Third Exam ChE 226
6 May 1999

Conversion notes: \( MW, C = 12 \); \( H = 1 \), \( R = 8.314 \text{ J/gmoleK} = 1.98 \text{ cal/moleK} \); 1 ton of refrigeration = 12,000 Btu/h; \( 1.34 \text{ hp} = 10^3 \text{ J/s} = 56.87 \text{ Btu/min} \)

All heat exchangers will employ a minimum 10K approach.

State all your assumptions

1. (35) You enter a power plant which is burning the off-gas from a natural gas purification process (containing various C3 and C4 hydrocarbons). You notice that the air coming out of the compressor is at 400°C and 191 PSIG while the gas exiting the turbine to the exhaust stack is at 527°C. Assume that the gas entering the plant is at one atmosphere and 27°C, room temperature. Use the attached H-S diagram for air. Draw the steps for the process and calculate the following:

   A. What is the efficiency of the compressor?

   Assume the compressor and turbine are equally efficient and calculate:

   B. What is the temperature coming out of the combustion process?

   C. How much work is lost in this process?

   D. What is the overall efficiency of the power plant?

   E. What would be the overall plant efficiency if the compressor and compressor were 100% efficient?

Extra Credit (leave the following to the end): How would you estimate the heat of combustion of the hydrocarbon mixture and the efficiency of the combustion process?

2. (30) The hydrocarbon employed in the above process needs to be transported as a liquid from its source to the power plant. It is to be liquefied in a simple Linde plant without any internal heat exchange (only heat exchange to the ambient atmosphere). Assume that the gas is propane and use the attached diagram for \( C_3H_8 \). The hydrocarbon flows into the liquefaction process at 2 atm and 300 °K at a rate of 0.25 m³/s. It leaves the process at the same pressure. The compression ratio of the compressor is 25/1.

   A. Calculate the rate of production of liquid propane (kg/hour).

   B. What is the capacity (m³/hour of hydrocarbon at room temperature) and the "ideal" horsepower required for the compressor?

   Draw the process (as much as possible) on the attached diagram and relate it to the process steps.
3. (25) If the desired increase in pressure during a stage in a process is large, it is often more efficient (less total work is required) to compress a fluid in several stages. The efficiency depends on the intermediate pressures (from the first to the second... to the final pressure).
   A. Express the work required to compress an ideal gas from an initial Pressure, \( P_o \), to a final pressure, \( P_f \), as a function of the intermediate pressure, \( P_i \), for two stage compression. (no inter-cooling)
   B. Contrast this with the work required for a single stage compression.
   C. Derive the most efficient intermediate pressure for an ideal gas for a two stage compression process. You can do this assuming \( C_p = 2R \) and that the gas between the two compressors is returned to the same initial temperature.

   Hint: in terms of \( P_o - P_i \) and \( P_i - P_f \); or \( P_o/P_i \) and \( P_i/P_f \).

Note: A graphical representation may be employed to receive most of the credit for this problem.

(leave the following to the end)

Extra Credit: Discuss the influence of additional heating or cooling between the two stages.

4. (20) The process in problem 2 involves recycle of the some gaseous hydrocarbon. It would be possible to eliminate the recycle by cooling the propane below -25\(^\circ\)C (at 2 Bar). This would require energy to provide refrigeration. Use the attached diagram for refrigerant 12 and determine the minimum energy (hp) required (per kg of gaseous propane) to liquify the propane employing this fluid (12) as the refrigerant (using an expansion valve and an ideal compressor) and air (300K) as the heat exchange medium for the refrigeration.

Hint: The temperatures of the fluid in the two heat exchangers of the refrigerator are first estimated. Draw the diagram and estimate the COP. This can be related to the heat of liquification of propane with specific assumptions (state them).

Note: A process where saturated liquid either enters or exits the expansion valve will be counted as correct. We will discuss this next class.