16.050 Thermal Energy Problem Set #5– Fall 2002

Time spent on problems:

Problem 1:

Problem 2:

Problem 3:

Problem 4:

Problem 5:

Problem 6:

16.050 Thermal Energy

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Do all problems. Please use a separate sheet of paper for each problem.

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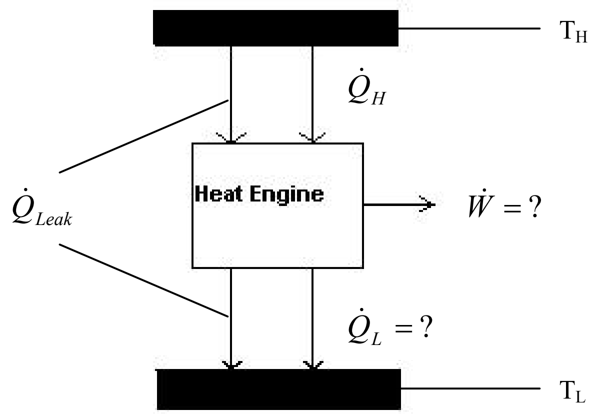
1. Air is to be compressed from atmospheric pressure at 290 K to 7 atm in a centrifugal compressor (isentropic efficiency about 0.70). The flow rate will be 3.75 kg/s. Specify the power requirement for the driving motor. You may assume the working fluid is a perfect gas with cp=1 kJ/kgK.

2. Air enters an adiabatic nozzle at 800 K and 140 kPa and emerges at 7 kPa. The isentropic efficiency of the nozzle is known to be 0.96. Determine the discharge velocity. Sketch the process on a *T-s* diagram and label the states. You may assume the working fluid is a perfect gas with cp=1 kJ/kgK.

3. An inventor has developed a method to run a Carnot cycle, as shown in the figure below, between two temperatures, T_H and T_L. The rate of heat removed from the high temperature source is $\dot{Q}_H$. The only drawback is that there is a small leak so that a quantity of heat, $\dot{Q}_{Leak}$, per second "leaks" through the engine from the high temperature heat source to the low temperature heat sink.

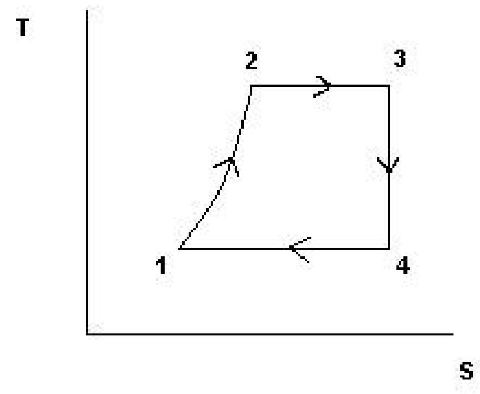


   a) What is the power produced by the leaky Carnot cycle?

   b) What is the thermal efficiency of the leaky Carnot cycle?

   c) What is the rate of entropy production of the leaky Carnot cycle?

4. The figure at the top of the next page gives the *T-s* for a closed system undergoing a power cycle. Internal irreversibilities are present during the adiabatic process from State 1 to State 2. All other processes are internally reversible. The temperature at States 2 and 3 is 600 K and the temperature at States 1 and 4 is 300 K. Entropy at States 3 and 4 is 1.1 kJ/K, entropy at State 1 is 1.0 kJ/K, and entropy at State 2 is 1.02 kJ/K. Determine the thermal efficiency and compare with the thermal efficiency of a Carnot power cycle operating between reservoirs at the same maximum and minimum temperatures.



Problem 4

5. Compressor efficiency is defined as the ratio of the ideal (reversible, adiabatic) work to achieve a given pressure ratio compared to the actual work to achieve the same pressure ratio. You may assume the working fluid is a perfect gas with cp=1 kJ/kgK.

   a) For a jet engine compressor with a mass flow rate of air of 100 kg/s, and a pressure ratio of 12, what would be the ideal work, assuming no heat transfer? Assume standard take-off conditions, T=288 K, P=100 kPa.

   b) If the process were 90% efficient, again assuming no heat transfer, what would be the work?

   c) If the compression process were reversible and *isothermal*, what would be the work needed to reach a pressure ratio of 12?

6. Air flows through an insulated throttle before it enters a turbine as sketched in the figure below. The turbine has an adiabatic efficiency of 80%. There is a stagnation pressure drop, ΔP_t, across the throttle. The air enters the throttle at a stagnation pressure P_{t1} = 10 bar and a stagnation temperature T_{t1} = 600 C. The turbine exit stagnation pressure is P_{t3} = 1 bar.

   a) Sketch the throttling process from state 1 to state 2 in an *h-s* diagram. Explain the rationale behind your sketch (one to two sentences are needed, possibly with an equation)

   b) The throttle (think of a valve) can be operated over a range of conditions. If it is fully opened there is no stagnation pressure drop, $P_{t1} = P_{t2}$. If it is closed as far as possible there is only a small leakage flow so the stagnation pressure change across the turbine is negligible and $P_{t2} = P_{t3}$. Sketch the stagnation states in these two "limiting cases" for the expansion through the overall *throttle-turbine combination* on an *h-s* diagram.

   c) Assuming that the throttle is fully open ($P_{t1} = P_{t2}$) what is the shaft work, per unit massflow, produced in the turbine? The gas can be considered to have a specific heat of c_p = 1000 J/kgK and a ratio of specific heats of k = 1.4.

   d) Assuming that the throttle is closed as far as possible so that $P_{t2} = P_{t3}$ what is the change in entropy across the throttle *between stations 1 and 2*?