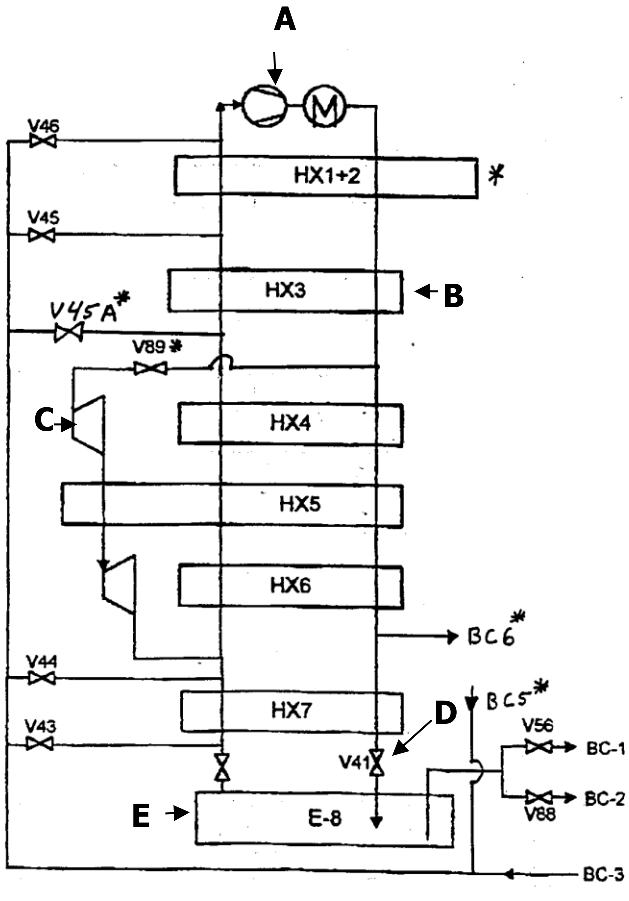
USPAS Cryogenic Engineering (June 21 – July 2, 2021)

Instructors: John G. Weisend II (ESS, Sweden), Ram C. Dhuley (FNAL, USA)
Grader: Greg Tatkowski (FNAL, USA)

Homework Problems for Tuesday June 24, 2021

1. Calculate the Coefficient of Performance for an ideal Carnot Cycle Refrigerator operating between 300 K and 30 K. How many Watts of power at 300 K are required to remove 1 Watt of heat at 30 K using this refrigerator?

2. Identify the indicated components on the Collins cycle refrigeration plant schematic shown below:



CTI 4000 Upgrade 12 / 2 / 99

*** Indicates new or changed component**

A:

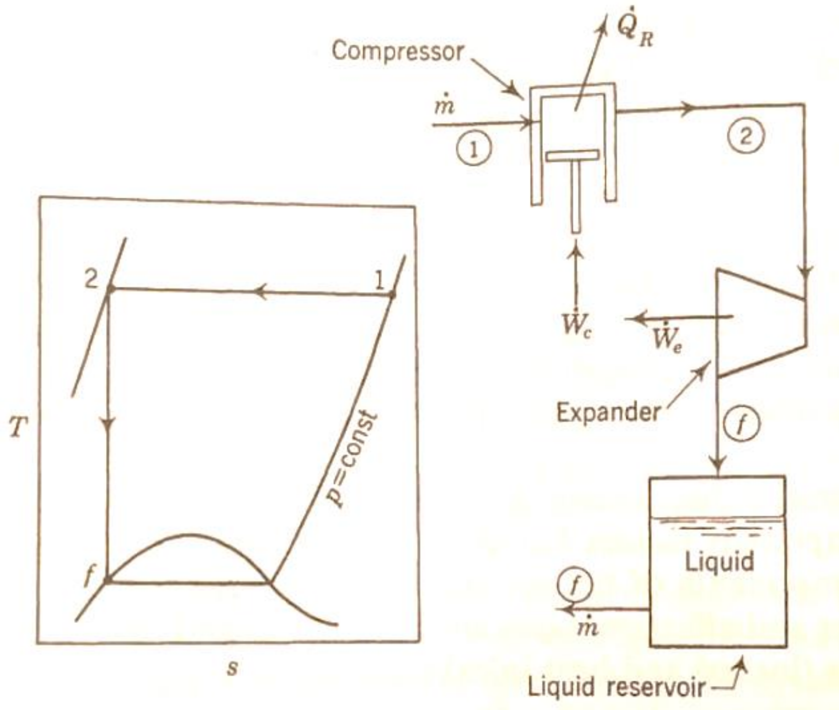
B:

C:

D:

E:

3. Liquefaction of gases is a major industrial application involving cryogenics. The thermodynamically ideal gas liquefaction cycle is depicted below:



The process starts at '1' with the gas at ambient temperature of 300 K and 1 bar pressure. The gas is liquefied in two steps: (1) from '1' to '2' and (2) from '2' to 'f', where it becomes a saturated liquid at 1 bar pressure.

(a) Looking at the temperature-entropy diagram, name the type of processes '1' to '2' and '2' to 'f' involved in the liquefaction cycle

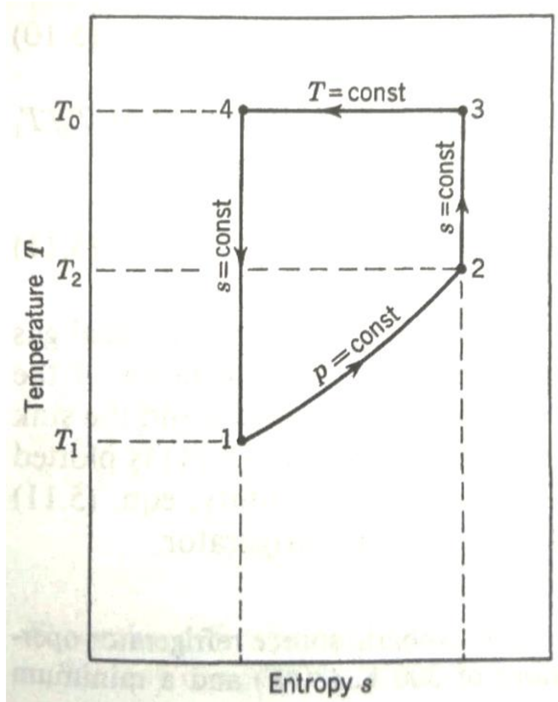
(b) Apply first law of thermodynamics to the cycle and derive an expression for ideal work of liquefaction

(c) Using the above derived expression for ideal work of liquefaction, calculated the ideal work for the following

   a. helium-4
   b. hydrogen
   c. neon
   d. nitrogen

   Use NIST Thermophysical Properties database to obtain the fluid properties https://webbook.nist.gov/chemistry/fluid/.

4. Ideal refrigeration cycle with a non-isothermal refrigeration load is depicted on a temperature-entropy diagram below:



By applying first law of thermodynamics to this cycle, we saw in the class that the COP of this cycle is given by:

$$COP_{isoP,ideal} = \frac{Q_{ref}}{\dot{W}_{net,in}} = \frac{h_2 - h_1}{T_{amb}(s_2 - s_1) - (h_2 - h_1)}$$

(a) Show that for an ideal gas, the above expression simplifies to:

$$COP_{isoP,ideal} = \frac{(T_2/T_1) - 1}{(T_{amb}/T_1)\ln(T_2/T_1) - ((T_2/T_1) - 1)}$$

(b) Suppose we want to construct an ideal cycle refrigerator working between T_{amb} = 300 K, T_1 = 120 K, and T_2 = 140 K. Assuming ideal gas, which one amongst nitrogen, neon, and helium would you use to maximize the COP of this cycle?

(c) Simplify the above COP expression for the condition $T_1 = T_2$ and show that it corresponds to COP for an ideal isothermal refrigerator. (Hint: see lecture slides for the expression of COP for an ideal isothermal refrigerator).