steam, $x3$, at the entry to the condenser (1 mark)

B. the specific volume of the steam, $v3$, at the entry to the condenser (2 marks)

C. the specific entropy of the steam, $s3$, at the entry to the condenser (1 mark)

D. the work output from the turbine (3 marks)

(iii) Using the provided tables of thermodynamic properties, determine the feedpump work in b(ii) above, hence calculate the work ratio for the cycle (5 marks)

(iv) If instead the turbine had an isentropic efficiency of 80%, what would be the specific enthalpy of the steam as it is exhausted to the condenser? (2 marks)

QUESTION FIVE (20 MARKS)

(a) Define convective heat transfer and further distinguish between the two types of convection

(2 marks)

(b) A 0.3-cm-thick, 12-cm-high, and 18-cm-long circuit board houses 80 closely spaced logic chips on one side, each dissipating 0.06 W. The board is impregnated with copper fillings and has an effective thermal conductivity of 16 W/m.^{0}C. All the heat generated in the chips is conducted across the circuit board and is dissipated from the back side of the board to the ambient air. Use Fourier's law to determine the temperature difference between the two sides of the circuit board (2 marks)

If the ambient air is at 25^0C and flows freely over the board, thus maintaining the surface of the board at 17.6^0C, at what rate does it transfer heat away from the surface of the board? Take the heat transfer coefficient to be 25 W/m^2.^{0}C (2 marks)

(c) (i) What is a heat exchanger and how does it differ from a mixing chamber? (2 marks)

(ii) A parallel flow double-pipe heat exchanger is to heat water from 20^0C to 30^0C at a rate of 1.5 kg/s. The heating is to be accomplished by geothermal fluid available at 120^0C at a mass flow rate of 2 kg/s. The inner tube is thin-walled and has a diameter of 10 cm. Given that the overall heat transfer coefficient of the heat exchanger is 640 W/m^2.^{0}C, and the specific heat capacities of water and geothermal fluid are 4.18 and 4.31 kJ/kg.^{0}C respectively, use the effectiveness-NTU method to determine the length of the heat exchanger required to achieve the desired heating (12 marks)

Heat exchanger type	NTU relation
1 *Double-pipe:*	
Parallel-flow	$\text{NTU} = -\dfrac{\ln[1-\varepsilon(1+c)]}{1+c}$
Counter-flow	$\text{NTU} = \dfrac{1}{c-1}\ln\left(\dfrac{\varepsilon-1}{\varepsilon c-1}\right)$
2 *Shell and tube:* One-shell pass 2, 4, . . . tube passes	$\text{NTU} = -\dfrac{1}{\sqrt{1+c^2}}\ln\left(\dfrac{2/\varepsilon-1-c-\sqrt{1+c^2}}{2/\varepsilon-1-c+\sqrt{1+c^2}}\right)$
3 *Cross-flow (single-pass):* C_{max} mixed, C_{min} unmixed	$\text{NTU} = -\ln\left[1+\dfrac{\ln(1-\varepsilon c)}{c}\right]$
C_{min} mixed, C_{max} unmixed	$\text{NTU} = -\dfrac{\ln[c\ln(1-\varepsilon)+1]}{c}$
4 *All heat exchangers with $c = 0$*	$\text{NTU} = -\ln(1-\varepsilon)$