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NUMERICAL STUDY ON THE THERMAL MANAGEMENT OF MOBILE PERSONAL COMPUTER WITH HEAT SPREADER

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ABSTRACT Parametric study for the cooling characteristic investigation of a mobile PC mounted with heat spreader has been numerically performed. Two cases of air-blowing and air-exhaust at vent were tested. The cooling effects of parameters such as, velocities of air-blowing and air-exhaust, materials of heat spreader, and CPU powers were simulated for two cases. Cooling performance in the case of air-blowing was better than the case of air-exhaust.

Keywords: Mobile Personal Computer, Heat Spreader, Thermal Management

1. INTRODUCTION

While the usage of mobile PC(Personal Computer) has been gradually increased for several years, performance of the mobile PC has rapidly upgraded. Therefore, the power of CPU(Central Processing Unit) has been gradually increased with increasing of performance of the mobile PC. CPU power was about 4 W in 66 MHz 486-mobile PC of the past, is about 13~15 W in 300~330 MHz Pentium of the current, and is estimated about 16~28 W in 400~600 MHz within a few years.[1] Because of smaller and smaller volume of mobile PC, CPU becomes very hot, namely 'hot-spot'. The CPU limit case temperature($T_{CPU,\ limit}$) is about 85°C in mobile PC.[2] Therefore, CPU power should be dissipated below the CPU limit case temperature.

Since heat spreader is effective heat dissipation module for small volume such as mobile PC, heat spreader has mounted in mobile PC. From references on cooling of mobile PC, it is found that there has been few study on cooling of mobile PC mounted with heat spreader. [2-6] Therefore, the purpose of present study is to enhance the cooling performance of mobile PC mounted with heat spreader, using numerical parameters such as, velocities of air-blowing and air-exhaust, materials of heat spreader, and CPU powers.

2. NUMERICAL MOBILE PC MODEL

As shown in Fig. 1, numerical mobile PC of the present study was modeled from commercial mobile PC except liquid crystal display. Whole dimension of mobile PC is 310 mm × 255 mm × 22 mm, according as the

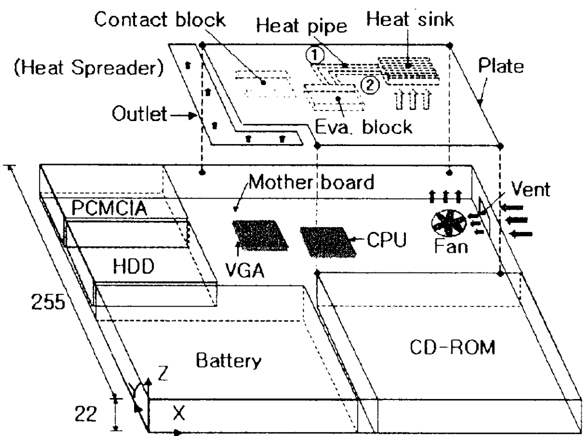

Fig. 1 Numerical model of mobile PC(unit: mm).

coordinates in Fig. 1. Mobile PC consists of Battery, CD-ROM, HDD, PCMCIA, Mother board, VGA chip, CPU, and fan. Detail dimensions of the components in mobile PC are shown in Table 1. [5] Heat spreader on VGA chip and CPU was used to cool VGA chip and CPU which have the high heat density and the possibility of hot spot. Heat spreader consists of Al plate, contact block, evaporator block, two heat pipe, and heat sink as shown in Fig. 1. Thermal properties of components in heat spreader are summarized in Table 2. VGA chip is contacted to the plate through contact block and it has a role in transferring the heat of VGA chip to the plate. Evaporator block is contacted to the plate through contact block and it has a role

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Table 1 Summary of the data for the components.

Component	Dimension (mm×mm×mm)	Thermal Conductivity (W/m-K)	Power (W)
Battery	158×95×22	90	5
CD-ROM	145×115×22	204	5
HDD	105×70×20	204	5
PCMCIA	105×80×20	204	5
Mother	250×135×2	25	5
VGA	33×33×10	18	4
CPU	33×33×10	18	13
Fan	30×30×6	-	-

Table 2 Summary of elements of the heat spreader.

Element	Dimension (mm×mm×mm)	Material	Thermal Conductivity (W/m-K)
Plate	171×66×1+131×49×1	Al	204
Contact block	33×33×9	Al	204
Eva. Block	33×33×9	Al	204
Heat pipes	①: 60×4×2 ②: 50×4×2	Cu	5000*
Heat sink	60×40×9	Al	204

*The value was calculated from experimental data.

in transferring the heat of CPU to heat pipe. Heat pipe was regarded as a solid pipe which use thermal conductivity measured from experimental heat pipe. Heat transferred through heat pipe is spread at heat sink and plate. Heat transferred at heat sink is eliminated by fan which is located below heat sink and exits to the vent, finally. Heat spread at plate is transferred to the ambient air by means of natural convection. Vent means a right side hole of the fan modeled as a box in Fig. 1. Thus, the cooling air from vent flows inside fan. Then, the air is impinged on heat sink and flows inside mobile PC. When the fan is installed inversely, air in mobile PC is exhausted to the ambient air. the former is called the case of air-blowing, and the latter is called the case of air-exhaust.

3. MATHEMATICAL FORMULATION AND NUMERICAL APPROACH

Flow in mobile PC model of the present study was consider as turbulent flow, since Reynolds number at Vent and fan was observed about 3000. Standard k-ε turbulent model was introduced in present study. Governing equations of the present study were modeled with three dimensional, incompressible, steady, and mixed convection heat transfer using Boussinesq approximation for air density, and those equations are as follows :

$$\frac{\partial u}{\partial x_j}(\rho u_j) = 0 \qquad (1)$$

$$\frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left\{(\mu + \mu_t)\frac{\partial u_j}{\partial x_j}\right\} + g_i \beta\rho(T - T_o) \qquad (2)$$

$$\frac{\partial}{\partial x_j}(\rho u_j k) = \frac{\partial}{\partial x_j}\left(\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j} + G - \rho\varepsilon - g_j \beta \frac{\mu_t}{\sigma_T}\frac{\partial T}{\partial x_j}\right) \qquad (3)$$

$$\frac{\partial}{\partial x_j}(\rho u_j \varepsilon) = \frac{\partial}{\partial x_j}\left(\frac{\mu_t}{\sigma_k}\frac{\partial \varepsilon}{\partial x_j}\right) + \left(C_1 G - C_2 \rho\varepsilon - C_3 g_j \beta \frac{\mu_T}{\sigma_T}\frac{\partial T}{\partial x_j}\right)\frac{\varepsilon}{k} \qquad (4)$$

$$\frac{\partial(\rho u_j T)}{\partial x_j} = \frac{\partial}{\partial x_j}\left\{\left(\frac{\mu}{\Pr} + \frac{\mu_t}{\Pr_t}\right)\frac{\partial T}{\partial x_j}\right\} + S \qquad (5)$$

where,

$$\mu_t = C_\mu \frac{\rho k^2}{\varepsilon} \qquad (6)$$

$$G = \mu_t\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\frac{\partial u_i}{\partial x_j} \qquad (7)$$

C_1=1.44, C_2= 1.92, C_3=0.7, C_μ=0.09, σ_k=1.0, σ_T=1.0, and σ_ε= 1.3 were used for turbulent constants. T_o and S in equation (2) and (5) means reference temperature and volumetric heat rate of component, respectively. Velocity and temperature boundary conditions at vent were used with typical data from actual mobile PC : 1.2 m/s and 24°C for case of air-blowing, and 1.2 m/s and 42°C for case of air-exhaust. The turbulent kinetic energy at vent was given to 0.025 u_{vent}^2, where u_{vent} is vent velocity. The turbulent energy dissipation rate at vent was calculated with characteristic length, $\lambda = L_{vent}/2$, where L_{vent} is vent width, 40mm. Pressure based-boundary condition at outlet was given to 0 Pa. Heat transfer between all surfaces of mobile PC and ambient air was dominated by natural convection, using the heat transfer coefficient at all surfaces, h=10 W/m^2-K, and the ambient air temperature, T_a=24°C.[7]

Above governing equations and boundary conditions were solved by using commercial program code, PHOENICS V.3.2. PHOENICS[8] has been developed with the finite volume method for the discretization of Navier-Stokes equation and staggered grid system. Grid number in the present study is 39(x)×34(y)×15(z)=19890. In addition to former grid number, two grid number, i.e., 30×26×10=7800 and 50×45×17=38250 were tested and it was concluded that grid dependence was not found. The

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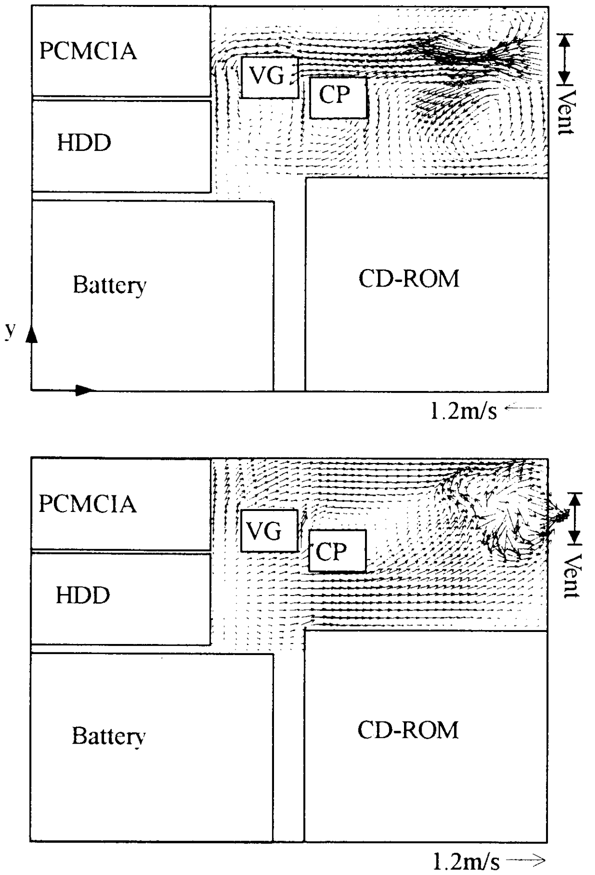

Fig. 2 Air-flows at z=5.5 mm in notebook($|u_{vent}|$=1.2 m/s and Q_{CPU}=13 W).

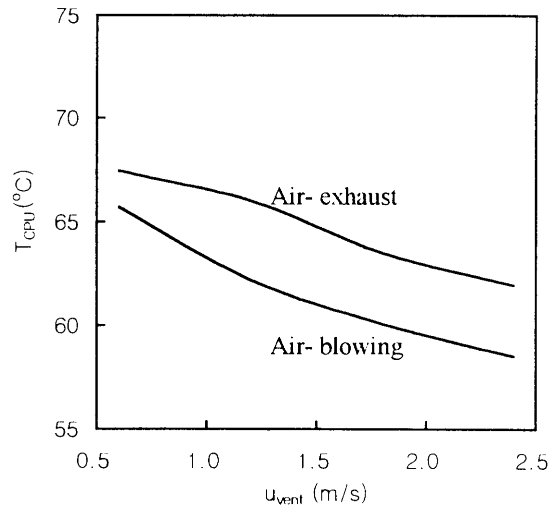

Fig. 3 CPU temperatures for various vent velocity in two cases.

Table 3 Thermal resistances for various vent velocity in two cases.

Case		u_{vent} (m/s)				Average
		0.6	1.2	1.8	2.4	
R_{CPU} (°C/W)	Air-blowing	3.2	2.9	2.8	2.7	2.9
	Air-exhaust	3.3	3.2	3.0	2.9	3.1

relaxation factor values for velocity, pressure, turbulence, and temperature during iteration were 0.1, 0.3, 0.3 and 0.5, respectively.

4. RESULTS AND DISCUSSION

For validation of numerical method in the present study, measurement for temperature with actual mobile PC which was identical to numerical model was performed, previously. Numerical result was in a good agreement within 5% error, as compared with experimental results. The parameters such as vent velocity magnitude, materials of heat spreader, and CPU powers which work on the cooling characteristics of mobile PC were selected as numerical conditions for the two case of air-blowing and air-exhaust. These parameters are available for actual mobile PC. Vent velocity magnitude increased and decreased from 1.2 m/s in the range of 0.6~2.4 m/s. The material of heat spreader has been changed with copper and magnesium from conventional aluminum. However, the material of heat pipe on heat spreader was not changed, because copper heat pipe was very useful for actual mobile PC. CPU power increased from 13 W up to 28 W.

Airflow in mobile PC has an important effect on the cooling characteristic of mobile PC. Therefore, airflows in two cases of the air-blowing and the air-exhaust were compared in Fig. 2. Velocity vector distributions in x-y plane at u_{vent}=1.2 m/s and z=5.5mm were shown in this figure. It can be seen in (a) of this figure that the air entered from vent flows into fan, where speed of airflow is increasing relatively. This airflow impinges on heat sink located above of fan. Hence, heat sink is cooled by the impingement of the airflow. It results in cooling of CPU. While main flow goes to the outlet about normally 0.9 m/s, re-circulation flow is built up around CD-ROM. The cooling of mobile PC is disadvantage due to this re-circulation flow, therefore, this problem can be solved by means of adjusting the proper location of outlet. In (b) of this figure, the flow exhausting from inside mobile PC to the outside are distributed about normally 0.8 m/s. The swirling flow at fan is generated and the air is exhausted through vent. Since there is not airflow impinging on heat sink in (b), the case of air-exhaust, it is decided that the cooling of CPU in the case of air-exhaust is disadvantage than the case of air-blowing.

The cooling characteristics data for various vent velocities can be used for the fan power design of mobile PC. For this purpose, CPU temperatures for various vent velocities in two cases are presented in Fig. 3. CPU temperatures, T_{CP} in present study means the value normalized of the local temperatures on CPU. As shown in this figure, when the vent velocity increases in the range of 0.6~2.4 m/s, T_{CPU} decreases linearly in the range of 65.7~58.5 °C for the case of air-blowing, and 67.7~62.1 °C for the case of air-exhaust. T_{CPU} of the case of air-blowing

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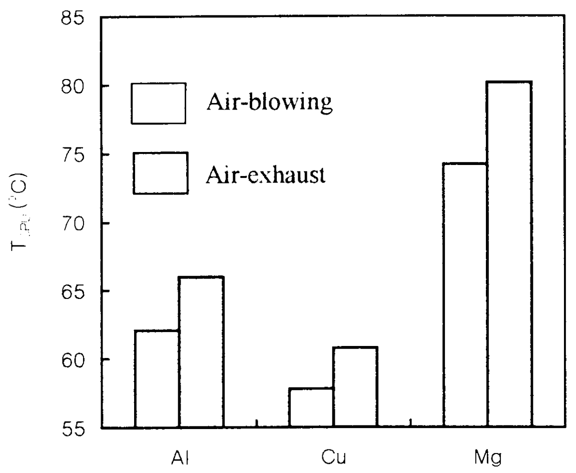

Fig. 4 Comparison of CPU temperatures for various materials of heat spreader

Table 4 Thermal resistances for various materials of heat spreader.

Case		Materials of heat spreader Al	Cu	Mg	Aver.
R_{CPU} (°C/W)	Air-blowing	2.9	2.6	3.9	3.1
	Air-exhaust	3.2	2.8	4.3	3.5

are about 2.0~3.6 °C lower than the case of air-exhaust, and the decreasing rate of T_{CPU} in the case of air-blowing grows up more than the case of air-exhaust. Therefore, it is revealed that the cooling of CPU in the case of air-blowing is more effective. The cooling performances of CPU in two cases are quantitatively discussed in Table 3 in terms of thermal resistances which is defined as following equation.[9]

$$R_{CPU} = (T_{CPU} - T_a) / Q_{CPU} \tag{8}$$

Where, R_{CPU}, T_a and Q_{CPU} mean CPU thermal resistance, ambient temperature and CPU power, respectively. It is natural that the smaller the CPU thermal resistance becomes, the better the CPU cooling performances of CPU becomes. Table 3 shows that CPU thermal resistance decreases as vent velocity increases, and the average value of CPU thermal resistances in case of air-blowing is 7% smaller than case of air-exhaust. Hence, it is concluded that the cooling performances of CPU in case of air-blowing gets better, and the cooling performances of CPU can be increased by means of the increasing of the vent velocity.

CPU temperatures for various materials of heat spreader was investigated as shown in Fig. 4. The copper heat spreader is the most effective for CPU cooling among three materials of heat spreader. Thermal resistances for various materials of heat spreader is presented in Table 4. In case of air-blowing, thermal resistances of aluminum, copper and magnesium heat spreader are respectively 2.9, 2.6 and 3.9, and the average value of these thermal resistances is about 3.1. It can be estimated that thermal resistances of the aluminum and the copper heat spreader are smaller than the average value, thermal resistance of the magnesium heat spreader is larger. Therefore, aluminum and copper are recommended as the material of heat spreader, except magnesium. Furthermore, it is revealed that copper heat spreader can enhance the cooling performance of CPU 12% more than aluminum heat spreader. In case of air-blowing of Table 4, thermal resistances for various materials of heat spreader are slightly larger than case of air-blowing, but the trend of thermal resistances about materials are similar to case of air-blowing.

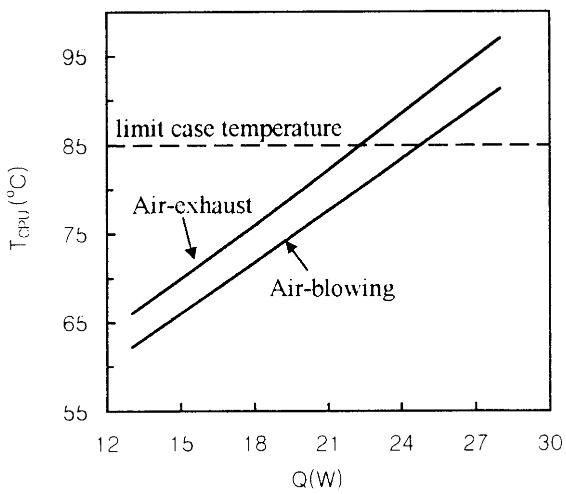

Fig. 5 CPU temperatures for increase of CPU power.

When the heat spreader of the present study was used in mobile PC, the maximum available CPU power was investigated as shown in Fig. 5. The criterion of the maximum available CPU power was defined with limit case temperature of CPU(85°C) in mobile PC. As shown in this figure, the maximum available CPU power is about 25 W in case of air-blowing, and about 22 W in case of air-exhaust.

5. CONCLUSIONS

Parametric study for the cooling characteristic investigation of a mobile PC mounted with heat spreader has been numerically performed. Two cases of air-blowing and air-exhaust at vent were tested. The cooling effects of parameters such as, velocities of air-blowing and air-exhaust, materials of heat spreader, and CPU powers were simulated for two cases. The results in the present study are as follows:

(1) The case of air-blowing which has the airflow impingeing on heat sink is 7% more advantageous in the CPU cooling performance than the case of air-exhaust.
(2) The increase of vent velocity can be enhanced the CPU cooling performance.
(3) The copper heat spreader improves 12% of the CPU cooling performance compared with aluminum heat spreader.

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(4) Using the aluminum heat spreader and u_{in}=1.2 m/s. the maximum available CPU power is about 25 W in case of air-blowing. and about 22 W in case of air-exhaust.

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