GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam – Spring Semester 2020

THERMODYNAMICS

EXAM AREA

Assigned Number (DO NOT SIGN YOUR NAME)

✷ Please sign your **name** on the back of this page —

Problem 1

At steady state, an insulated mixing chamber receives two liquid streams of the same substance at temperatures T_1 and T_2 and mass flow rates $\dot{m}1$ and $\dot{m}2$, respectively. A single stream exits with mass flow rate $\dot{m}3$. Using the incompressible substance model with constant specific heat, *c*:

a) derive the simplified first law of thermodynamics for this system;

b) calculate the temperature of the exiting stream, T_3, as a function of T_1, T_2 and the ratio of the mass flow rates $\dot{m}1/\dot{m}3$;

c) calculate the rate of entropy production per unit of mass exiting the chamber.
Without solving the equations again, comment on how would the answers to the above questions change if this was an assisted mixing, with a paddle wheel requiring a power $\dot{W}$. Specifically, comment if the new final temperature T'_3 would be higher or lower than in part (b) and if the rate of entropy generation per unit of mass exiting the chamber be higher or lower. Why?

Problem 2

Suppose nitrogen flows steadily through two stages in series. At the inlet (State 1), the conditions of nitrogen are 580 K, 600 kPa and 62.0 m/s, with a cross-sectional area of 250 cm^2. The surroundings are at 20.0ºC and 100 kPa.

Stage I involves internally reversible, adiabatic flow through a turbine to turbine exit conditions (State 2) characterized by a pressure of 100 kPa and negligible kinetic energy per unit mass.

Stage II involves the reversible transfer of heat from the nitrogen via a heat exchanger to a reversible heat engine (which is really an infinite sequence of reversible heat engines). The nitrogen enters the heat exchanger with conditions of State 2. At the exit of the heat exchanger, the nitrogen is at the dead state (State 3). Note that the heat engine rejects heat to the environment, which is at 20.0ºC.

Compute:

a) the temperature (T_2) of the nitrogen at the turbine exit

b) the rate of work ($\dot{W}_I$) done by the nitrogen in Stage I

c) the rate of work ($\dot{W}_{II}$) done by the heat engine in Stage II

Hint: $\delta w_{II} = -\eta \delta q_{N_2}$ $\qquad$ $\eta = \eta(T)$ $\qquad$ $T_2 \geq T \geq T_3$

where T is the variable temperature of the nitrogen as it flows from the inlet of the heat exchanger to the exit of the heat exchanger

For convenience in performing the requested calculations above, you may assume:

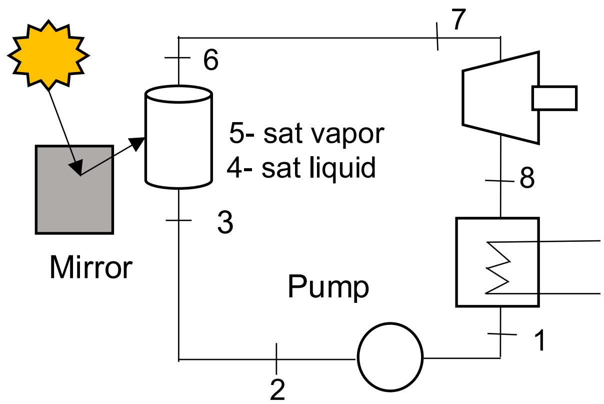
$$h(T) = c_p T$$

with

$$c_p = 1.04 \frac{\text{kJ}}{\text{kg-K}} \qquad R_{N_2} = 0.2968 \frac{\text{kJ}}{\text{kg-K}}$$

Problem 3

In a solar tower system, mirrors are used to focus sunlight to a tower in which the working fluid is heated to high temperatures. The tower system functions as the boiler used in conventional Rankine Cycles. This solar tower is incorporated into a Rankine cycle to generated electricity. The Rankine cycle utilizes water with a mass flowrate of 25 kg/s and the pumping energy requirements are 325 kW. Some properties are listed in the table. Assume steady state and that changes in KE and PE are negligible.



State	2	3	4	5	6	7	8	1
P(kPa)	6000	5000	5000	5000	5000	5000	10	10
T(°C)		20	263	263	500			40
h(kJ/kg)						3422		
x							0.95	

(a) If the pump is adiabatic, solve for the specific enthalpy and temperature at state 2?

(b) In the pipeline from the pump to the tower (2 to 3), there is heat loss. What is the rate of heat transfer loss along the pipe?

(c) What is the rate of heat transfer to the working fluid inside the solar tower, 3 to 6?

(d) What is the power output from the turbine which functions adiabatically?

(e) Assume that the cooling water in the condenser comes from a lake at 12°C and returns to the lake at 25°C. Determine the rate of heat transfer in the condenser and the mass flow rate of the cooling water from the lake.

(f) What is the overall thermal efficiency?

(g) Assume the solar radiation energy flux is 1000 W/m^2, and the solar-to-heat conversion efficiency of this solar tower system is 90%. How large an area of mirrors is needed to power the Rankine cycle?