2020 ENTRANCE EXAMINATION FOR INTERNATIONAL MASTER'S PROGRAM
Departments of Mechanical Engineering and Hydrogen Energy Systems

Thermal Engineering (Group A) [10:45~12:15]

Examinee's number ______________________________ Score ________

I An ideal gas undergoes the following refrigeration cycle.

(A) State 1 → 2: The gas at a temperature of T_1 is isentropically compressed up to a pressure of p_2 by a compressor.

(B) State 2 → 3: The gas is cooled at a constant pressure of p_2 to a temperature of T_3.

(C) State 3 → 4: The gas is isentropically expanded from a pressure of p_3 to p_4 by a turbine.

(D) State 4 → 1: The gas is heated at a constant pressure of p_4 from a temperature of T_4 to T_1.

The subscripts 1-4 denote each state. The gas constant and the specific-heat ratio of the ideal gas are given by R and κ, respectively. The ideal-gas specific heat is constant and independent of temperature. Answer the following questions. (25 points)

(1) Draw the process of this cycle with the numbers of State 1, 2, 3 and 4 on the p-v (pressure-specific volume) diagram below.

(2) Determine the temperature T_2 with T_1, p_2, p_4 and κ. In addition, determine the temperature T_4 with T_3, p_2, p_4 and κ.

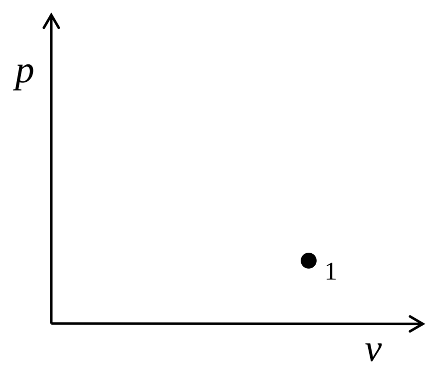
(3) Obtain the heat per unit mass q_{41} absorbed from the surrounding of the system ($q_{41} > 0$) during the process D with T_1, T_4, R and κ.

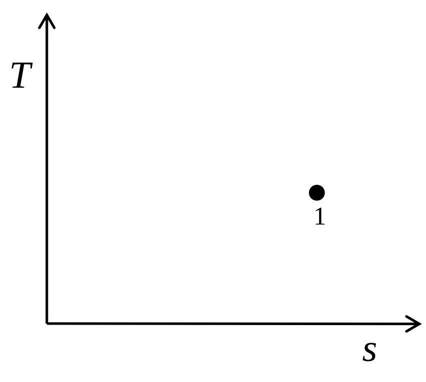
(4) Draw the process of this cycle with the numbers of State 1, 2, 3 and 4 on the T-s (temperature-specific entropy) diagram below, and determine the entropy change per unit mass $s_3 – s_2$ during the process B with T_2, T_3, R and κ.

(5) Obtain the coefficient of performance (COP) ε_R for the refrigeration with p_1, p_2 and κ.

(6) In actual cycle, the adiabatic efficiencies of the compressor and the turbine are given as η_c and η_t, respectively. Obtain the net-work input to the cycle per unit mass w' with T_1, T_2, T_3 T_4, R, κ, η_c and η_t.

(7) In practical refrigeration cycles, a throttling process is used instead of the mechanical expansion. The value of the Joule-Thomson coefficient μ is important for considering the replacement. Joule-Thomson coefficient is given by $\mu \equiv \left(\frac{\partial T}{\partial p}\right)_h = \left\{T\left(\frac{\partial v}{\partial T}\right)_p - v\right\} \Big/ c_p$, here v is the specific volume, h is the enthalpy, and c_p is the isobaric specific heat. Calculate the Joule-Thomson coefficient of the ideal gas, and answer whether the throttling process can be used instead of the mechanical expansion in the ideal gas cycle with reasons from the point of view of the Joule-Thomson coefficient.





(Use the second sheet if necessary.)

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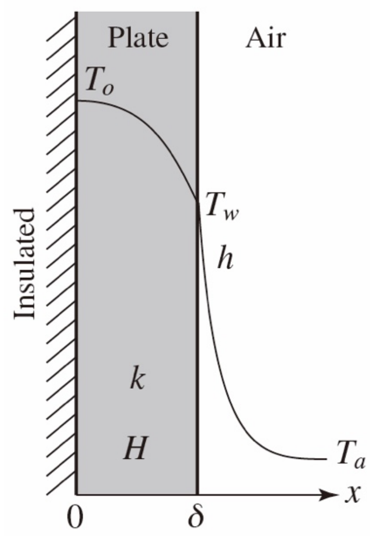

II A flat plate with a thickness of δ [m] and the constant thermal conductivity of k [W/(m·K)] is heated with uniform heat generation of H [W/m^3]. One side of the plate is insulated and the other side is exposed to the ambient air at temperature T_a [K]. The heat transfer coefficient between the plate and the air is h [W/(m^2·K)]. Heat conduction equation is given by $\frac{d}{dx}\left(k\frac{dT}{dx}\right)+H=0$. Answer the following questions. (25 Points)

(1) Obtain the heat flux q [W/m^2] from the plate surface to the air.

(2) Obtain the temperature difference between the two sides of the plate, $T_o - T_w$ [K].

(3) Obtain the temperature difference between the plate surface and the air, $T_w - T_a$ [K].

(4) Obtain the temperature difference between the insulated surface of the plate and the air, $T_o - T_a$ [K].

(5) The temperature at the insulated surface of the plate increases to $T_o{}'$ [K] when the plate surface at $x=\delta$ is covered with an insulation material. Its thickness and the thermal conductivity are δ_i [m] and k_i [W/(m·K)], respectively. Obtain the temperature difference between the insulated surface of the plate and the air, $T_o{}' - T_a$ [K].

(6) After the temperature of the insulated surface of the plate reached $T_o{}'$ [K], the heat generation rate was decreased to H' [W/m^3] and then $T_o{}'$ [K] returned to original temperature T_o [K]. Determine the value of H' when $\delta_i=\delta,\ k_i=\frac{2}{5}k,\ h=\frac{2k}{5\delta}$.