College of Engineering
Department of Mechanical Engineering

M E 417 Thermodynamics II

Final Examination

December 2003, D.J. Bergstrom

TIME: 3 hours

Provide complete answers to the following questions. State the major assumptions. Where applicable, sketch the process diagram and identify the state points. Reference all property tables that are used.

You are only permitted to refer to the property tables in the appendices of the text, the conversion tables on the inside front cover, and your own assignment problem solutions. A generic version of a formula sheet is also attached.

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1. [20 marks] The energy required to vaporise the working fluid passing through the boiler of a simple vapour power plant is provided by the complete combustion of methane, CH_4, with 110 percent theoretical air. The fuel and air enter in separate streams at $25\,^{\circ}C, 1\,atm$, while the products of combustion exit the stack at $157\,^{\circ}C, 1\,atm$. If the thermal efficiency of the plant is 35 percent, calculate the mass flow rate of the fuel required in *kg/h per MW* of power developed.

2. [20 marks] Methane burns with 90 percent of theoretical air to form an equilibrium mixture of $CO_2, CO, H_2O(g), H_2$ and N_2 at $1000\,K$, $1\,atm$.

   a) Determine the composition of the exiting mixture per *kmol* of fuel.
   b) Comment on the effect of adding N_2 on the equilibrium composition of the mixture.

3. [15 marks] Air flows through a converging-diverging nozzle operating at steady state. The flow conditions at the inlet to the nozzle (section 1) are: $M = 0.4$, $p = 3.4\,bar$ and $T = 530\,K$. The area at the throat of the nozzle is $A_t = 7.6\,cm^2$. A normal shock wave exists downstream of the throat at section 2 where $M = 1.8$. For air, assume constant specific heats with $k = 1.4$.

   a) Calculate the area at section 1.
   b) Calculate the pressure immediately downstream of the normal shock wave.
   c) Briefly comment on how the energy and exergy change across the normal shock wave.

4. [30 marks] A gas turbine can be operated as a refrigeration unit by interchanging the turbine and compressor unit with each other. The efficiency of the refrigeration unit is then measured by the coefficient of performance, which is the ratio of the rate of heat transfer from the cold region to the power supplied to the compressor. Consider a simple Brayton refrigeration cycle. Air enters the compressor at $260\ K, 100\ kPa$ and is compressed to $300\ kPa$. Air enters the turbine at $300\ K, 300\ kPa$, and expands to $100\ kPa$. Assume compressor and turbine efficiencies of 80 percent, and use air standard analysis.

   a) Sketch the process on a $T-s$ plot.
   b) Calculate the net work per unit mass flow of air in *kJ/kg*.
   c) Calculate the coefficient of performance.
   d) If the compression process was polytropic, with exponent *n*, indicate <u>how</u> you could calculate the compression work. (Just set up the equation – a complete solution is not required.)
   e) The turbine inlet temperature is limited to that of the high temperature thermal reservoir. Referring to the cycle diagram, indicate how a regenerator could be used to decrease the turbine inlet temperature. What practical effect would this have on the refrigeration unit?

5. [15 marks] A cylinder of an internal combustion engine contains $2450\ cm^3$ of gaseous combustion products at a temperature and pressure of $887\ ^\circ C$ and 7 *bar*, respectively, just prior to the exhaust valve opening. Neglect the effects of motion and gravity, and model the exhaust products as air. Let $T_o = 17^o C$, $p_o = 1.013\ bar$, and assume air standard behaviour.

   a) Calculate the specific exergy of the gas in *kJ/kg*.
   b) Comment on the significance of the 'energy loss' associated with the exhaust gases.
   c) Briefly explain why exergy depends on the state of the environment, i.e. the dead state.

THE END