2022 ENTRANCE EXAMINATION FOR INTERNATIONAL MASTER'S PROGRAM
Departments of Mechanical Engineering and Hydrogen Energy Systems

Thermal Engineering (Group A) [11:10~12:40]

(I) Consider a reversible cycle that consists of four processes between a heat source at a temperature of T_H and a heat sink at a temperature of T_L using a mass of m of an ideal gas as a working fluid.
Initially (State 1) the temperature and pressure of the gas are T_H and p_1, respectively.
State 1→2 : The gas at State 1 is isothermally expanded to State 2 (pressure p_2).
State 2→3 : The gas at State 2 is adiabatically expanded to State 3 (temperature T_L, pressure p_3).
State 3→4 : The gas at State 3 is isothermally compressed to State 4 (pressure p_4) until the pressure of p_4 is equal to p_2.
State 4→1 : The gas at State 4 is adiabatically compressed to State 1.
The gas constant and the specific-heat ratio of the gas are given by R and κ, respectively. The specific heat is constant and independent of temperature. Noting that the subscripts 1-4 denote each state, answer the following questions using the given physical quantities: m, R, T_H, T_L, p_2 and κ. (25 points)

(1) Illustrate the $p-V$ (pressure-volume) diagram of this cycle indicating States 1, 2, 3 and 4.
(2) Determine the pressure p_3 at State 3 and the pressure p_1 at State 1.
(3) Determine the work L_{12} done by the gas and the entropy change $S_2 - S_1$ during the process of State 1→2.
(4) Determine the internal energy change $U_3 - U_2$ during the process of State 2→3.
(5) Determine the net work L_{net} done by the gas during one cycle.
(6) In this cycle, consider new conditions (States $1'$, 2, $3'$ and $4'$) that m, R, κ, T_H, p_2 and p_4 remain the same, but the heat-sink temperature is changed to T_L'. The heat Q_{12}' absorbed from the heat source during the process of State $1'$→2 is twice as much as the heat Q_{12} absorbed from the heat source during the process of State 1→2 in the original cycle. Determine the heat-sink temperature T_L', the thermal efficiency η_{th}', and the net work L_{net}' done by the gas during one cycle in the new conditions.

(II) A flat plate of thickness L and thermal conductivity k is initially at a uniform temperature T_0. The x-axis is set in the thickness direction of the plate. The left side of the plate ($x = 0$) is insulated, and the other side ($x = L$) is in contact with the fluid flowing along the plate as shown in Fig. 2-

1. At the time of $t = 0$, the plate starts to experience uniform volumetric heating at a rate $\dot{q_v}$ per unit volume and time, and heat is transferred to the fluid at temperature of T_0 by convection having heat transfer coefficient h. Assume one-dimensional heat conduction in the x direction across the plate. The heat conduction equation at steady-state condition is given by $k\frac{\mathrm{d}^2T}{\mathrm{d}x^2}+\dot{q_v}=0$. Answer the following questions. (25 points).

(1) Assuming the maximum temperature T_{max} in the plate and the temperature T_{w} at $x=L$ in the steady state ($t\rightarrow\infty$), sketch the temperature distribution at steady-state condition in Fig. 2-2.

(2) Express the heat flux q at $x=L$ in the steady state using L and $\dot{q_v}$.

(3) Determine the temperature distribution $T(x)$ in the plate as a function of x in the steady state using h, k, L, $\dot{q_v}$ and T_0.

(4) Answer whether the wall temperature $T(x=L)$ in the transient state is higher or lower than the wall temperature T_{w} at the steady state. Also, answer the reason.

(5) If the heat transfer coefficient h increases due to an increase in the flow rate, the steady-state temperature difference T_{w}-T_0 decreases. Does this make the temperature difference T_{max}-T_{w} in the plate change? Answer with the reason.

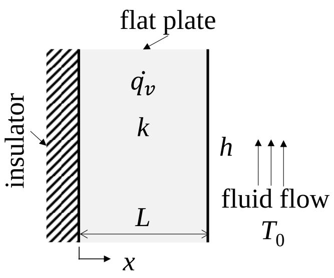

Fig. 2-1

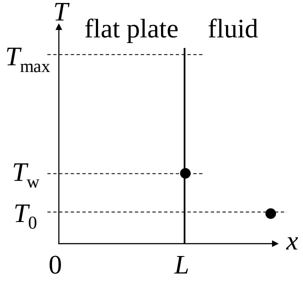

Fig. 2-2