注意：考試開始鈴響前，不得翻閱試題，

並不得書寫、畫記、作答。

國立清華大學 109 學年度碩士班考試入學試題

系所班組別：工程與系統科學系

乙組

科目代碼：3102

考試科目：熱力學

一作答注意事項一

1. 請核對答案卷（卡）上之准考證號、科目名稱是否正確。
2. 作答中如有發現試題印刷不清，得舉手請監試人員處理，但不得要求解釋題意。
3. 考生限在答案卷上標記「由此開始作答」區內作答，且不可書寫姓名、准考證號或與作答無關之其他文字或符號。
4. 答案卷用盡不得要求加頁。
5. 答案卷可用任何書寫工具作答，惟為方便閱卷辨識，請儘量使用藍色或黑色書寫；答案卡限用 2B 鉛筆畫記；如畫記不清（含未依範例畫記）致光學閱讀機無法辨識答案者，其後果一律由考生自行負責。
6. 其他應考規則、違規處理及扣分方式，請自行詳閱准考證明上「**國立清華大學試場規則及違規處理辦法**」，無法因本試題封面作答注意事項中未列明而稱未知悉。

1. Complete the questions below **(20%; 5 pts each)**:

   Q1-1. Sketch the temperature vs. specific volume diagram for the heating process of water at a constant pressure of 1 atm from 25 °C to 300 °C. Indicate the areas of the saturated mixture, superheated vapor and compressed liquid.

   Q1-2. Compared with saturated vapor, superheated vapor is generally characterized by

   - Lower or higher pressures at a given temperature?
   - Lower or higher temperatures at a given pressure?
   - Lower or higher specific volumes at a given temperature/pressure?
   - Lower or higher internal energies at a given temperature/pressure?
   - Lower or higher enthalpies at a given temperature/pressure?

   Q1-3. Compared with saturated vapor, a compressed liquid is generally characterized by

   - Lower or higher pressures at a given temperature?
   - Lower or higher temperatures at a given pressure?
   - Lower or higher specific volumes at a given temperature/pressure?
   - Lower or higher internal energies at a given temperature/pressure?
   - Lower or higher enthalpies at a given temperature/pressure?

   Q1-4. 1-kg water is boiled in a pot. During the heating process, half of the water by mass is evaporated in 10 mins. If the heat loss from the pot is negligible, the power needed in this heating process is

   (a) 3.8 kW, (b) 2.2 kW, (c) 1.9 kW, (d) 1.6 kW, (e) 0.8 kW

   The thermodynamic properties you may need are listed in the table below. You need to show your calculation work.

		Specific volume, m^3/kg		*Internal energy,* kJ/kg			*Enthalpy,* kJ/kg		
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g
101.325	99.97	0.001043	1.6734	418.95	2087.0	2506.0	419.06	2256.5	2675.6

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2. The general energy equation on a rate form is known to be:

$$\frac{dE_{\text{C.V.}}}{dt} = \dot{Q}_{\text{C.V.}} - \dot{W}_{\text{C.V.}} + \dot{m}_i e_i - \dot{m}_e e_e + \dot{W}_{\text{flow in}} - \dot{W}_{\text{flow out}}$$

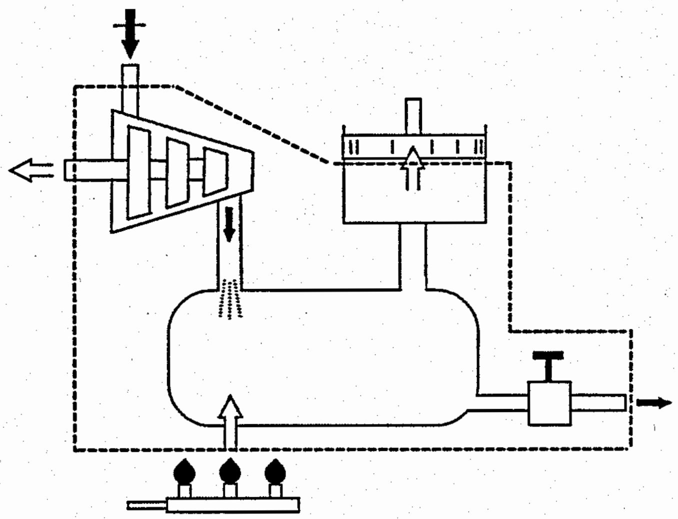
Answer the questions below **(20%; 4 pts each)**:

Q2-1. Explain the meaning of each term in the equation of the 1st law of thermodynamics above.

Q2-2. Explain how the general energy equation on a rate form above is expanded to the following form:

$$\frac{dE_{\text{C.V.}}}{dt} = \dot{Q}_{\text{C.V.}} - \dot{W}_{\text{C.V.}} + \dot{m}_i \left(h_i + \frac{1}{2}\text{V}_i^2 + \text{gZ}_i\right) - \dot{m}_e (h_e + \frac{1}{2}\text{V}_e^2 + \text{gZ}_e)$$

Q2-3. To the best of your knowledge, indicate how EACH term in the equation of the 1st law of thermodynamics in Q2-2 is used to analyze the corresponding components in the image below. You need to briefly reproduce the image in your answer sheets.



Q2-4. The "flow work" is shown in the general energy equation. Graphically indicate where the flow work is generated in the control volume of the image in Q2-3. What is flow work? Give two examples of thermodynamic analyses that need to take into the flow work account.

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Q2-5. The first term on the left-hand side of the 1st law equation in Q2-2 is $\dot{E}_{C.V.}$ When this term is integrated over a period, it is equal to the total energy, $m(e_2 - e_1)$. Expand $m(e_2 - e_1)$ in terms of THREE energy types involved and indicate the meaning of each term denoted by a subscript notation 1 or 2.

3. A rigid tank that has a volume of 750 L is filled with 250 °C water consisting of 50% (in volume) liquid and 50% vapor (in volume). Accidently, the bottom of the tank breaks and liquid is flowing out. For a safety issue, a heating source mounted on the tank wall is initiated to avoid the drop of the working fluid temperature. Answer the questions below to determine the total heat transfer energy needed to deal with the situation after half of the initial water mass is lost. The thermodynamic properties at this fluid condition are: v_f = 0.001252 m³/kg, v_g = 0.050085 m³/kg, u_f = 1080.7 kJ/kg, u_{fg} = 1521.1 kJ/kg, u_g = 2601.8 kJ/kg, h_f = 1085.7 kJ/kg, h_{fg} = 1715.3 kJ/kg, h_g = 2801.0 kJ/kg. **(20%; 4 pts each)**

Q3-1. Sketch the problem and graphically indicate the control volume to be analyzed.

Q3-2. Develop the mass balance using the full form of the continuity equation:

$$m_2 - m_1 = \sum m_i - \sum m_e$$

Q3-3. Customize the 1st law of thermodynamics equation to determine the total heat transfer energy.

Q3-4. Are the thermodynamic properties of the working fluid looked up from the table of compressed liquid water, superheated or saturated water?

Q3-5. In order to calculate the heat transfer of the initiated heating source in the equation of Q3-3, what are the unknown properties that need to be obtained? Estimate these properties and then calculate the total heat transfer in terms of kJ.

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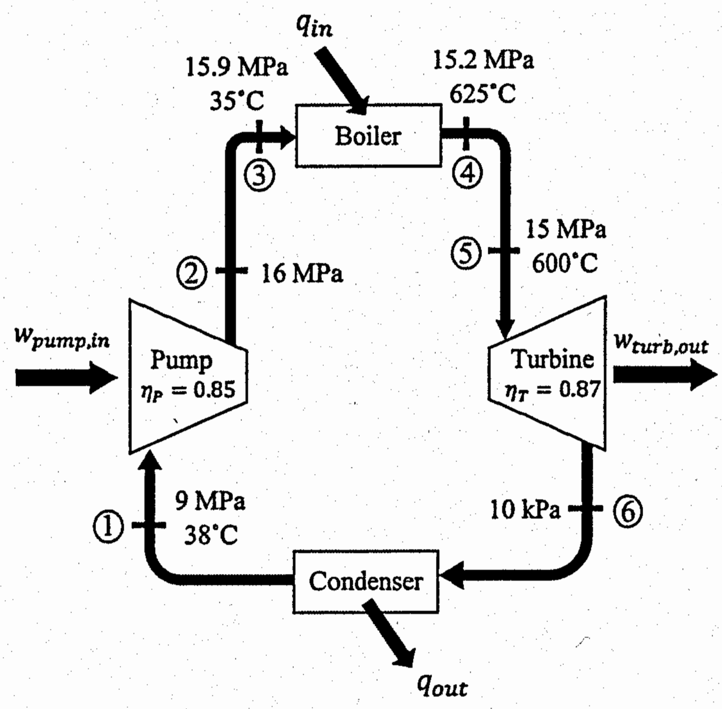
4. The working fluid (steam) circulating in an actual steam power plant has been monitored with pressure gauges and thermometers. **(20%; 5 pts each)**



Q4-1. Sketch an ideal temperature-entropy diagram, where a loop of the working fluid circulates through the four components. Indicate the constant-pressure processes and three zones: compressed liquid, liquid-vapor mixture and superheated vapor.

Q4-2. Based on your *T*-s diagram in Q4-1 and the *T* and *P* values given in the picture above, you are asked to sketch a *T*-*s* loop of the working fluid that circulates through the four components with the actual conditions. Clearly show the data points that deviate from each constant-pressure phase change process. Indicate the corresponding locations of each component. Hint: You need to clearly show the non-isentropic processes involved.

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Q4-3. The thermal efficiency of the power plant is known to be $\eta_{th} = w_{net}/q_{in}$. Mathematically show:

- the equation that calculates intensive net work w_{net} in terms of actual work produced or consumed by individual components.
- the equations that can calculate actual work produced or consumed by individual components in terms of the given isentropic efficiency, fluid properties (P, T) and unknown thermodynamic properties (v, h, u, or s). Explain step by step how you can obtain the values of these unknown thermodynamic properties based on the given T, P values in the picture.
- the equation that calculates intensive heat input q_{in} in terms of the unknown thermodynamic properties (v, h, u, or s). Explain step by step how you can obtain the values of these unknown thermodynamic properties based on the given T, P values in the picture.
- Explain mathematically how you can calculate the intensive heat output q_{out} in terms of the information that you have collected so far.

Q4-4. The general form of a rate equation for entropy is expressed as:

$$\dot{S}_{c.m.} = \sum \frac{\dot{Q}_{c.m.}}{T} + \dot{S}_{gen}$$

Revise the general form above and write the equation ($\dot{S}_{gen} = \cdots$) to calculate the total entropy generation for the entire power plant operated at a steady-state condition with a known mass flow rate. You need to expand the summation of heat transfer terms in the general form. Explain why a heat transfer term is positive or negative on the right-hand side of the $\dot{S}_{gen}$ equation.

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5. In a chemically reacting steady-flow system, the 1st law of thermodynamics is expressed as:

$$\underbrace{Q_{in} + W_{in} + \sum N_r(\bar{h}_f^\circ + \bar{h} - \bar{h}^\circ)_r}_{\substack{Energy\ transfer\ in\ per\ mole\ of\ fuel \\ by\ heat,\ work,\ and\ mass}} = \underbrace{Q_{out} + W_{out} + \sum N_p(\bar{h}_f^\circ + \bar{h} - \bar{h}^\circ)_p}_{\substack{Energy\ transfer\ out\ per\ mole\ of\ fuel \\ by\ heat,\ work,\ and\ mass}}$$

where N_r and N_p represent the number of moles of the reactant r and the product p, respectively, per mole of fuel. Answer the following questions **(20%; 4 pts each)**:

Q5-1. $\bar{h}_f^\circ$ is known to be enthalpy of formation. What is enthalpy of formation? Explain why the substances listed in the table below have zero, positive, and negative enthalpies of formation, respectively?

Substance	Formula	$\bar{h}_f^\circ$ kJ/kmol
Carbon	$C(s)$	0
Hydrogen	$H_2(g)$	0
Nitrogen	$N_2(g)$	0
Oxygen	$O_2(g)$	0
Carbon monoxide	$CO(g)$	-110,530
Carbon dioxide	$CO_2(g)$	-393,520
Water vapor	$H_2O(g)$	-241,820
Water	$H_2O(l)$	-285,830
Hydrogen peroxide	$H_2O_2(g)$	-136,310
Ammonia	$NH_3(g)$	-46,190
Methane	$CH_4(g)$	-74,850
Acetylene	$C_2H_2(g)$	+226,730
Ethylene	$C_2H_4(g)$	+52,280

Q5-2. What is this term $\bar{h} - \bar{h}^\circ$ called? Explain its physical meaning.

Q5-3. Describe in detail (using an example) how you can use the 1st law of thermodynamics to calculate a higher or lower heating value of methane. What gas temperatures (room or combustion) are to be achieved in order to obtain the thermodynamic property values for reactants and products? How do you obtain the mole numbers?

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Q5-4. Describe in detail (using an example) how you can use the 1st law of thermodynamics to calculate the adiabatic flame of methanol in a steady-flow combustion process. What gas temperatures (room or combustion) are to be achieved in order to obtain the thermodynamic property values for reactants and products? How do you obtain the mole numbers?

Q5-5. Rewrite the 1st law of thermodynamics for a reacting steady-flow system, which calculates the heat of combustion produced during a very short period of ignition in a combustion chamber of a gasoline engine, where a piston is fixed at the top dead center. The enthalpies are to be derived at the temperatures of the compressed gas and ignited gas, respectively. How can these temperature values be calculated?