**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 108 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**

考試科目(代碼)：**熱力學(3102)**

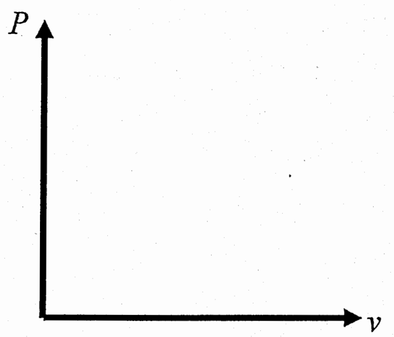
## —作答注意事項—

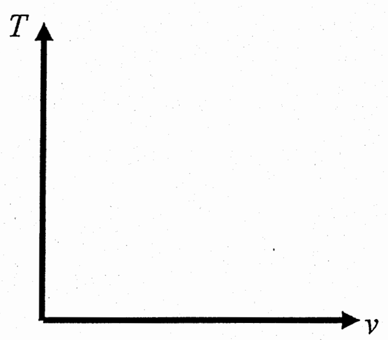
1. 請核對答案卷（卡）上之准考證號、科目名稱是否正確。
2. 作答中如有發現試題印刷不清，得舉手請監試人員處理，但不得要求解釋題意。
3. 考生限在答案卷上標記「由此開始作答」區內作答，且不可書寫姓名、准考證號或與作答無關之其他文字或符號。
4. 答案卷用盡不得要求加頁。
5. 答案卷可用任何書寫工具作答，惟為方便閱卷辨識，請儘量使用藍色或黑色書寫；答案卡限用 2B 鉛筆畫記；如畫記不清（含未依範例畫記）致光學閱讀機無法辨識答案者，其後果一律由考生自行負責。
6. 其他應考規則、違規處理及扣分方式，請自行詳閱准考證明上「**國立清華大學試場規則及違規處理辦法**」，無法因本試題封面作答注意事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

1. Four conditions of water and their states are listed in the table below. Follow the steps below to identify their locations in the *P*-*v* and *T*-*v* diagrams. (20%)

| Point | Temperature, pressure and specific volume | State |
|---|---|---|
| 1 | 20 °C, 500 kPa, 0.001002 $m^3$/kg | Compressed liquid |
| 2 | 152 °C, 500 kPa, 0.2 $m^3$/kg | Mixture of liquid & vapor; quality of 0.53 |
| 3 | 200 °C, 1400 kPa, 0.14302 $m^3$/kg | Superheated vapor |
| 4 | 300 °C, 8581 kPa, 0.01762 $m^3$/kg | Mixture of liquid & vapor; quality of 0.8 |

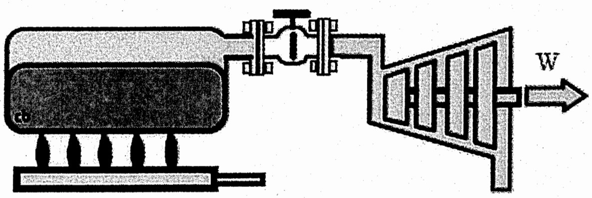
- Step 1: Sketch the saturated liquid line, saturated vapor line and critical point in a pressure-specific volume (*P*-*v*) diagram and a temperature-specific volume (*T*-*v*) diagram. (6 pts)
- Step 2: Sketch the constant-temperature phase change process at 20, 152, 200 and 300 °C in the *P*-*v* diagram. (4 pts)
- Step 3: Sketch the constant-pressure phase change process at 500, 1400 and 8518 kPa in the *T*-*v* diagram. (3 pts)
- Step 4: Locate the four points in the *P*-*v* and *T*-*v* diagrams. (7 pts)




2. A steam engine is driven by saturated vapor at high pressure ($P_h$) and discharges saturated vapor to surrounding. The saturated vapor comes from a boiler tank with a volume of $V$. If the boiler initially stores atmospheric liquid water with a specific volume of $v_{liquid}$ and then heated up with a closed pressure regulator until the tank pressure reaches $P_h$. At the vapor pressure of $P_h$, the pressure regulator opens. Eventually, the boiler tank has only vapor left over with a specific volume of $v_{vapor}$ at $P_h$. The time taken for the boiler to evaporate all the liquid is $\Delta t$. There is no

significant heat loss observed from the turbine housing and boiler tank. Answer the following questions to analyze the thermodynamic process in the steam engine. (20%)




Q2-1. Simplifying the mass flow rate balance equation $(\dot{m}_{in} - \dot{m}_{out}) = \Delta m_{\text{system}}/dt$ for the discharging process in the boiler tank. (4 pts)

Q2-2. Following Q2-1, derive the equation that estimates the mass of vapor leaving the boiler tank in the discharging process in terms of the specific volumes of the working fluid and volume of the boiler tank. (4 pts)

Q2-3. Now, let us take the control volume of the tank boiler and apply the first law of thermodynamics for transient processes listed below:

$${}_1\dot{Q}_2 - {}_1\dot{W}_2 + \sum \dot{m}_{\text{in}} h_{\text{in}} - \sum \dot{m}_{\text{out}} h_{\text{out}} = \dot{m}_2(u_2 + \tfrac{1}{2}V_2^2 + gZ_2) - \dot{m}_1(u_1 + \tfrac{1}{2}V_1^2 + gZ_1)$$

Subscripts 1 and 2 are states; subscripts in and out are inlet and outlet, respectively. **Show how you simplify the first law above and derive an equation** to estimate the total heat transfer rate needed for the boiling process. (4 pts)

Q2-4. In your simplified equation in Q2-3, what are the unknown thermodynamic properties that need to be looked up in thermodynamic tables? (4 pts)

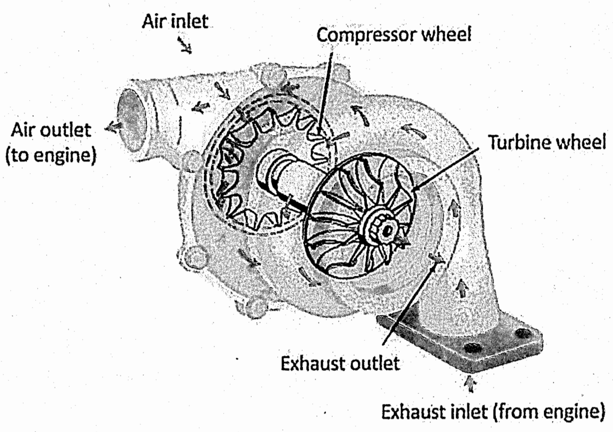
Q2-5. Now, you take a control volume of the turbine under the steady-flow condition and apply the 1st law of thermodynamics for steady-state processes listed below:

$$\dot{Q} - \dot{W} = \Sigma_{\text{out}} \dot{m}\left(h + \tfrac{1}{2}V^2 + gZ\right) - \Sigma_{\text{in}} \dot{m}\left(h + \tfrac{1}{2}V^2 + gZ\right)$$

How do you simplify the equation above to estimate the power produced from the turbine? In your simplified equation, what is/are the unknown thermodynamic property(ies) that has or have not yet shown in the previous questions and need to be looked up in thermodynamic tables? (4 pts)

3. A small air compressor driven by a turbine in a turbocharger is used for car engines (shown below). This compressor takes in air at 20 °C with a mass flow

rate of 0.1 kg/s and compresses air to 200 °C. The heat loss from the air compressor is negligible. Following the questions below, you are now asked to analyze the compressor using the 2nd law of thermodynamics. (30%)

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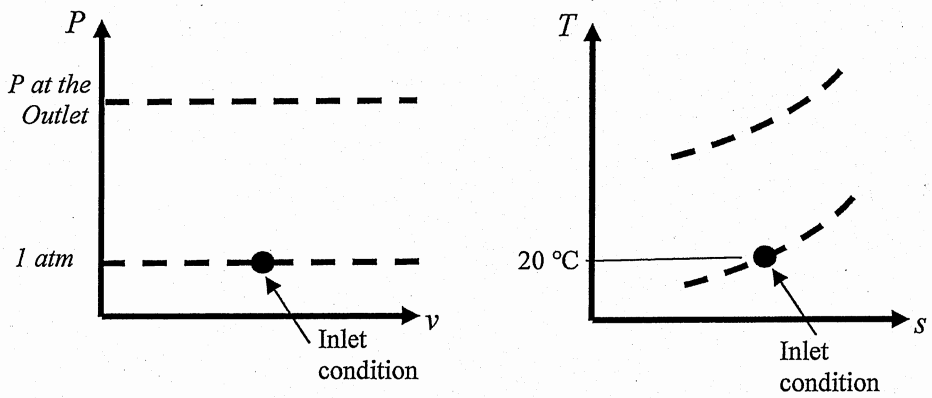



Q3-1. Draw the ideal (reversible & adiabatic) flow process in the pressure-specific volume (*P*-*v*) diagram and temperature-entropy (*T*-*s*) diagram above. (5 pts)

Q3-2. Draw the actual flow process in the *P*-*v* diagram and *T*-s diagram above. (5 pts)

Q3-3. The first law of thermodynamics for transient processes is listed below:

$$\dot{Q}_{\text{net,in}} - \dot{W}_{\text{net,out}} + \sum \dot{m}_i h_{tot\ i} - \sum \dot{m}_o h_{tot\ o} = \dot{m}_2(u_2 + \tfrac{1}{2}V_2^2 + gZ_2) - \dot{m}_1(u_1 + \tfrac{1}{2}V_1^2 + gZ_1)$$

Subscripts 1 and 2 are states; subscripts *i* and *o* are inlet and outlet, respectively. Please make the assumptions to simplify the equation that can calculate power needed to drive the compressor, where the air flow is steady-state. Hint: $dh = c_p dT$; For simplicity, take $c_p$ = 1.00 kJ/kg-K, $c_v$ = 0.718 kJ/kg-K for air at 300 K. (5 pts)

Q3-4. The rate of entropy change within the control volume during a process is equal to the sum of the rate of entropy transfer through the control volume boundary by heat transfer ($\sum \dot{Q}_k/T_k$), the net rate of entropy transfer into the control volume by mass flow ($\sum \dot{m}_i s_i - \sum \dot{m}_e s_e$), and the rate of entropy generation ($\dot{S}_{\text{gen}}$) within the boundaries of the control volume as a result of irreversibilities. The entropy balance relation can be written as:

$$\sum \frac{\dot{Q}_k}{T_k} + \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \dot{S}_{\text{gen}} = (S_2 - S_1)_{\text{cv}}/dt,$$

where any process (A to B) of the entropy change of ideal gases can be approximated with constant specific heats: $ds = c_{\text{v,avg}} \ln(T_B/T_A) + R\ln(v_B/v_A)$. **Write down the assumptions to simplify the equation above and derive the isentropic equation** that allows you to analyze the relationship between the temperature and pressure of the compressed air (5 pts):

$$P_e = P_i(\frac{T_{es}}{T_i})^{\frac{k}{k-1}}$$

Q3-5. The polytropic equation listed in Q3-4 allows you to determine the real pressure of the compressed air ($P_e$). However, $T_{es}$, the ideal temperature of the compressed air, is unknown. Note that $T_{es}$ can be determined by the ideal power driving the compressor. Now, you are told that the isentropic (polytropic) efficiency of the compressor is 70%. Accordingly, show your procedure to calculate $T_{es}$ and the $P_e$. (5pts)

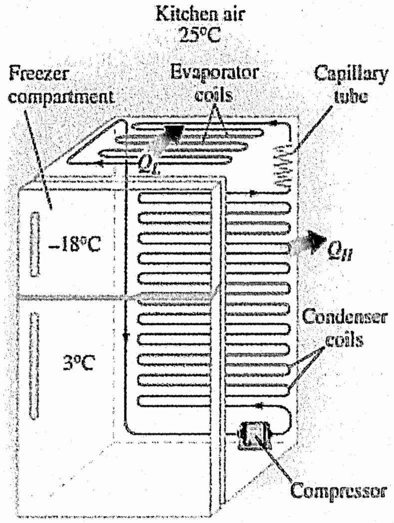
Q3-6. Explain why the isentropic (polytropic) efficiency of the compressor is not 100%. (5 pts)

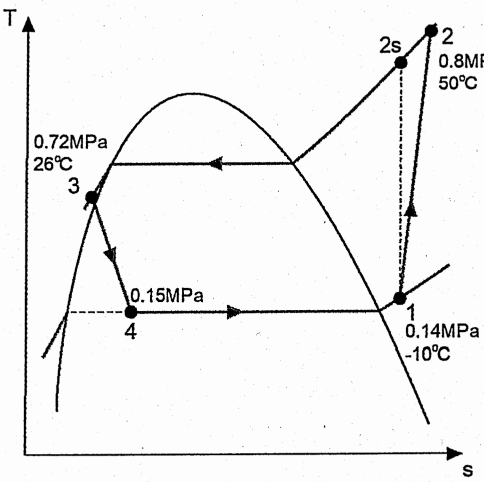
4. Refrigerators that produce refrigeration are used in our daily life. A household refrigerator and its components are shown in the image below (left). Answer the questions below. (15%)

Q4-1. Please indicate the components for their corresponding processes, 1 → 2, 2 → 3, 3 → 4 and 4 → 1, in the actual cycle of refrigeration in the *T-s* diagram below (right). (5 pts)

Q4-2. Write down the equation to calculate the coefficient of performance (COP). (5pts)

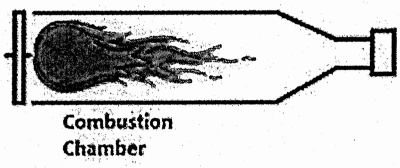
Q4-3. What thermodynamic properties do you need to determine for the equation of COP? (5pts)




Source: Thermodynamics-An Engineering Approach by Cengel & Boles

5. A combustion chamber consumes ethanol ($C_2H_5OH$) with air in a steady-flow process. Answer the questions below: (15%)

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Q5-1. Balance mole coefficients in the global reaction for 1 kmol of fuel with air at a stoichiometric condition where products yields include carbon dioxide, water, nitrogen. (4 pts)

Q5-2. Considering 120% theoretical air in the reaction, redo the balance for the mole coefficients. Hint: the products terms need to be revised for the lean-burn combustion. (4 pts)

Q5-3. Calculate the air-fuel ratios in terms of mass for the conditions in Q5-2. Hint: mole times molecular weight is mass. (4 pts)

Q5-4. The reactants enter the combustion chamber at the low temperature $T_L$, and products exist at high temperature $T_h$. The equation for heat of combustion is calculated by $Q_{cv} = (H_p^0 + \Delta H_p) - (H_R^0 + \Delta H_R)$. Explain the difference between two enthalpy terms in one of the two parentheses on the right-hand side of the equation. (3 pts)