Thermodynamics Qualifying Exam
Spring 2008

Problem 1

A frictionless piston/cylinder is loaded with a linear spring whose spring constant is 100 kN/m. The cross-sectional area of the piston is 0.1 m^2. Initially, the cylinder has a volume of 20 L and contains air at a pressure of 200 kPa and temperature of 10°C. The cylinder has a set of stops that prevent its volume from exceeding 50 L, as shown in the following figure. A valve connects the cylinder to a pipeline of air at 800 kPa and 50°C.

In a filling process, the valve is gradually opened to allow air to flow into the cylinder until its inner pressure reaches 800 kPa, at which point the temperature inside the cylinder is 80°C. The valve is immediately closed to end the process.

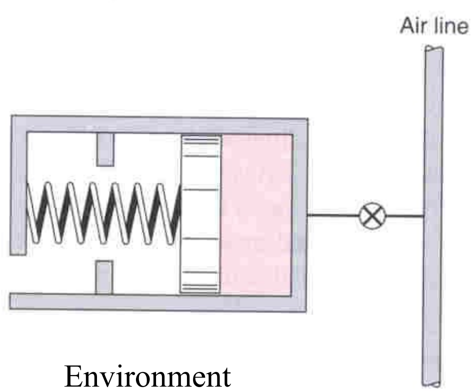
(a) What is the volume at the final state? Show this process in a $P - V$ diagram.

(b) Determine the amount of air flowing into the cylinder.

(c) Determine the amount of work done by the cylinder to compress the spring.

(d) Determine the amount of heat transferred from the cylinder to the environment.

[Note that 1 L = 0.001 m^3. For air, use constant properties: c_p = 1.004 kJ/kg·K, c_v = 0.717 kJ/kg·K, and R = 0.287 kJ/kg·K.]



Problem 2

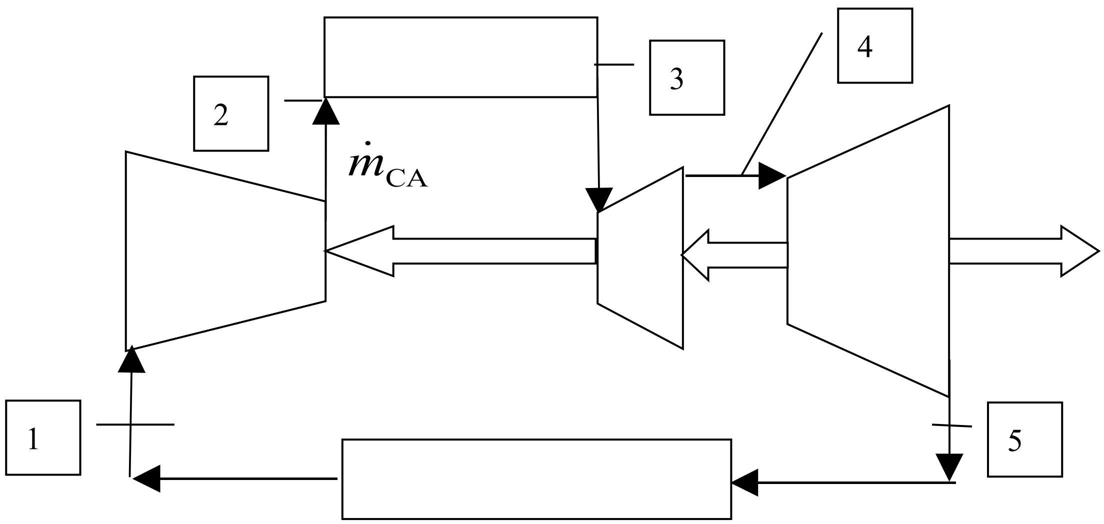
A piston/cylinder system is utilized to extract useful work from a biomass cartridge reacting with air. The cylinder is initially at 300K and 1atm. The auto ignition temperature for the biomass is reached after compressing the initial cylinder charge through a 15.77:1 pressure ratio. The combustion of the cartridge can be modeled as a constant volume, adiabatic heat input of 0.995MJ/kg-air. The useful work is extracted by allowing the cylinder to over-expand down to a final exhaust pressure of 2.5 atm. In the practical piston/cylinder device, the efficiency of the compression and expansion processes is 80%.

a) Calculate the change in specific entropy of air in the process.
b) Determine the useful work output per unit air mass, and sketch the process on the T-s diagram.
c) Calculate the specific exergy of the exhaust.

NOTE: Do not assume constant properties.

Problem 3

The ideal closed gas turbine system shown below operates in a steady state. The working fluid is **helium** with 4.00 molar mass and constant 1.67 specific heat ratio. This system includes a high pressure isothermal turbine with pressure ratio of 2 and a low pressure adiabatic turbine with pressure ratio of 14. The overall pressure ratio is 28. There are no viscous pressure drops in the gas ducts or the heat exchangers. The compressor and the turbines are reversible. Pressure and temperature at the adiabatic compressor inlet are 350 K and 200 kPa. Temperature at the heat input exchanger outlet, station 3, is 1600 K. Ambient temperature is 300 K and ambient pressure is 100 kPa. Reference states for entropy and enthalpy are 300 K and 100 kPa.



station	P	T	h	s	
1					
2					
3					
4					
5					

Answer or solve the following questions or problems. Show all work on attached worksheet.

(1) Verify that the Cp of this helium is about 5.18 kJ/kg-K.

(2) Complete at least the temperature (Kelvins) and pressure (kPa) columns in the table above. Complete other columns only as you find necessary.

(3) Find the cycle efficiency, which is output power/inlet heat rate.

Enter answer **here** __________ ← enter answer **here**!!!!

(4) Would addition of a recuperator improve the efficiency? Explain your answer.

(5) Perform exergy analysis on the **isothermal turbine only**, not the entire system. Illustrate your results with a sketch, and on the sketch show all exergy transports. What is the exergy destruction in this **turbine**? __________ kJ/kg