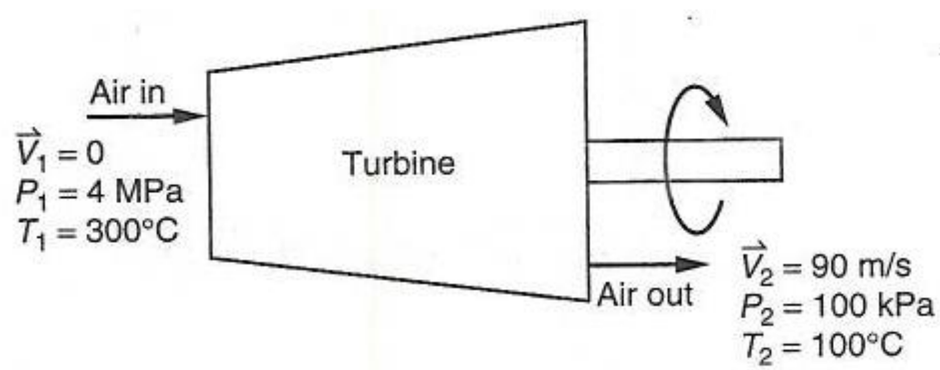
ECHE 363 – Thermodynamics of Chemical Systems
Homework #3

100 points total. Complete the following problems and upload your solutions to the Canvas assignment dropbox by the due date/time.

You are strongly encouraged to collaborate with your classmates on the homework, but each student is required to come up with a unique solution to the homework problems. For full credit, you must show all work. This includes showing all steps involving algebra and/or calculus. Your calculator can only be used for the final evaluation of numerical answers and may not be used for solving algebraic equations and/or integrals.

1. Two moles of nitrogen are initially at 15 bar and 500 K in piston–cylinder assembly. The system is expanded adiabatically against a constant external pressure of 1 bar until it reaches mechanical equilibrium. Calculate the final temperature, the heat transferred, and the work of the system. You may assume ideal gas behavior for nitrogen. Use a temperature-dependent heat capacity for nitrogen. These data can be found in the appendices of the Koretsky textbook.

2. Air enters a well-insulated turbine operating at steady, state with negligible velocity at 4 MPa, 300 °C. The air expands to an exit pressure of 100 kPa. The exit velocity and temperature are 90 m/s and 100 °C, respectively. The diameter of the exit is 0.6 m. Determine the power developed by the turbine (in kW). You may assume air behaves like an ideal gas throughout the process.



3. Sulfur dioxide (SO_2) with a volumetric flow rate of 5000 cm^3/s at 1 bar and 100 °C is mixed with a second SO_2 stream flowing at 2500 cm^3/s at 2 bar and 20 °C. The process occurs at steady state. You may assume ideal gas behavior and that the process is adiabatic. For SO_2, take the heat capacity at constant pressure to be:

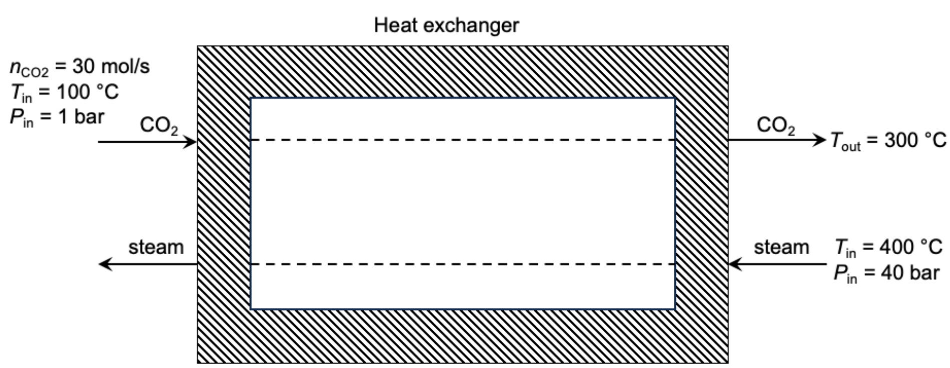
$$\frac{c_{\mathrm{p,m}}}{R} = 3.627 + 5.324 \times 10^{-3} T$$

where T is in [K].

   a. What is the molar flow rate of the exit stream?

   b. What is the temperature of the exit stream?

4. You wish to heat a stream of CO_2 at pressure 1 bar, flowing at 30 mol/s, from 100 °C to 300 °C in a countercurrent heat exchanger. To do this task, you have been asked to use a stream of high-pressure steam available at 40 bar and 400 °C, as shown in the following figure. You may assume the pressure of each stream stays constant as it flows through the heat exchanger (i.e., neglect the pressure drop of the flowing streams). The entire system is well insulated, as shown. <u>It is undesirable for the steam to condense in the heat exchanger tubes</u>. What is the minimum volumetric flow rate of the steam inlet required (in m^3/s) to keep it from condensing at the exit?



5. At steady state, an ideal gas enters a compressor with a molar flow rate of 20 mol/s. The inlet pressure is 1 bar and the inlet temperature is 25 °C. The gas exits at 50 bar and 100 °C. The ideal gas molar constant-pressure heat capacity is given by:

$$c_{p,m}/R = 3.60 + 0.500\times10^{-3}T$$

where T is in [K].

a. Assuming the compressor is adiabatic, calculate the power (in kW) required.

b. In the real process, there is a finite amount of heat transfer. If the compressor operates between the same initial state and final state as in Part A, will the actual power required be greater than, equal to, or less than that calculated in Part A? Explain.

6. Answer the following reflection questions (5 points):

   a. What about the way this class is taught is helping your learning?

   b. What about the way this class is taught is inhibiting your learning?