ENGR 352 (SECTION 1) – THERMODYNAMICS – FALL 2017 – TERM EXAM II

Please read the following information closely.

- You have **110 minutes** from the moment that the beginning of the exam is announced.

- This exam consists of five problems. Each is worth up to six credits, out of 100 credits for the whole course. At most 15 credits can be gained from the present term exam.

  You need to **work on three problems** to achieve an optimal outcome.

- If you **choose to work on three problems**, the two problems with the best outcome will count normally (i.e., up to six credits each), and the third problem will count with a factor of 50% (i.e., up to three credits), yielding an **optimum total of 15 credits**.

- If you choose to work on more than three problems, the outcomes will be ordered by the number of credits achieved. **The two best problems count with a factor of 100%**, and **the third problem counts with a factor of 50%**, yielding up to 15 credits for the exam as a whole. The outcome of the other problems does not influence your grade.

- Do not return an empty submission. Most of you know how to draw the relevant diagrams. If you feel insecure about the present exam or do not know how to start, draw these diagrams on the basis of the information that you find in the text. Three problems include diagrams: Problem II.1 (log p-h diagram), Problem II.3 (T-s diagram), and Problem II.4 (p-v diagram).

- Appealing to the head of department, board of trustees, etc., will not change any grades.

Make sure that **every sheet of paper** 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 them on the front desk.

The exam time is far greater than the time that should be required. Recall that it is sufficient to **solve three out of the five present exam problems**. Accordingly, feel free to hand in your submission at any time and leave the room quietly without disturbing the other participants.

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[Problem II.1] As part of a refrigeration cycle operating in a steady state, the working fluid **R134a** is **adiabatically throttled** from a vapor-liquid equilibrium state at T_{in} = 325.0 K to a vapor-liquid equilibrium state at T_{out} = 275.0 K. During adiabatic throttling, the specific enthalpy $h = u + pv$ remains constant. At the throttling valve inlet, the fluid has a molar volume of v_{in} = 0.50 l mol^{-1}.

Is this process reversible, irreversible, or impossible? **Determine the quality**, i.e., the fraction of the total amount of substance which belongs to the vapor phase, at the inlet and at the outlet. Sketch a **log *p*-*h* diagram** with this isenthalpic transition and the vapor-liquid coexistence curve of R134a.

At **275.0 K:** Vapor pressure: 312.9 kPa; sat. liquid volume: 0.07918 l mol^{-1}; sat. liquid internal energy: 20.64 kJ mol^{-1}; sat. vapor volume: 6.632 l mol^{-1}; sat. vapor internal energy: 38.71 kJ mol^{-1}.

At **325.0 K:** Vapor pressure: 1380 kPa; sat. liquid volume: 0.09330 l mol^{-1}; sat. liquid internal energy: 27.88 kJ mol^{-1}; sat. vapor volume: 1.463 l mol^{-1}; sat. vapor internal energy: 41.25 kJ mol^{-1}.

[Problem II.2] By going through an **adiabatic nozzle** that operates in a steady state without dissipation, krypton, a noble gas to be treated here as an **ideal gas** with a specific isobaric heat capacity given by $c_p = (\partial h / \partial T)_p$ = 248.1 J K^{-1} kg^{-1}, is accelerated from its initial velocity, at the inlet, to an outlet velocity of 150.0 m s^{-1}. From inlet to outlet, the temperature decreases by $T_{\text{out}} - T_{\text{in}}$ = −40.30 K.

Determine the velocity at the inlet. For an ideal gas, the speed of sound is given by $\mathcal{V}_s = (\kappa p v / M)^{1/2}$, where κ = 5/3 is the polytropic exponent of krypton, M = 83.80 g mol^{-1} is its molar mass, p is the pressure, and v is the molar volume. The universal gas constant is R = 8.3145 J K^{-1} mol^{-1}.

Reversible adiabatic transitions are isentropic, the total differential for specific enthalpy is given by $dh = v\,dp - T\,ds$, and you may assume that for gaseous krypton, h is a function of temperature only.

[Problem II.3] How much heat needs to be transferred to a system containing **water, initially as a saturated liquid**, while it **expands** reversibly from an initial (1) volume of V_1 = 250 ml to the final (2) volume V_2 = 750 ml **at a constant temperature** of 200 °C? By what amount does the **entropy of the fluid** change during this process? Recall the definition of entropy, in differential form, $dS = dQ^{\text{rev}} / T$.

Sketch the transition from (1) to (2) in a ***T*-*s* diagram** that contains the vapor-liquid coexistence curve for water. For **water at 200 °C**, the vapor pressure is 1555 kPa, the saturated liquid density is given by 48.00 mol l^{-1}, and the saturated vapor density is given by 0.4364 mol l^{-1}. The molar internal energy $u = U/n$ is 15.32 kJ mol^{-1} for the saturated liquid and 46.74 kJ mol^{-1} for saturated vapor at 200 °C.

[Problem II.4] Consider the following **reversible cycle** with the working fluid nitrogen, which is here to be regarded as an **ideal gas** with the specific isochoric heat capacity $c_v = (\partial u / \partial T)_v = 2.50\,R$:

- State 1 to state 2 (1 → 2), **adiabatic** compression from p_1 = 60.0 kPa to p_2 = 100 kPa.
- State 2 to state 3 (2 → 3), **isobaric** expansion until a volume of v_3 = 75.0 l mol^{-1} is reached.
- State 3 to state 1 (3 → 1), **isochoric** cooling until the pressure p_1 = 60.0 kPa is reached.

Show the states and the transitions between them in a ***p*-*v* diagram**. You may assume that for an ideal gas, u is a function of temperature only. The universal gas constant is R = 8.3145 J K^{-1} mol^{-1}.

Is it a power or refrigeration cycle? Determine the **net power received by** the gas and the **net heat transferred to** the gas per time for a (molar) substance flow rate of 5.70 mol s^{-1}. Pay attention to the signs. *To the fluid:* positive; *from the fluid:* negative. The molar mass of N_2 is M = 28.01 g mol^{-1}.

[Problem II.5] A **heat pump** with the working fluid **carbon dioxide** (critical temperature: T_c = 304.3 K) and a coefficient of performance of 4.0 transfers heat from a cold reservoir at 285 K to a hot reservoir at 330 K. Calculate the **rate of entropy change** for a system consisting of the heat pump and the reservoirs if 4.64 kW of heat are transferred to the hot reservoir. **Do these statements violate the Second Law?** For the same temperatures, would a coefficient of performance of 6.0 be possible?

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