ENGR 352 – THERMODYNAMICS – SPRING 2018 – TERM EXAM II

Recommendation: Solve two out of the three given problems.

- You have **110 minutes** from the moment that the beginning of the exam is announced.
- This exam consists of three problems. Each is worth up to 20 credits, out of 100 credits for the whole course. At most 35 credits can be gained from the present term exam.

  You need to **work on two problems** to achieve an optimal outcome.
- If you **choose to work on two problems**, the problem with the best outcome will count normally (i.e., up to 20 credits), and the other problem will be scaled by a factor of 75% (i.e., up to 15 credits), yielding an **optimum total of 35 credits**.
- If you choose to work on all three problems, the outcomes will be ordered by the number of credits achieved. **The best problem counts with a factor of 100%**, and **the second best problem is scaled by a factor of 75%**, yielding up to 35 credits for the exam as a whole. The outcome of the remaining problem does not influence your grade.
- Any concerns on scheduling, grading, or any other matter should, as always, be addressed to the ENGR vice head of department Raguez Taha.

Make sure that **every paper** that you submit contains your **name** and **student ID**. Any access to means of communication is a case of cheating irrespective of what is communicated. It is enough to **turn off your cell phones**. *You absolutely do not need to place your cell phones on the front desk.*

Recall that it is sufficient to **solve two out of the three present exam problems**. Feel free to hand in your submission at any time and leave the room without disturbing the other participants.

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American University of Iraq, Sulaimani

[Problem II.1] In an adiabatic compressor operating in a steady state, ideal gas isobutane is compressed reversibly, without dissipation, from a density of ρ_{in} = 0.01 mol l^{-1} at the inlet to a density of ρ_{out} = 0.03 mol l^{-1} at the outlet. The temperature of the gas at the inlet is T_{in} = 15 °C, and its molar entropy is s_{in} = 137.2 J K^{-1} mol^{-1}.

The volume flow rate at the outlet is 0.0025 m^3 s^{-1}.

Determine **a)** the outlet temperature T_{out}, **b)** the molar entropy s_{out} at the outlet, **c)** the technical power, in units of W, that is supplied to the compressor, **d)** the efficiency η of the compressor.

Reversible adiabatic processes are isentropic. The molar isochoric and isobaric heat capacities of isobutane are c_v = 6.22 R and c_p = 7.22 R, and R = 8.3145 J K^{-1} mol^{-1} is the universal gas constant. Changes in kinetic and potential energy may be neglected.

[Problem II.2] A rigid tank containing n = 5 mol octane in a vapor-liquid equilibrium state, initially with a quality x_1 = 0.08 (i.e., initially, 4.6 mol liquid and 0.4 mol vapor) at p_1 = 30 kPa and T_1 = 87 °C, is heated reversibly until the pressure p_2 = 40 kPa is reached. Determine **a)** the temperature T_2 in the final state, **b)** the quality x_2 in the final state, **c)** the amount of heat Q_{12} transferred to the octane in the tank.

The following vapor-liquid equilibrium data (liquid: v^{l}, h^{l}, u^{l}; vapor: v^{ll}, h^{ll}, u^{ll}) are available:

p = 30 kPa: v^{l} = 0.18 l mol^{-1}, v^{ll} = 97.45 l mol^{-1}, h^{l} = −11.32 kJ mol^{-1}, h^{ll} = 25.76 kJ mol^{-1}, u^{l} = −11.33 kJ mol^{-1}, u^{ll} = 22.84 kJ mol^{-1}

p = 35 kPa: v^{l} = 0.18 l mol^{-1}, v^{ll} = 84.31 l mol^{-1}, h^{l} = −10.07 kJ mol^{-1}, h^{ll} = 27.01 kJ mol^{-1}, u^{l} = −10.08 kJ mol^{-1}, u^{ll} = 24.06 kJ mol^{-1}

p = 40 kPa: v^{l} = 0.18 l mol^{-1}, v^{ll} = 74.36 l mol^{-1}, h^{l} = −8.95 kJ mol^{-1}, h^{ll} = 28.13 kJ mol^{-1}, u^{l} = −8.96 kJ mol^{-1}, u^{ll} = 25.16 kJ mol^{-1}

Temperatures are not given here, except for the boiling temperature at 30 kPa, which is 87 °C. The simplified Clausius-Clapeyron equation in the form $\Delta(\ln p^{sat}) / \Delta(T^{-1}) = -\Delta h^{v}/R$ can be used.

[Problem II.3] A reversible Carnot heat engine operates with octafluoropropane C_3F_8 as a working fluid, receiving $q_{T high}$ = q_{12} = +11 kJ mol^{-1} heat per mole of working fluid from a high-temperature reservoir at T_{high} = 440 K. The engine rejects heat to a low-temperature reservoir during an isothermal compression transition (3 → 4, see below) after which the working fluid has the pressure p_4 = 257 kPa, the molar volume v_4 = 11.8 l mol^{-1}, and the molar entropy s_4 = 305 J K^{-1} mol^{-1}.

The critical temperature of the working fluid is T_c = 345 K, and its molar entropy at the critical point is s_c = 250 J K^{-1} mol^{-1}. The relation between p, v, and T is given by the van der Waals equation of state, $(p + av^{-2})(v - b) = RT$, with the coefficients a = 1.0 J m^3 mol^{-2} and b = 0.10 l mol^{-1}.

a) Determine the molar entropies s_1, s_2, and s_3, and the temperature T_{low} at which heat is rejected.

b) Sketch the process in a T-s diagram containing the vapor-liquid coexistence curve (binodal).

c) Determine the thermal efficiency η of this reversible power cycle.

The Carnot power cycle consists of four states (1, 2, 3, and 4) and the following four transitions:

- **1 → 2:** Isothermal expansion at the temperature $T_{high} = T_1 = T_2$
- **2 → 3:** Adiabatic expansion with a temperature decrease from $T_{high} = T_2$ to $T_{low} = T_3$
- **3 → 4:** Isothermal compression at the temperature $T_{low} = T_3 = T_4$
- **4 → 1:** Adiabatic compression with a temperature increase from $T_{low} = T_4$ to $T_{high} = T_1$

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