M E 417 Thermodynamics II
Midterm Examination
October 2002, D.J. Bergstrom

TIME: 1 ½ 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 permitted to use the property tables in the appendices of the text, the conversion tables on the inside front cover, and your own problem solutions. A generic version of a formula sheet is also attached.

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1. [40 marks] Air flows from an insulated tank through a nozzle into the atmosphere where $p = 100\ kPa$ and $T = 300\ K$. The area at the throat of the nozzle is $A_t = 10\ cm^2$. A normal shock waves stands in the exit of the nozzle, where $A = 14\ cm^2$. Assume constant specific heats with $k = 1.4$.

   a) Sketch the flow. Is the nozzle converging or converging-diverging? Justify your answer.
   b) Estimate the pressure in the tank.
   c) Calculate the mass flow rate.

2. [25 marks] Consider a gas turbine for which the pressure ratio had been selected to obtain the *maximum work output per unit mass flow rate*. The turbine unit is modelled by a cold air standard ideal Brayton cycle with k = 1.4. The inlet temperature to the compressor is 300 K, and the temperature at the exit of the combustor is 1800 K.

   a) Sketch the cycle on a *T-s* diagram.
   b) Determine the pressure ratio across the compressor.
   c) SHOW ANALYTICALLY that the temperature, T_2, at the exit of the compressor is equal to the temperature, T_4, at the exit of turbine.
   d) Comment on the potential for regeneration.

3. [10 marks] Calculate the minimum force on the piston in a cylinder required to produce choked flow through an exit passage 3 mm in diameter. The fluid is air at 300 K, the piston diameter is 12 cm, and the external pressure is 100 kPa. Carefully identify all of your assumptions.

4. [25 marks] Consider a two-stage air compressor with intercooling. At the inlet to the compressor, $T_1 = 300\,K$ and $p_1 = 1\,bar$. The pressure ratio across the first stage is r = 3, and between stages the air is cooled down to $T_3 = 300\,K$. Assume isentropic compression.

   a) Sketch the process on a *T-s* diagram.
   b) Use air standard analysis to calculate the temperature, T_2, at the exit of the first stage. DON'T use relative pressure, but still work from the ideal gas tables.
   c) Use cold air standard analysis to predict the same temperature.
   d) Calculate the work (per unit mass) required for the first stage compression based on the air standard analysis.
   e) Calculate the amount of heat (per unit mass) removed by intercooling based on the air standard analysis.
   f) **[Bonus]** If the intermediate pressure, p_2, was selected to give minimum work, determine the pressure at the exit to the second stage.

THE END