# ANALYTICAL MODEL TO PREDICT THERMAL RESISTANCES OF HOLLOW FIN HEAT SINKS

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***Abstract****. This article describes analytically the thermal behavior of a heat sink from the vapor chamber type with pin fin. The objective of the vapor chamber is to spread uniformly the heat coming from electronic components over its base. The temperature distribution and the internal and global thermal resistances of the heat sink are obtained analytically in this paper. The effects of the parameters affecting the thermal resistance of the vapor chamber heat sink are also discussed here.*

***Keywords:*** *Heat Sink, Electronics Cooling, Vapor Chamber.*

## 1. INTRODUCTION

The trend of miniaturization of electronic components, together with the increasing levels of heat generation by Joule effect, lead to constant increasing levels of heat density flux. This heat must be removed from the component to assure that its temperature remains in acceptable levels of operation. The conventional methods to remove this heat are reaching their performance limit. A new technique under development is the use of vapor chambers, which consists basically of a conventional spreader with a hollow base. After evacuation, an amount of working fluid is placed inside the chamber. As it receives the heat from the electronic component and evaporates, the generated vapor spreads for all over the chamber and condensates on the internal walls. The condensate returns to the bottom of the chamber, completing a cycle. Consequently, the generated heat is spread uniformly on the base of the vapor chamber. Most of the researches in the literature have conducted heat transfer experiments in vapor chambers spreaders for laptop computers.

There are several papers in the literature related to the heat spreaders that use the vapor chamber principle. Mashiko *et al.* (1999) showed that the total thermal resistance of the heat sink with vapor chamber is smaller than that of the heat sink without the vapor chamber when the ratio of the bottom area of the heat sink to the top area of the microprocessor units (MPUs) is greater than 5. Wuttijummong *et al.* (2000) examined the effect of the amount of the working fluid the heat transfer characteristics of the heat sink vapor chamber.

Nguyen *et al.* (2000) concluded experimentally that the performance of heat sink with the vapor chamber is approximately 25% and 45% better than that of the heat sink with the conventional heat spreaders made of copper and aluminum respectively.

Mochizuki *et al*. (2006) performed several experiments with different types of wick structures used on the vapor chamber to evaluate the better structure.

All the papers found in the field employed conventional fins in the vapor chamber heat sinks. However, it is well known that the fin efficiency is smaller than 100%. Temperature gradients along the fins make them to lose efficiency. An alternative to this problem is to use hollow fins along with the vapor chamber concept. The idea is to extend the vapor chamber into the fins, so the vapor reaches the entire fin, making the fin temperature to be uniform, i. e., making the fin efficiency to be nominally 100%. The objective of this paper is to develop an analytical model for determining the temperature distribution and the internal and global thermal resistances of a vapor chamber heat sink with hollow pin fin.

**2. Analytical Model**

The analytical model is based on the following assumptions:

- one dimensional heat transfer;
- metal constant thermal conductivity;
- constant external convection heat transfer coefficient along the fins;
- constant working fluid physical properties;
- uniform heat flux in the evaporator;

Table 1 presents the values of parameters used to obtain the analytical model. Figure 1 shows an illustrative schematic of the heat sink, where *a* e *b* are the external dimensions of the vapor chamber , *c* [m] is the external dimensions of square the heat source, $e_b$ [m] is the thickness of the vapor chamber wall, $r_e$ [m] is the external radius of the pins, $r_i$ [m] is the internal radius of the pins, *N* is the total number and $P_w$ is the fan power.

Table 1. Parameters of the heat sink of Fig. 1

| a (m) | b (m) | c (m) | L (m) | $L_c$ (m) | $r_i$ (m) | $r_e$ (m) | $e_b$ (m) | N | $P_w$ (W) |
|---|---|---|---|---|---|---|---|---|---|
| 0,130 | 0,135 | 0,04 | 0,063 | 0,009 | 0,003765 | 0,004765 | 0,00165 | 77 | 2,88 |

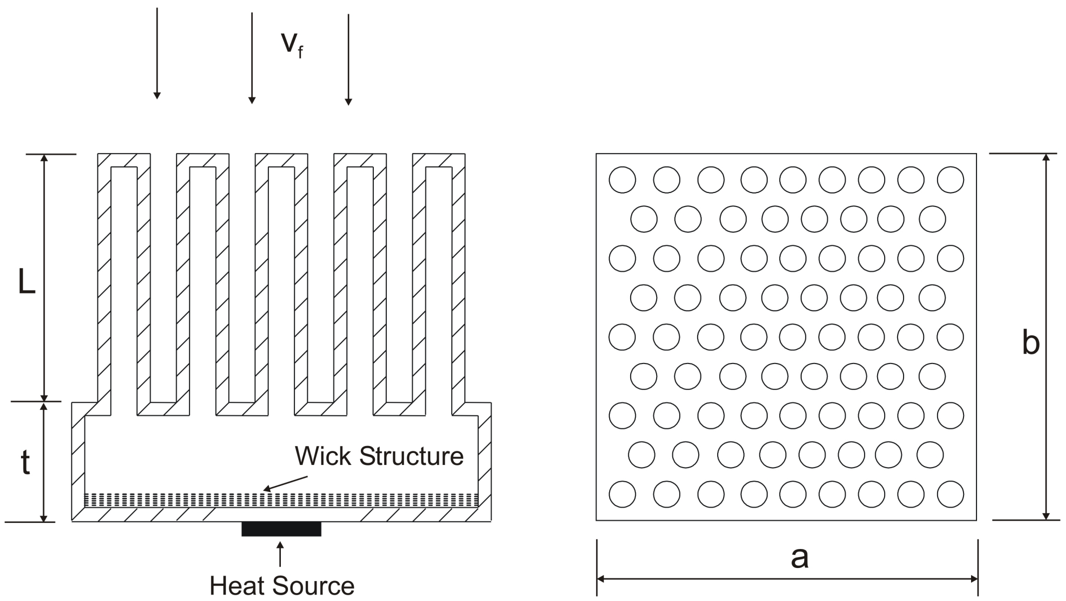


Figure 1. Schematic of pin array heat sink.

The analytical model is based on the thermal resistance defined by Eq. (1) below:

$$R_G = \frac{\Delta T}{Q} \tag{1}$$

where *Q* [W] is the heat transfer rate applied on the vapor chamber base, $\Delta T$ [ºC] is the difference between the base average temperature and the a room air temperature and $R_G$ [ºC/W] is the global thermal resistance.

The vapor chamber is modeled for steady state conditions, using analogy with electric circuits, resulting in a thermal circuit, which is composed by five thermal resistances in serial, as shown in fig. 2, where $R_1$, $R_2$, $R_3$, $R_4$ and $R_5$ are respectively: the conduction thermal resistance in the vapor chamber wall; the boiling thermal resistance; the condensation thermal resistance over the hollow fin internal walls, the radial conductive thermal resistance through the fin walls and the external convection thermal resistance.

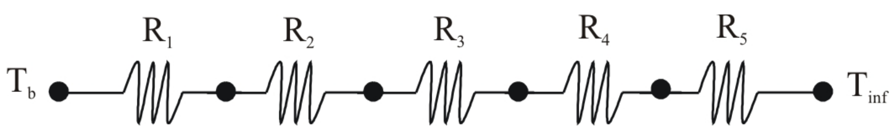

Figure 2. Global thermal circuit

The thermal resistances $R_1$, $R_2$, $R_3$, $R_4$ e $R_5$ are calculated by the following expressions respectively:

$$R_1 = \frac{e_b}{kA_{source}}, \tag{2}$$

where $k$[W/m°C] is the thermal conductivity and $A_{source}$ [m$^2$] is the area of the square heat source;

$$R_2 = \frac{1}{h_{ebu} A_{source}}, \tag{3}$$

where $h_{ebu}$ [W/m$^{2o}$C]is the boiling coefficient of heat transferring;

$$R_3 = \frac{1}{Nh_{cond} A_{cond}}, \tag{4}$$

where $h_{cond}$ [W/m$^{2o}$C] is the condensation heat transfer coefficient and $A_{cond}$ [m$^2$] is the condensation area of the fin internal walls;

$$R_4 = \frac{\ln(r_e / r_i)}{N 2\pi k L}, \tag{5}$$

where $L$[m] is the height of the fin; and finally

$$R_5 = \frac{1}{Nh_{conv} A_{conv}} \tag{6}$$

where $h_{conv}$ [W/m$^{2o}$C] is the external convection heat transfer coefficient and $A_{conv}$ [m$^2$] is the convection area on the fins external walls.

The convection heat transfer coefficient used is presented by Wirtz (1997):

$$h_{conv} = 3{,}2x10^{-6} C_{Pw}{}^{0,52} \left(\frac{L}{a}\right)^{-0,205} \left(\frac{p}{d_e}\right)^{0,89} \frac{k_a}{a} \tag{7}$$

where $p$ is the pin-fin pitch, $d_e$ is the external diameter of the fin, $k_a$ is the is the thermal conductivity of air and $C_{pw}$ is defined by Eq. 8:

$$C_{PW} = \frac{\rho_a{}^2 L P_w}{\mu_a{}^3} \tag{8}$$

where $\rho_a$ is the density of air, $\mu_a$ is the viscosity of air and $P_w$ is the fan power.

## 3. RESULTS AND DISCUSSION

### 3.2 Internal Thermal Resistances

Figure 3 presents the internal thermal resistance as a function of the heat transfer rate input. The internal thermal resistance is defined by addition of $R_1$, $R_2$, $R_3$ and $R_4$. It shows three theoretical curves obtained from three different correlations for the boiling heat transfer coefficient determination, which are: Foster and Zuber (1955), Kutateladze (1959) and Stephan and Abdelsalam (1980). Through out the correlation of Kaminaga (1997) the condensation heat transfer coefficient is obtained. It is observed between 25 and 150 W, the internal thermal resistance is relatively high., because of the low boiling heat transfer coefficient. From 150 W and above, the internal thermal resistance decreases with heat input and gives approximately the same result. Observe that below 150 W, the correlation of Stephan and Abdelsalam gives almost twice the resistance of Foster and Zuber.

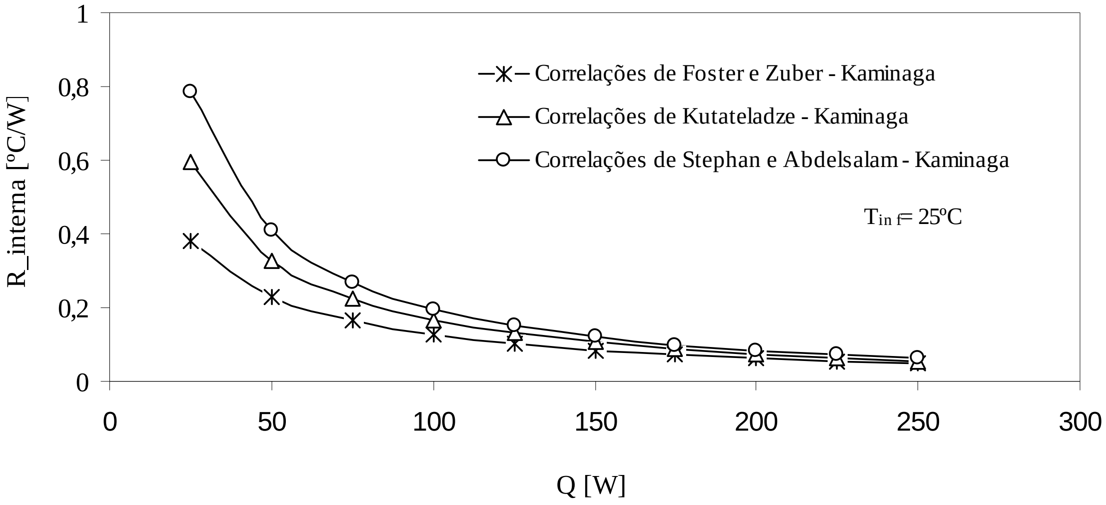


Figure 3. Internal Thermal Resistance

Figure 4 shows the values of the individual thermal resistances of the heat sink as a function of the heat transfer rate input. The larger thermal resistance corresponds to the boiling process, while the other resistances have a much smaller influence. Therefore, it is concluded that the boiling thermal resistance is who governs the thermal behavior of the vapor chamber type heat dissipater.

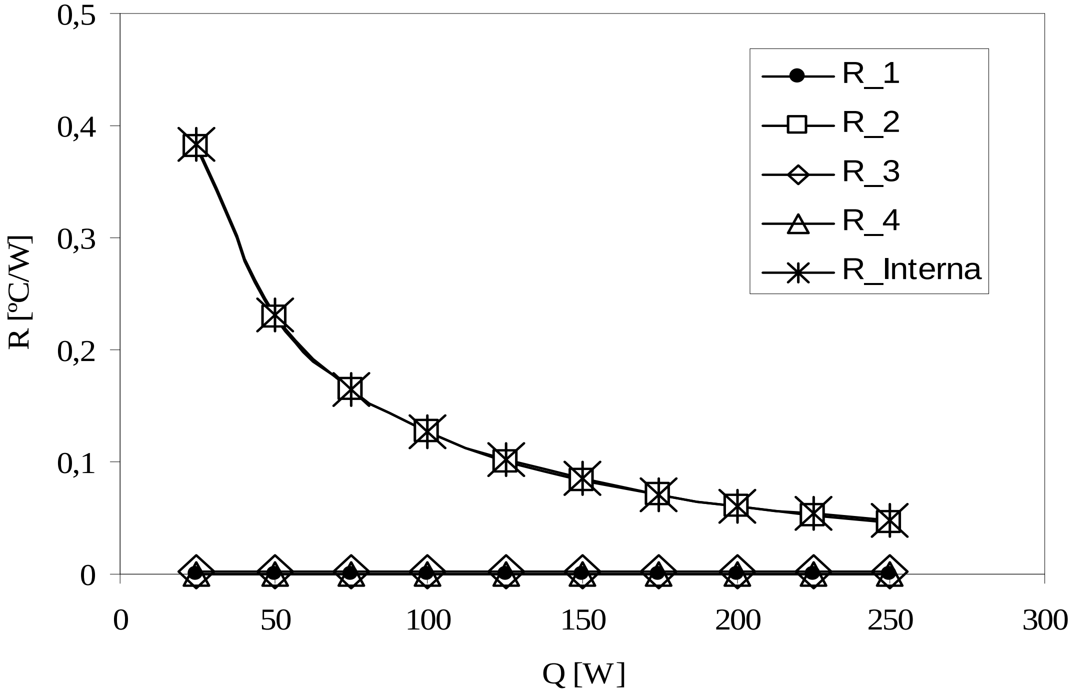


Figure 4. Influence of the thermal resistances on the heat sink behavior.

**3.3 Global Thermal Resistance**

Figure 5 shows three theoretical curves obtained from the correlations previously mentioned. One can see that they have similar behaviors. The global thermal resistance decrease very quickly with increasing heat transfer rate due to the decrease of the boiling heat transfer resistance. The global thermal resistances tend to remain constant with increasing heat input above 100 W.

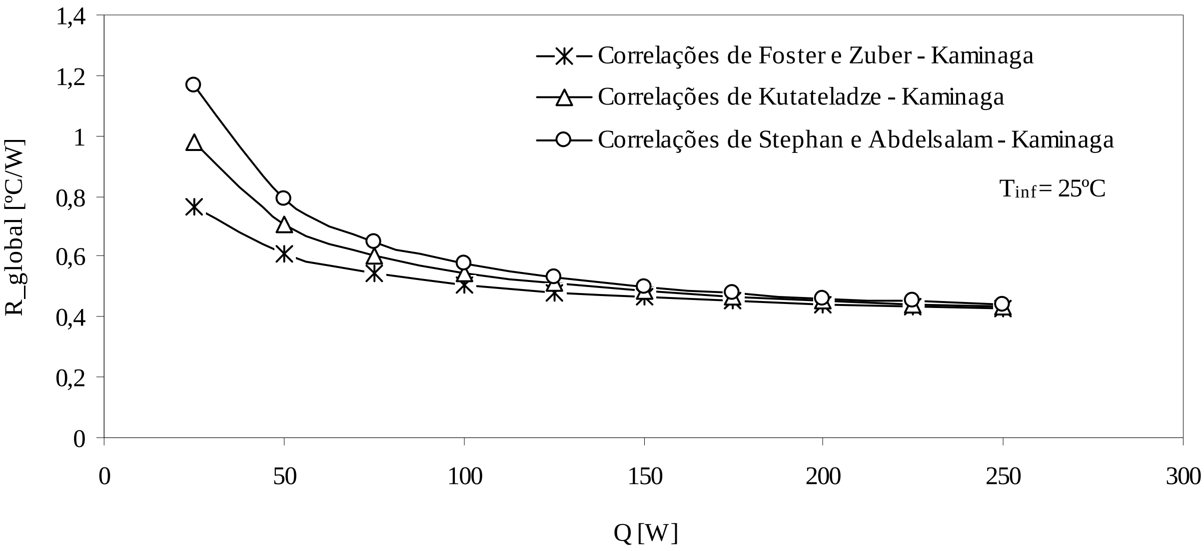


Figure 5. Global Thermal Resistance

It is observed in Fig. 6 that below 75W, there are two thermal resistances that influence on the thermal behavior: boiling thermal resistance and external convection resistance. Above of this heat rate, the external convection thermal resistance is the most significant. The other resistances present lower influence in the thermal behavior of the heat sink.

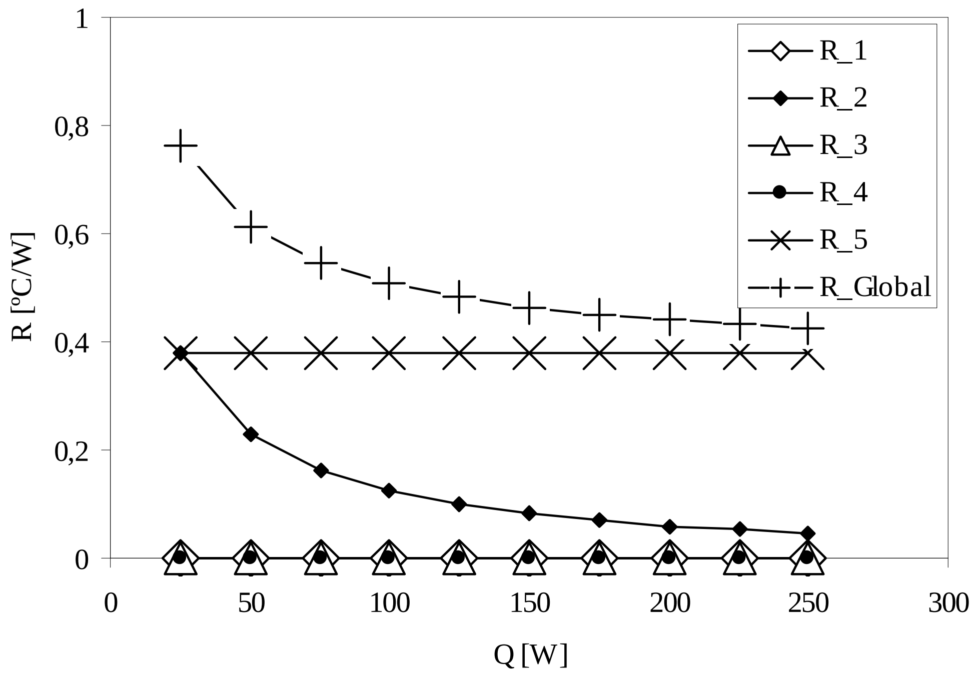


Figure 6. Influence of thermal resistances on the behavior of the heat sink.

### 3.1 Temperature Distribution

The vapor generated in the vapor chamber base spreads uniformly inside the heat sink, homogenizing the temperature. An illustrative schematic of the pin fin vapor chamber is shown in Figure 7.

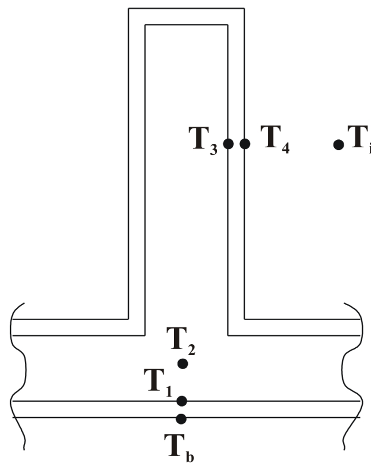


Figure.7. Distribution of internal temperature in a hollow pin fin of the heat sink.

In this figure, $T_b$ ,$T_1$, $T_2$, $T_3$, $T_4$ e $T_{inf}$ are respectively the temperature where the heat is applied, the temperature of the internal wall in the vapor chamber, the vapor temperature, the fin internal wall temperature, the fin external wall temperature, and the room air temperature. Figure 8 shows the theoretical temperature distribution inside the heat sink. It can be noticed that temperatures $T_b$ ,$T_1$, $T_2$, $T_3$ and $T_4$ presents almost the some level, while the room temperature is well below the other. This shows that the external convection resistance $R_5$ of Fig. 2, is the largest of all.

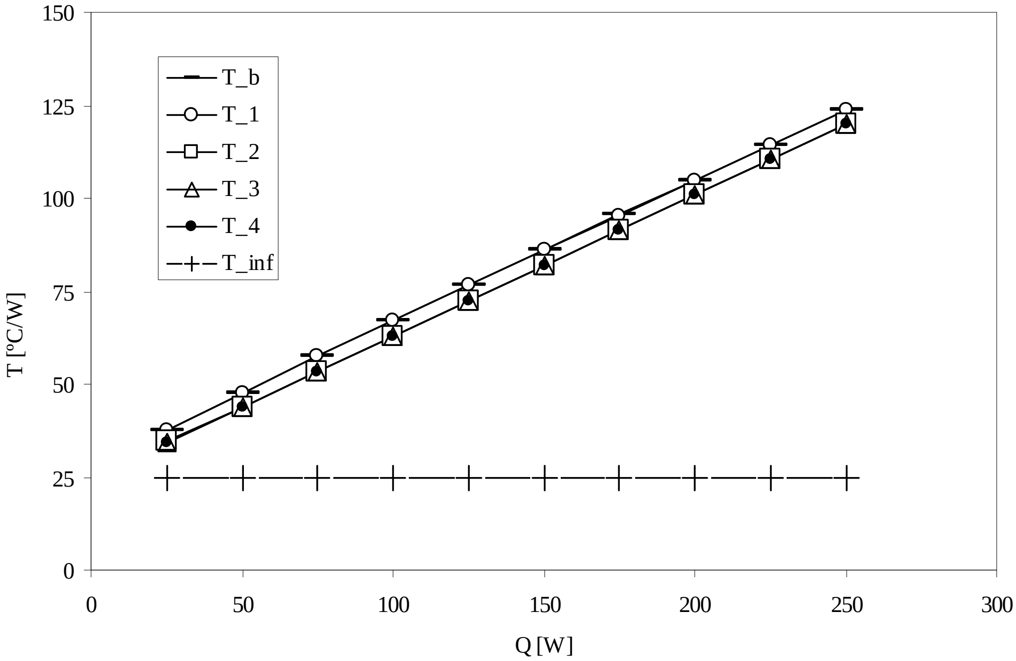


Figura 8. Distribution of temperature in the hollow fin heat sink.

## 4. CONCLUSION

In this paper, an analytical model to predict the global and internal thermal resistances and the temperature distribution of a vapor chamber heat sink with hollow pin fins is presented

. The results show that the heat sink performance increases with heat transfer rate and stabilizes for heat rates larger than 150 W. The internal resistances are much smaller than the external convection resistance, which makes the temperature distribution inside the heat sink to be practically uniform. An experimental prototype is under construction in order to validate the analytical model and will be ready to be tested soon.

## 5. REFERENCES

Forster, H. K. e Zuber, N., (1955), Dynamics of Vapor Bubbles and Boiling Heat Transfer, *A.I.Ch.E. Journal*, vol. 1, pp. 531.535.

Iincropera, F.P., and De Witt, D.P., 2003, "Fundamentals of heat and Mass Transfer", John Willey & Sons, New York, 5th edition.

Kaminaga, F., Okamoto. Y. and Susuki, T., "Study on Boiling Heat Transfer Correlation in a Closed Two-Phase thermosyphon", 8th International Heat Pipe Conference, Beijing, pp. 1-6, !992.

Kaminaga, F., Hashimoto, H., Feroz, C. and Matsumura, K., 1997, "Heat transfer Characteristics of Evaporation and condensation in a Two Phase Closed Thermosyphon",10th International Heat Pipe Conference, Stuttgart, pp. 1-6.

Kiyooka, F., Saito, Y., Mochizuki, M., Nguyen, T. and Kawahara, Y., "A Novel Thermal solution Using Vapor chamber Technology for Cooling High Performance Desktop CPU in Notebook PC", 8th International Heat Pipe Symposium, Kumamoto – Japan, 24-27 september /2006.

Koito, Y., Komiya, M., Nakano, Y., Imura, H., Mochizuki, M. and Torii, S., "A Three-dimensional Heat Transport Analysis of a Vapor Chamber", 8th International Heat Pipe Symposium, Kumamoto – Japan, 24-27 september /2006.

Koito, y., Nakahara, D., Nunoda, A., Imura, H., Mochizuli, M., Saito, Y. and Torii, S., "An Experimental Investigation on Cooling of High Power Microchips in a Confined Space", 8th International Heat Pipe Symposium, Kumamoto – Japan, 24-27 september/2006.

Koito, Y., Motomatsu, K., Imura, H., Mochizuki, M. and Saito, Y., "Fundamental Investigations on Heat Transfer Characteristics of Heat Sinks with a Vapor Chamber", 7th International Heat Pipe Symposium, Jeju – Korea, 12-16 november/2003.

Kutatekadze, S. S., 1059, "Heat Transfer in Condensation and Boiling"AEC –tr-4770,pp.129.

Mochizuke, M., Nguyen, T., Saito Y., Horiuchi, Y., Machiko, K., Sataphan, T. and Kawahara, Y., "Latest Vapor Chamber Technology for Computer", 8th International Heat Pipe Symposium, Kumamoto – Japan, 24-27 september /2006

Mochizuki, M., Saito, Y., Kiyooka, F. and Nguyen, T., "High Power Cooling Chips by Heat Pipes and Advanced Heat Spreader", 8th International Heat Pipe Symposium, Kumamoto – Japan, 24-27 september /2006.

Mochizuki, M., Nguyen, T., Moshiko, K., Nguyen, T., Wu, X. P. and Wuttijummong, V., "Overview Latest Technologies Using Heat Pipe and Vapor chamber for Cooling of High Heat Generation Notebook Computer", ", 7th International Heat Pipe Symposium, Jeju – Korea, 12-16 november/2003.

Stephan, K. e Abdelsalam, M., (1980), Heat Transfer Correlations for Natural Convection Boiling, *International Journal of Heat and Mass Transfer*, vol. 23, pp. 73.87.

Wirtz, R. A., Sohal, R. and Wang, H., "Thermal Performance of Pin Fin Fan-Sink Assemblies", Journal oh Electronic Pakaging, 1997, vol. 119, pp. 26-31.