ENGR 352 (SECTION 1) – THERMODYNAMICS – FALL 2017 – FINAL EXAM

Please read the following information closely.

- You have **115 minutes** from the moment that the beginning of the exam is announced.

- This exam consists of five problems. Each is worth up to 20 credits, out of 100 credits for the whole course. At most 50 credits can be gained from the present term exam. Bonus credits from the optional term paper will be added to your grade at this stage.

  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 20 credits each), and the third problem will count with a factor of 50% (i.e., up to ten credits), yielding an **optimum total of 50 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 50 credits for the exam as a whole. The outcome of the other problems does not influence your grade.

- Three problems include diagrams: Problem 1 (T–s diagram), Problem 2 ($\log p^{sat}$ over $1/T$), and Problem 4 (p–v diagram). 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.

- 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.

Recall that it is sufficient to **solve three out of the five present exam problems**.

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[Problem 1] In a **reversible Carnot heat engine** operating between reservoirs at T_{high} = 400 K and T_{low} = 325 K with a net power output of 600 W, nitrogen is used as working fluid. Nitrogen can be considered here as an ideal gas with M = 28.01 g mol^{-1}, c_v = 2.5 R, and $c_p = c_v + R$, wherein R = 8.3145 J K^{-1} mol^{-1}. The cycle operates in a steady state with a substance flow rate of 0.5 mol s^{-1}. Before the isothermal expansion (transition 2 → 3, at $T_2 = T_3 = T_{high}$), i.e., after the adiabatic compression (transition 1 → 2, $T_1 = T_{low}$ and $T_2 = T_{high}$), the working fluid has the molar entropy s_2 = 184 J K^{-1} mol^{-1}. The Sackur-Tetrode equation, in differential form, is given by $ds = Rv^{-1}\,dv + c_vT^{-1}\,dT$.

a) What is the thermal efficiency of this reversible power cycle?
b) **Draw a T–s diagram with the four transitions and the four states** of the cycle.
c) Beside s_2, which is given, determine the molar entropy for the other three states.

[Problem 2] At a pressure of 10 kPa, **octane** has a boiling temperature of 59 °C. The enthalpy of vaporization of octane at 59 °C is $\Delta h^v = h^{II} - h^{I}$ = 344.4 kJ kg^{-1}. The triple point of octane is at −57 °C, the critical point at 296 °C; its molar mass is M = 114.2 g mol^{-1}.

Assume that the **Clausius-Clapeyron equation** can be simplified here to the identity $d(\ln p^{sat}) / d(T^{-1}) = -\Delta h^v / R$, as discussed in the lecture, and assume Δh^v to be approximately constant. The universal value of R, using moles, is 8.3145 J K^{-1} mol^{-1}.

a) What is the boling temperature of octane at 1 kPa and at 100 kPa, respectively?
b) Draw the **vapor pressure curve** in a **diagram with log p** (“y axis”) **over T^{-1}** (“x axis”).

[Problem 3] **An ideal mixture of ideal gases** in a piston-cylinder device undergoes a chemical reaction **at a constant pressure** of 80 kPa. Initially, the cylinder contains 2 mol acetylene (C_2H_2), 2.5 mol oxygen (O_2), and 6 mol nitrogen (N_2), and its initial volume is 0.525 m^3. The **acetylene is combusted**, producing CO_2 and water vapor (i.e., steam) while O_2 is consumed, **until the system runs out of oxygen**. Thereby, the initial and the final temperature are the same. The enthalpy of combustion is −1300 kJ mol^{-1} for acetylene, and the universal gas constant is R = 8.3145 J K^{-1} mol^{-1}. Determine

a) the chemical reaction equation for the combustion of acetylene;
b) the final composition of the mixture, as mole fractions, i.e., in units of mol mol^{-1};
c) the work done to the fluid and the heat transferred to the surroundings.

[Problem 4] Discuss the following reversible cycle with the working fluid N_2, to be considered as an ideal gas with M = 28.01 g mol^{-1} and c_v = 2.5 R, wherein R = 8.3145 J K^{-1} mol^{-1}.

Transition 1 → 2: Adiabatic compression from p_1 = 60 kPa to p_2 = 100 kPa.
Transition 2 → 3: Isothermal expansion ($T_2 = T_3$) to a molar volume v_3 = 75 l mol^{-1}.
Transition 3 → 1: Isochoric cooling ($v_3 = v_1$) until a pressure p_1 = 60 kPa is reached.

a) Determine the pressure and the molar volume for all states of the cycle, and **show the three states and the three transitions** between them **in a p–v diagram**.
b) Determine the net work done to the gas and the net heat transferred to the gas, respectively, per time (i.e., in units of W), with the substance flow rate 7.5 mol s^{-1}.

[Problem 5] **a)** Consider air as a gas mixture with 0.7811 mol mol^{-1} N_2, 0.2096 mol mol^{-1} O_2, and 0.0093 mol mol^{-1} Ar. Determine the mass fraction of O_2, in units of kg kg^{-1}, if the molar mass is 28.01 g mol^{-1} for N_2, 32.00 g mol^{-1} for O_2, and 39.95 g mol^{-1} for Ar.
b) Determine the heat required to **increase the temperature** of a constant amount of air, occupying 1 m^3 initially, from an initial temperature of 300 K to a final temperature of 400 K, by a reversible process **at a constant pressure** of 101.3 kPa.

Treat this system as an **ideal mixture of ideal gases**. The specific isochoric heat capacity can be approximated by c_v = 2.5 R for nitrogen and oxygen and by c_v = 1.5 R for argon, with $c_p = c_v + R$ where R = 8.3145 J K^{-1} mol^{-1} is the universal gas constant.

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