Université d'Ottawa • University of Ottawa

Faculté de génie
Génie mécanique

Faculty of Engineering
Mechanical Engineering

MCG 2175 - THERMODYNAMICS II

Final Examination
21 April 2005
Prof. W. Hallett

Time: 3 hours

Closed book. Non-programmable calculators only allowed. Properties data, equations and a psychrometric chart are given at the end of the paper.

1. Descriptive questions (10 marks total)

(a) (3 marks) A bottle of beer at a temperature of 5°C is removed from the refrigerator in a room in which the air has a dry-bulb temperature of 20°C and a wet bulb temperature of 10°C. Will condensation form on the surface of the bottle? Give reasons for your answer.

(b) (3 marks) A thermodynamics student decides to cool his room by leaving the door of his refrigerator open for a long period of time. Assuming that the room is adiabatic, what will happen to the temperature in the room? Explain your answer. Will the student pass thermodynamics?

(c) (4 marks) "Greenhouse gas" emissions are a concern in choosing fuels for vehicles. For powering an automobile, you have a choice between the following two fuels:

- methanol: CH_3OH, higher heating value 752 MJ/kmol;
- *n*-octane: C_8H_{18}, higher heating value 5460 MJ/kmol.

Assuming that the quantity of fuel is chosen such that the total heat release is the same for both fuels, which fuel will produce a smaller quantity of CO_2?

2. (10 marks total) Fresh air enters a building at a temperature of $T_1 = 2°C$ and relative humidity $\phi_1 = 80\%$, and is mixed with recirculated air from the building at $T_2 = 24°C$ with a wet-bulb $T_{WB2} = 20°C$. The mass flow ratio of fresh air to recirculated air is $(\dot{m}_1 / \dot{m}_2) = 0.5$ and the total pressure is 100 kPa.

(a) (6 marks)Determine the temperature, relative humidity and dew point of the air leaving the mixing process.

(b) (4 marks) If the mass flow rate of the fresh air entering is 10 kg dry air /min, determine the volume flow rate of moist air leaving the mixing process in m^3 / min.

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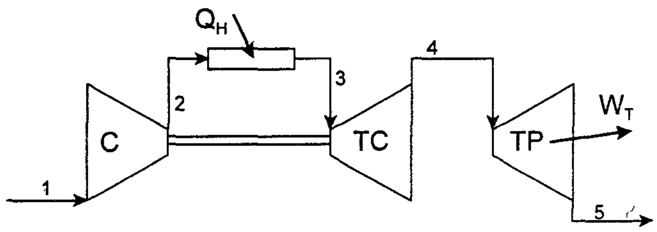
3. (14 marks total) The figure shows an industrial gas turbine. The compressor C is driven by the compressor turbine TC, while the output power of the engine $\dot{W}_T$ is produced by the power turbine TP. The compressor has an isentropic efficiency of $\eta_C = 88\%$, while both turbines have isentropic efficiencies of $\eta_T = 90\%$. The inlet state is $T_1 = 20°C$, $P_1 = 101$ kPa, $P_2 / P_1 = 30$, and the combustor outlet temperature is $T_3 = 1300°C$. The working fluid may be assumed to be air.



(a) (2 marks) Sketch a T-s diagram for this cycle.
(b) (4 marks) Determine the compressor work in kJ/kg.
(c) (2 marks) Determine the outlet temperature T_4 from the compressor turbine.
(d) (3 marks) Determine the outlet pressure P_4 from the compressor turbine.
(e) (3 marks) Determine the air mass flow required to produce an output power of $\dot{W}_T = 40$ MW.

4. (11 marks total) A natural gas consists of 90% CH_4 and 10% N_2 by volume. After it is burned in a furnace, the products of combustion contain 9% CO_2 by volume on a dry basis. The total pressure is 101 kPa, and the natural gas and air both enter the furnace at 25°C.
(a) (4 marks) Determine the percent excess air.
(b) (3 marks) The products leave the furnace at 40°C. Determine the composition of the products after condensation in kmol/kmol fuel.
(c) (4 marks) Calculate the heat transfer to the furnace in MJ/kmol fuel.

(For properties see end of paper.)

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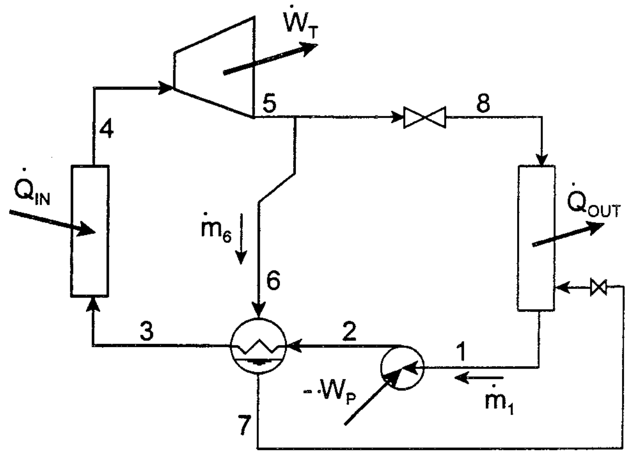
5. (15 marks total) The sketch shows a proposed "steam" cycle for power generation from waste heat which uses R134a as its working fluid. R134a enters the pump as saturated liquid at $T_1 = 30°C$ and is pumped to a pressure $P_2 = 4$ MPa. It passes through a closed feedwater heater, leaving at $T_3 = 70°C$, then enters the boiler and is turned into vapour at $T_4 = 140°C$. The turbine exit is kept at a pressure of $P_5 = 1$ MPa by a valve in the turbine exhaust line (near point 8).



(a) (3 marks) Write the pressure at each numbered point in the cycle, and draw a T-s diagram for the cycle. Why must pressure P_5 be higher than P_1?
(b) (5 marks) If the turbine has an isentropic efficiency of 80%, determine the enthalpy at point 5.
(c) (4 marks) If the pump has an isentropic efficiency of 70%, determine the enthalpy at point 2.
(d) (2 marks) Calculate the ratio of the mass flow $\dot{m}_6$ passing through the feedwater heater to the mass flow $\dot{m}_1$ entering the pump.

Total marks for this paper: 60

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Properties Data

Air properties: Gas constant $R_a = 0.287$ kJ/kg K, $C_P = 1.1$ kJ/kg K, k = 1.40.
Composition 21% O_2, 79% N_2 by mol, or 3.76 kmol N_2 per kmol O_2

Gas constant for water vapour: $R_V = 0.4615$ kJ/kg K

The change in entropy for a perfect gas with constant specific heats is

$$s_2 - s_1 = C_P \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} = C_V \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}$$

The isentropic relations for a perfect gas with constant specific heats are:

$$\frac{T_{2S}}{T_1} = \left(\frac{P_2}{P_1} \right)^{(k-1)/k} = \left(\frac{v_1}{v_2} \right)^{(k-1)} ; \qquad \frac{P_{2S}}{P_1} = \left(\frac{v_1}{v_2} \right)^{k} ;$$

The work done in a reversible steady flow process on an incompressible substance is

$$w = -v_1 (P_2 - P_1)$$

Enthalpies for combustion calculations

Species	Enthalpy of formation $\bar{h}_{fi}^o$ kJ/kmol	Enthalpy at 40°C $\Delta \bar{h}_i$ kJ/kmol
CH_4	- 74 873	
CO_2	- 393 522	167.5
H_2O (liquid)	- 285 838	157.5
H_2O (vapour)	- 241 827	157.5
O_2	0	135
N_2	0	135

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