
QUEEN'S UNIVERSITY

FACULTY OF ENGINEERING AND APPLIED SCIENCE

DEPARTMENT OF CHEMICAL ENGINEERING

CHEE 210

FINAL EXAMINATION

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Instructions

PLEASE NOTE: "Proctors are unable to respond to queries about the interpretation of exam questions. Do your best to answer exam questions as written."

1. This examination is THREE HOURS in length. Please answer all questions in the answer books provided. Put your student number on the front of all answer booklets.
2. This is an open book exam. You are allowed to use your course text (Smith et al. any edition) and your course notes including any data sheets, math tables or equation pages.
3. Calculators are permitted (red sticker). (Notebook computers are NOT allowed.)
4. Be sure to include a clear statement of any assumptions made if doubt exists as to the interpretation of any question that requires a written answer.
5. There are **eight (8)** questions on this exam (**double-sided pages**). Answer all the questions. The value of each question is provided.

Have a good summer!

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Question 1 (5 marks)

For each of the following conditions determine whether the stream is: compressed sub-cooled water, superheated steam, wet steam, saturated liquid, saturated vapour. (Give your answer in the exam booklet)

a)	Pressure:	10 MPa	Volume:	0.003 m^3/kg
b)	Temperature:	200ºC	Volume:	0.1 m^3/kg
c)	Pressure:	2200 kPa	Enthalpy:	3134 kJ/kg
d)	Temperature:	300ºC	Pressure:	10 MPa
e)	Temperature:	5ºC	Volume:	147.2 m^3/kg

Question 2 (25 Marks)

In a modern Rankine Cycle power plant the boiler supplies steam to a turbine at **2900 kPa** and **500ºC** The exhaust from the turbine is at **125 kPa**. The exhaust steam is then condensed at constant pressure and fed to a pump to begin the cycle again. Given that the turbine and pump have efficiencies of $\eta_t = \eta_p = 0.85$ and assuming that the stream **leaving the condenser is saturated liquid at 125 kPa**. Calculate and report the turbine work, the pump work and boiler heat. What is the overall efficiency of the plant? Show your calculations.

Question 3 (20 marks)

A modern jet aircraft such as the Boeing 777 can carry 440 passengers and has a range of **14,260 km** at a maximum cruising speed of **900 km per hour**. The plane is powered by two **Brayton-cycle** gas turbines each of which can develop 90,000 pounds of thrust. The overall **pressure ratio (P_B/P_A)** of these engines is **34.4**. The inlet temperature **(T_A)** at an altitude of 10,500 metres (35000 ft) is **-54ºC** and the combustion zone temperature **(T_C)** is **1700ºC**. The high efficiency axial **compressor** section of the standard General Electric GE90 aircraft engine has an efficiency of **90%** and the **turbine** section has an efficiency of **85%**. The airliner can carry **171,000 L of fuel** and the energy content (enthalpy of combustion) of the fuel is **34.8 MJ/L.** Assume the working fluid is air with $\gamma = 1.4$.

(i) What is the total energy content of the fuel in megajoules (MJ)?

(ii) What is the efficiency of Brayton cycle gas turbine engines at an altitude of 10500 metres for the given conditions and the given compressor and turbine efficiencies?

(iii) Given the length of time the aircraft can stay in the air based on the range and maximum cruising speed what is the estimated power output of each engine? Give your answer in megawatts.

Question 4 (10 Marks)

A 40 L tank contains hydrogen at **5000 psia** and **25ºC.** (1 bar = 14.5038 psia)
Data:
Molar mass of H_2 = 2.016 g/mol
Critical Pressure, P_C = 13.13 bar
Critical Temperature, T_C = 33.19 K
Acentric factor, ω = -0.216

a) Using the appropriate generalized equation of state determine how many kilograms of hydrogen are stored in the tank.
b) According to the ideal gas law how many kilograms would be stored under these conditions?

Question 5 (15 marks)

Tests on an adiabatic gas compressor yield inlet conditions 300 K, 1.1 bar and outlet conditions 480 K and 8 bar. Assume ideal gas behaviour and constant heat capacities. $C_p = (11/2)R$

a) Determine what the final temperature would be for a reversible adiabatic compression.
b) Determine the actual work done by the compressor per mole of gas compressed using the measured temperature.
c) Using the result from part (a) to find the isentropic work, and the result from part (b) determine the compressor efficiency.

Question 6 (5 marks)

A pressure cooker has an operating gauge pressure of **110.2 kPa** (about 15 psi) greater than the ambient barometric pressure. At this increased pressure water boils at a higher temperature. The higher temperature causes food to cook faster; cooking times can typically be reduced by about 70 percent. For example, shredded cabbage is cooked in one minute, fresh green beans in three minutes, small to medium-sized potatoes cook in about eight minutes, and a whole chicken takes only twenty minutes. Brown rice and lentils and beans can be cooked in ten minutes instead of 45.

(a) On a given day when the barometric pressure is exactly **1 atm**, what is the **absolute** operating pressure in the pressure cooker in kilopascals (kPa)?
(b) On that same day what is the operating temperature in the pressure cooker (assuming the liquid contents behave as pure water)?
(c) If the pressure is released so that the water is boiling at barometric pressure what would the temperature in the cooker be?

Question 7 (10 marks)

For pure superheated steam at **11,400 kPa** and **650°C** find the residual volume (V^R). Report your answer in L/kg.

Question 8 (10 marks)

A mass of liquid water **m** at temperature $\mathbf{T_1}$ is mixed **adiabatically** and **isobarically** with an equal mass of liquid water at temperature $\mathbf{T_2}$. Assuming constant $\mathbf{C_P}$ show that:

$$\Delta S^t = \Delta S_{total} = mC_P \ln\left(\frac{\left[\frac{T_1 + T_2}{2}\right]^2}{(T_1 T_2)} \right)$$