AUIS ENGR 352 (Thermodynamics), Section 1, Course Assignment 4

Deadline:[1] November 14, 2017

Tutorial Discussion: November 19, 2017

1) A **reversible Carnot power cycle** with a net power output of 100.0 W operates with the working fluid **ammonia** as follows:

1 → 2: Vaporization of the working fluid at T_{12} = 375.0 K from the saturated liquid state **(1)** to the saturated vapor state **(2)**, in an evaporator with a heat input rate of 900.0 W.

2 → 3: Adiabatic expansion to a vapor-liquid equilibrium state **(3)** with s_3 = 84.20 J K^{-1} mol^{-1}.

3 → 4: Reversible condensation at constant pressure; thereby, the quality decreases, $x_4 < x_3$, and the amount of liquid increases, until the working fluid in state **(4)** has a molar entropy of s_4 = 52.49 J K^{-1} mol^{-1}.

4 → 1: Adiabatic compression until only saturated liquid remains.

a) Show this cycle in a **T-s diagram** containing the vapor-liquid coexistence curve for ammonia.

b) What is the **mass flow rate** of the working fluid? The molar mass is $M(NH_3)$ = 17.03 g mol^{-1}.

c) At which **temperature** does the **reversible condensation** occur? Thermodynamic properties of ammonia are available in the *U.S. National Institute of Standards and Technology* database.[2]

2) Using either the NIST database or Tables A–14 and A–1 from Moran *et al.*, determine the compressibility factor z for **saturated ammonia vapor** at p = 40, 100, 400, and 1000 kPa. What is the main tendency that can be observed here, and how can it be explained?

3) Nitrogen is **adiabatically throttled** from 4 bar to 1 bar, entering the throttling valve with a volume flow rate of 250 ml s^{-1} at the inlet.[3] After throttling, the fluid has a temperature of 300 K. **Determine the mass flow rate**, assuming that the throttling valve operates in a steady state; in particular, the inlet and the outlet have the same mass flow rate.

The thermodynamic properties of nitrogen gas can be approximated by the **ideal gas law**. Note that no technical work is done during throttling and, as usual for throttling, neglect changes in potential and kinetic energy of the fluid. The molar mass of nitrogen is given by M = 28.01 g mol^{-1}, and the speed of sound at p = 1 bar and T = 300 K is $\mathcal{V}_s$ = 353 m s^{-1}.

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1 *Each problem contributes 0.5% to the overall grade. Submissions, individually or in groups of two, can be handed in on November 14 (after, not during the lecture), or deposited in the B-F2-01 mailbox by November 13.*

2 http://webbook.nist.gov/chemistry/fluid/

3 *This "old" assignment problem was not discussed in Tutorial 3; it is reposed and will be discussed in Tutorial 4.*

4) A thermally insulated, rigid tank with the volume V = 900 ml contains n = 8.0 mol liquid isopropanol, in which initially (state 1), a temperature gradient is present. Approximate this by assuming that initially, n_A = 3.0 mol of the isopropanol have the temperature T_A = 320.0 K, while n_B = 2.0 mol are at T_B = 324.0 K, and n_C = 3.0 mol are at T_C = 328.0 K.

Eventually (state 2), an equilibrium without a temperature gradient is reached. Is this process **reversible or irreversible**? Does the **total entropy of the fluid** in the final state differ from the total entropy of the fluid in the initial state? If yes, by what amount $S_2 - S_1$ does it change?

You may assume that throughout this process, the system is close enough to equilibrium conditions such that thermodynamic properties, which are strictly well-defined in equilibrium only, can be employed just as usual. Assume that within the relevant temperature range, the specific isochoric heat capacity is constant, c_v = 15 R, where R is the gas constant.

5) Consider **two reversible heat engines** A and B, operating **between three reservoirs** α, β, γ. The temperature of the reservoir α is greatest; the temperature of the reservoir γ is smallest.

In the heat engine A, which operates between the reservoirs α and β with **water as a working fluid**, heat is transferred from reservoir α to the fluid reversibly, and hence, isothermally at $T = T_\alpha$ = 300 °C; heat transfer from the fluid to reservoir β occurs at $T = T_\beta$. The heat engine B operates between the reservoirs β and γ with **R134a as a working fluid**, taking heat reversibly from reservoir β at $T = T_\beta$ and reversibly releasing part of it to reservoir γ at $T = T_\gamma$ by condensation of the working fluid at a constant pressure of p = 200 kPa.

The thermal efficiency is twice as great for the cycle A as it is for the cycle B, i.e., $\eta_A = 2\eta_B$. The temperature T_α = 300 °C is given. **Determine the temperatures** of the reservoirs β and γ.

You can use lecture material (e.g., the log p – h diagram for R134a), tables from the book, or the NIST database to look up the required thermodynamic properties of water and R134a.