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NUMERICAL ANALYSIS OF THE SIZE RATIO OF INTEGRATED CIRCUIT AND HEATSINK WITH AND WITHOUT VAPOR CHAMBER

Reginaldo Ribeiro de Sousa

Tatiane Aparecida de Sousa

UFGD – Grande Dourados Federal University / FAEN-College of Engineering
Dourados-MS, Road MS-270/Dourados-Itahum, km 12, ZipCode: 79804-970
reginaldosousa@ufgd.edu.br, tatianeap.sousa@outlook.com

Abstract. *This article has as the main objective of this work is to verify how the size ratio between the integrated circuit and heatsink assembly influences the IC heat dissipation process, and if the use of vapor chamber alters this size ratio. This study was performed to two different types of sets of heat dissipation can work in a forced convection environment. The first set, which was called Model 1, is composed of a printed circuit board, integrate circuit and a heatsink. The second set (Model 2) is composed of a printed circuit board, integrate circuit, heatsink and a vapor chamber. For the accomplishment of this work, a simple thermal resistors model was constructed using ANSYS Fluent software, student license, as computational fluid dynamics tool, represented by blocks with fixed thermal properties, modifying only the dimensions. The results show the temperature behavior of the heatsink and the integrated circuit for each model. The results prove that using vapor chamber reduces the temperature of the integrated circuit by up to 14%. This occurs when the heatsink is 60 times larger than the IC. It was also observed that when using vapor chamber, a heatsink up to 60 times larger than the IC can be used, because up to this size ratio, there is a reduction in the IC's temperature. In the model without vapor chamber this process occurs when the heatsink is only 30 times larger than the IC.*

Keywords: *heatsink, vapor chamber, electronic component, numerical analysis*

1. INTRODUCTION

The heatsinks are metal objects usually made of aluminum or copper that serve to transfer heat by conduction. They are used to cool electronic components containing high heat dissipation, such as integrated circuits (IC) of computers with high processing capacity. With the constant evolution in electronic equipment, the electronic components became increasingly smaller, generating an increase in the heat flux inside them, and for cooling there was a need to look for new alternatives such as considerably increasing the size of the heatsinks. Recently, Peng et al., 2013, stated that temperatures are so high that the traditional heat pipe cannot dissipate all the heat generated.

For Koito et al., 2006, to solve this problem, the vapor Chamber has emerged. An advanced cooling instrument that functions as an efficient conductor of heat, this device is located between the IC and the heatsink and causes the heat supplied by the electronic component, spread evenly on the heatsink. Cooler Master, (2013) stated that the coolant molecules are heated they change phases. The vaporized coolant flows freely through the chamber. The Molecules then condense on cold surfaces, dissipate their heat load, and are channeled back to the coolant reservoir. Since the rate of condensation depends on the temperature delta of the coolant and the contact surface, the coolant automatically streams towards the coolest surface area. This self-organizing active molecular coolant stream within the Vapor Chamber is responsible for its superior thermal properties. As a result, it provides stable and evenly spread temperatures on all of its surfaces. But when should you use vapor chamber? Until when is it feasible to use only the heatsinks? Until what size ratio, can the vapor chamber evenly spread the heat in the heatsink?

Recent research by Advanced Cooling Technologies (2018) provides information on case studies comparing heatsinks, vapor chamber and summarizing each technology. Tang et al., 2013, proposed and tested a new vapor chamber with layered structures of sintered copper powders in their work and found that the heating area may influence the performance of vapor chamber, further stated that for a better performance the area of should be less than the vapor chamber area. Naphon et al., 2012, experimentally investigated the thermal cooling of the vapor chamber and verified that it has a significant effect on the energy consumption and the thermal cooling of a CPU.

Several studies on vapor chamber performance have already been performed and in this article, using numerical analysis will be studied two types of models, the first one (Model 1) using only the heatsink to cool the electronic component and the second (Model 2) using a vapor chamber between the heat source and the heatsink. The objective is

to verify the largest area in which each model works effectively in a forced convection environment and to examine when it is feasible or not to increase the size of the heatsink and that of the vapor chamber.

2. PROCEDURES AND NUMERICAL ANALYSIS

For the accomplishment of this work, a simple thermal resistors model was constructed using ANSYS Fluent software, student license, as computational fluid dynamics tool. The models created were based on real IC and vapor chamber, which can be purchased at specialized stores. The objective was to analyze sets of heat dissipators, vapor chamber and integrated circuit, very similar to reality. The models were constructed as blocks and each block represents a component, as described in section 2.1 of this article.

2.1 Description of components

The wind tunnel is the scenario in which the models were analyzed, it contains dimensions 300 x 300 x 50 mm, an ambient temperature of 20 °C has been considered inside, the walls in the axes “x” and “y” are adiabatic, in other words, the walls is in the boundary of the wind tunnel in the side of axis “minimum x” and “maximum x”, and side of axis “minimum z” and “maximum z” are adiabatic. In the z-axis the walls are opened and has an input velocity of 3 m/s in the z-axis direction. This speed value was used because this is a common speed for fans used in electronic devices. The model with the coordinate system can be seen in Fig 1.

The printed circuit board has dimensions of 120 x 180 x 1 mm and it is composed of FR-4 material. The electronic component considered was the Intel Pentium N3520 processor, has dimensions 27 x 25 x 1 mm, composed of Epoxy Resin-Typical material and power dissipation of 4.5 W (Intel, 2014).

The heatsink was created based on the work of Haskell, (2010), in which the author studies different equipment of materials for heatsinks. It is made of extruded aluminum, its fins have a thickness of 0.4 mm, height 9 mm and distance between fins of 0.664 mm. The base of the heatsink has a thickness of 1 mm and its dimensions change according to the model created, which will be shown in section 2.2. The initial model of the heatsink can be seen in Fig 2.

The vapor chamber was made from the datasheet of vapor chambers of Wakefield-Vette (2017). The model taken as base is the vapor chamber 90-90-3, has 3 mm thick and a thermal resistance of 0.143 °C/W.

To carry out the work is necessary the thermal conductivity of the vapor chamber which was not provided in the datasheet. However, it was possible to determine it using the thickness and the thermal resistance of the IC. Eq. (1) and Eq. (2) represent the thermal conductivity and thermal resistance equations respectively (Incropera and DeWitt, 2002).

$$k = q / (dT / dX) \quad (1)$$

$$Re = L / (k \cdot A) \quad (2)$$

Where:

k = thermal conductivity.

q = heat flux.

dT / dX = change in temperature in relation to the thickness.

Re = thermal resistance.

L = length.

A = area.

By analyzing the two equations, it can be seen that the thermal conductivity is the inverse of the thermal resistance divided by the thickness of the object, so the conductivity of the vapor chamber can be calculated by Eq.3:

$$kv = (1 / Re) / e \quad (3)$$

Where:

kv = thermal conductivity of the vapor chamber

Re = thermal resistance of the vapor chamber

e = thickness of the vapor chamber

Solving Eq. (3) with the vapor chamber data provided in item 2.1, we have that the thermal conductivity is 2231 W/m.°C.

2.2 Description of the models

The Model 1 consists of wind tunnel, printed circuit board, electronic component and heatsink. This model was analyzed in 13 different configurations: Model 1.1, Model 1.2 ... and Model 1.13. For each of these models, the

dimension of the heatsink was increased by 20 mm in the direction of the x-axis and 20 mm in z-axis. The x-axis variation corresponds to an increase of 3 fins in the heatsink. Only in the change from model 1.1 to model 1.2, that the difference in the number of the fins was only two. The z-axis variation generates an increase in the length of the heatsink. In the direction of the y-axis the model remained constant. For example, the heatsink of the first set (Model 1.1) has dimensions 27 x 25 x 10 mm and 4 fins as shown in Fig. 1, and with more detail in the Fig. 2. So in the second set (Model 1.2) the heatsink has 47 x 45 x 10 mm and 6 fins. In both cases the heatsink had a height of 10 mm, 9 mm referring to the height of the fins and 1 mm referring to the base of the heatsink. In both cases too, the printed circuit board had a thickness of 1 mm. The size of the electronic component is 27 x 25 x 1 mm, in this case 1 mm is the thickness. Figure 1 shows more detail of the heatsink of model 1.1.

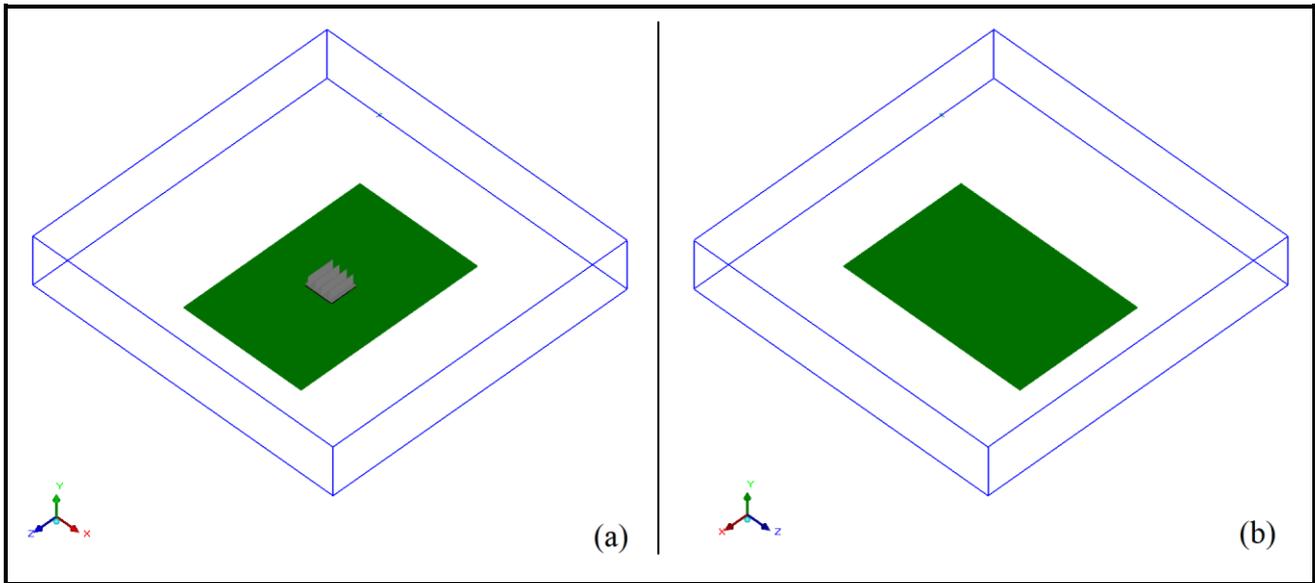


Figure 1. Model 1.1 without vapor chamber and heatsink with 4 fins.

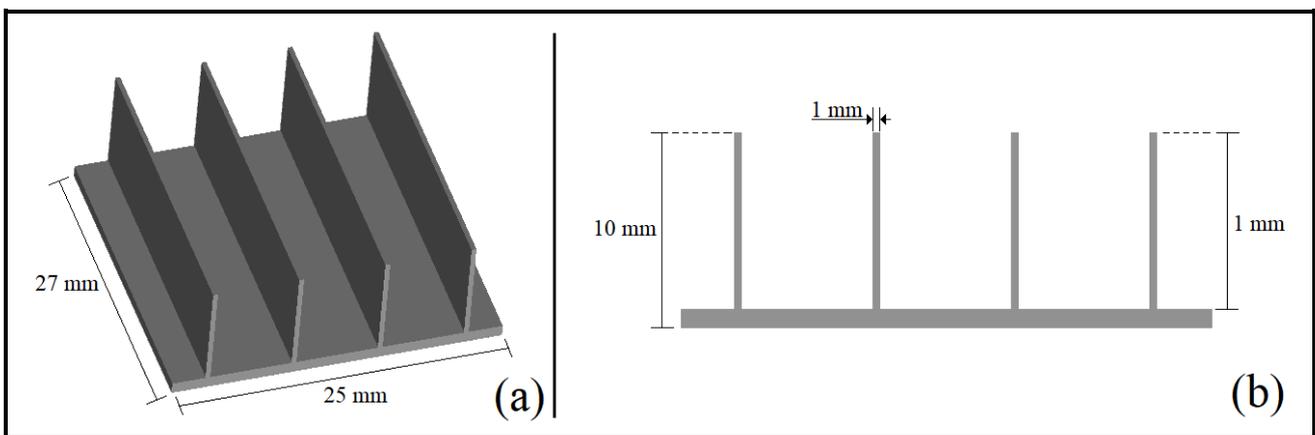


Figure 2. The heatsink of model 1.1.

The Model 2 is composed of the same elements of Model 1 with the addition of the vapor chamber. The vapor chamber used for this model is 3 mm thick. In addition, the vapor chamber was modeled as a solid material with a thermal conductivity of 2231 W/m.°C, as explained in item 2.1. As in the previous case, this model was also analyzed in 13 different configurations: Model 2.1, Model 2.2 ... Model 2.13. The components in common of the two models have the same dimensions and mechanical properties and their size has been increased in the same way as Model 1, and the size of the vapor chamber varies according to the size of the heatsink base, so that they always remain the same size. Figure 3 shows the Model 2.13, the largest model, containing 38 fins and dimensions 267 x 265 x 10 mm. Figure 4 show more detail of the model 2.6 (an intermediate model).

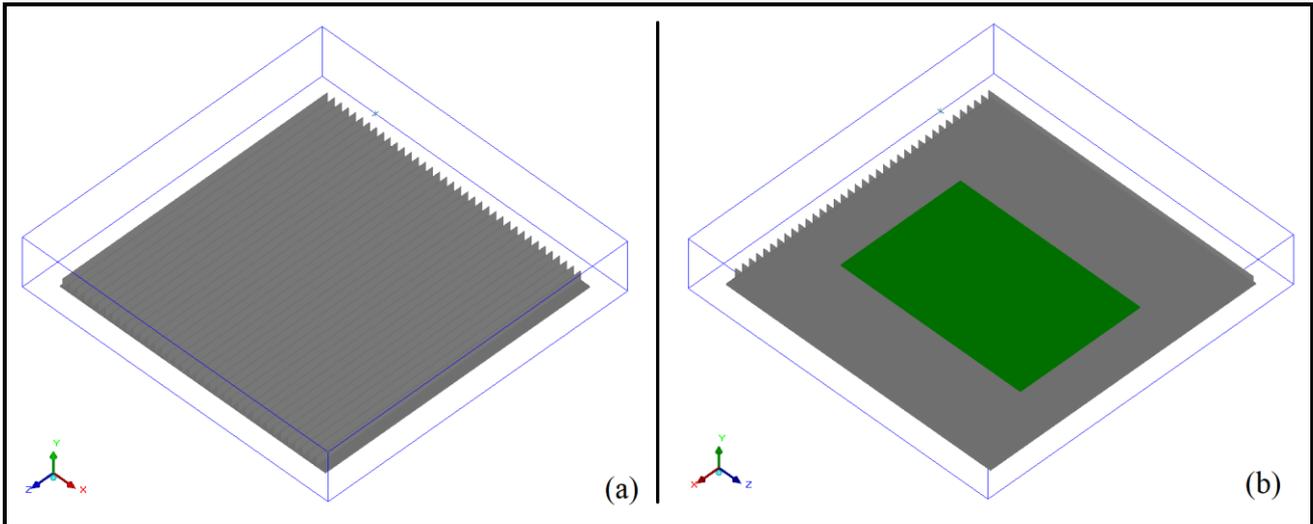


Figure 3. Model 2.13 with vapor chamber and heatsink with 38 fins.

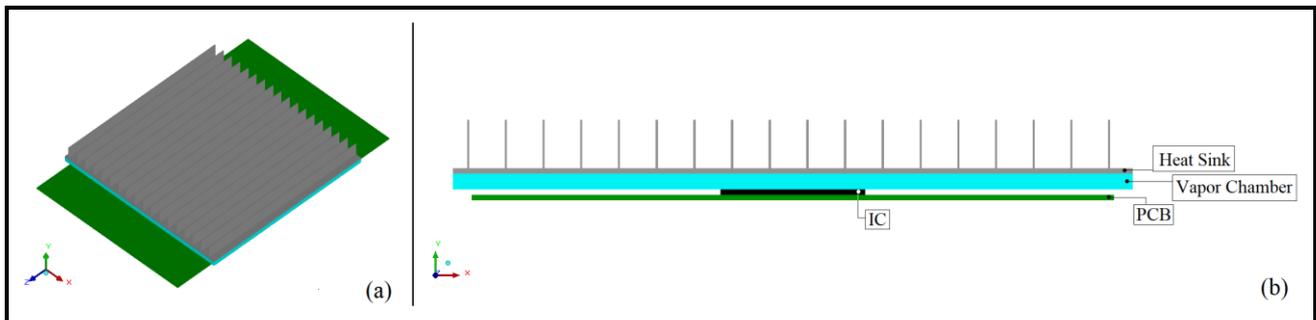


Figure 4. Model 2.6 Details of the model 2.6.

3. RESULTS

From the tests carried out, we have that the vapor chamber distributed very well the heat dissipated by the electronic component. When comparing model 1.13, Fig. 5 with model 2.13, Fig. 6, it can be noted that the temperature variation in the heatsink of the Fig. 5 is approximately 5 °C, in addition, the side fins are close to ambient temperature (20°C). This means that these fins aren't working as much as the middle fins. In model 2.7, the temperature varies about 0.5 °C, this shows that the vapor chamber is evenly spreading the heat generated by the electronic component in the heatsink. In this case, the entire heatsink is transferring heat to air through forced convection.

Table 1 and Tab. 2 respectively show the heatsink area and temperature of the upper surface of the electronic component of Model 1 and Model 2. Another very interesting result that can be shown, is the change of IC's temperature as a function of the size ratio between the heatsink base and the heat source, in other words, the area of the heatsink divided by the base's area of the integrated circuit ($A_{\text{heatsink}}/A_{\text{IC}}$). As already mentioned, the dimensions of the IC are 27 x 25 x 1mm. Thus, the base area of the IC is the multiplication of 27 x 25 mm (675 mm²).

Figure 7 shows the temperature plot on the surface of the electronic component relative to the area of the heatsink divided by the base's area of the integrated circuit ($A_{\text{heatsink}}/A_{\text{IC}}$) from the data in Table 1 and Table 2.

The temperature variation of model 2 can be calculated in relation to model 1. This is important data showing the influence of vapor chamber on IC temperature. To calculate this data, just use the difference between the temperature of model 1 and model 2, and divide the result by the temperature of model 1. The result of this is percentage data. This result is show in Tab. 3 e Fig. 8.

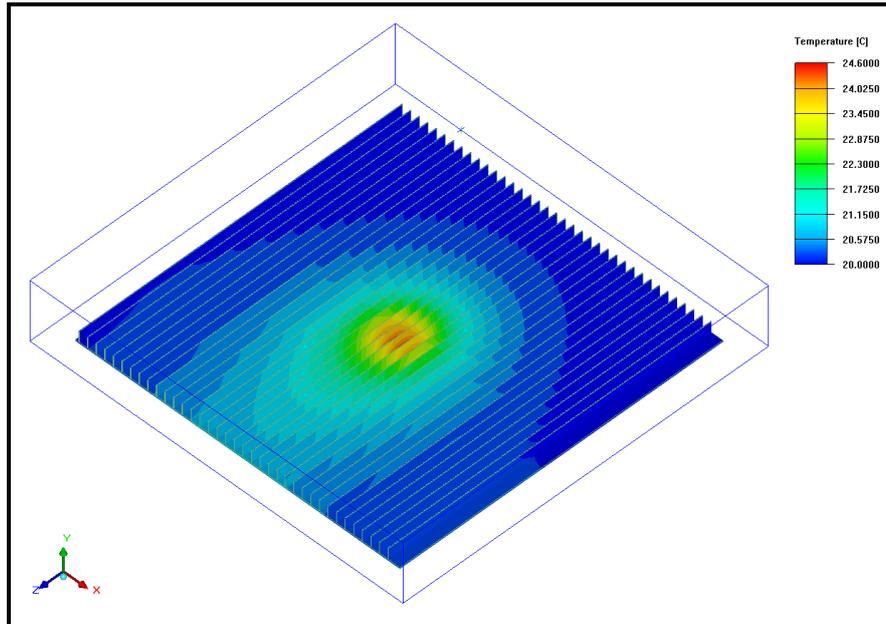


Figure 5. Contours of temperature in the heatsink without vapor chamber (model 1).

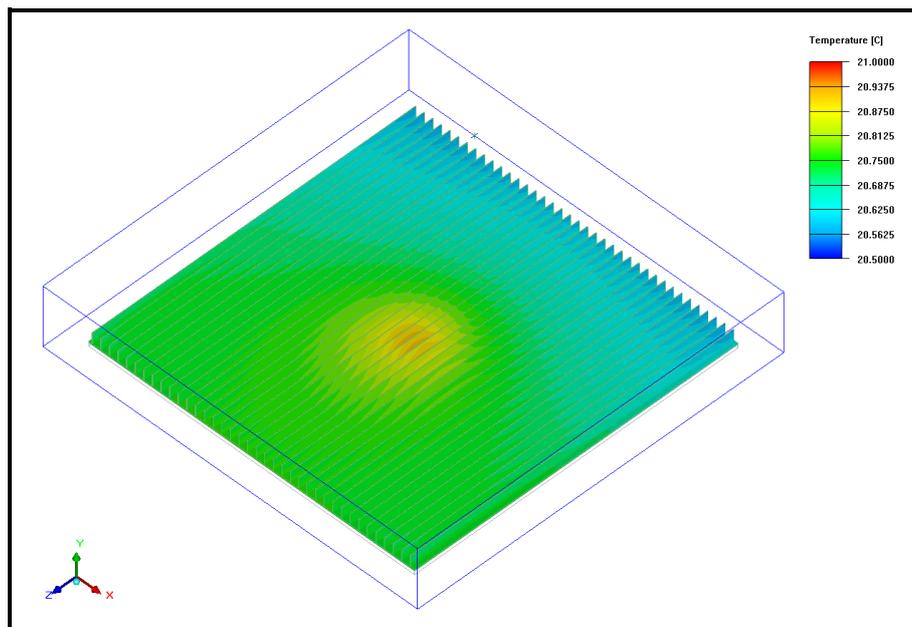


Figure 6. Contours of temperature in the heatsink with vapor chamber (model 2).

Table 1. Model 1 heatsink and processor data.

Model	N ^o of fins	Area of heatsink's base, m ²	$A_{\text{heatsink}}/A_{\text{IC}}$	Temperature of the IC's surface, °C
1.1	4	0.000675	1.0	50.5
1.2	6	0.002115	3.1	33.7
1.3	9	0.004355	6.5	28.6
1.4	12	0.007395	11.0	26.5
1.5	15	0.011235	16.6	25.5
1.6	18	0.015875	23.5	25.2
1.7	21	0.021315	31.6	24.8
1.8	23	0.027555	40.8	24.7

1.9	26	0.034595	51.3	24.7
1.10	29	0.042435	62.9	24.7
1.11	32	0.051075	75.7	24.6
1.12	35	0.060515	89.7	24.4
1.13	38	0.070755	104.8	24.4

Table 2. Model 2 heatsink and processor data.

Model	N° of fins	Area of heatsink's base, m ²	$A_{\text{heatsink}}/A_{\text{IC}}$	Temperature of the IC's surface, °C
1.1	4	0.000675	1.0	48.6
1.2	6	0.002115	3.1	32.2
1.3	9	0.004355	6.5	26.6
1.4	12	0.007395	11.0	24.1
1.5	15	0.011235	16.6	22.9
1.6	18	0.015875	23.5	22.2
1.7	21	0.021315	31.6	21.7
1.8	23	0.027555	40.8	21.5
1.9	26	0.034595	51.3	21.2
1.10	29	0.042435	62.9	21.2
1.11	32	0.051075	75.7	21.0
1.12	35	0.060515	89.7	20.9
1.13	38	0.070755	104.8	21.0

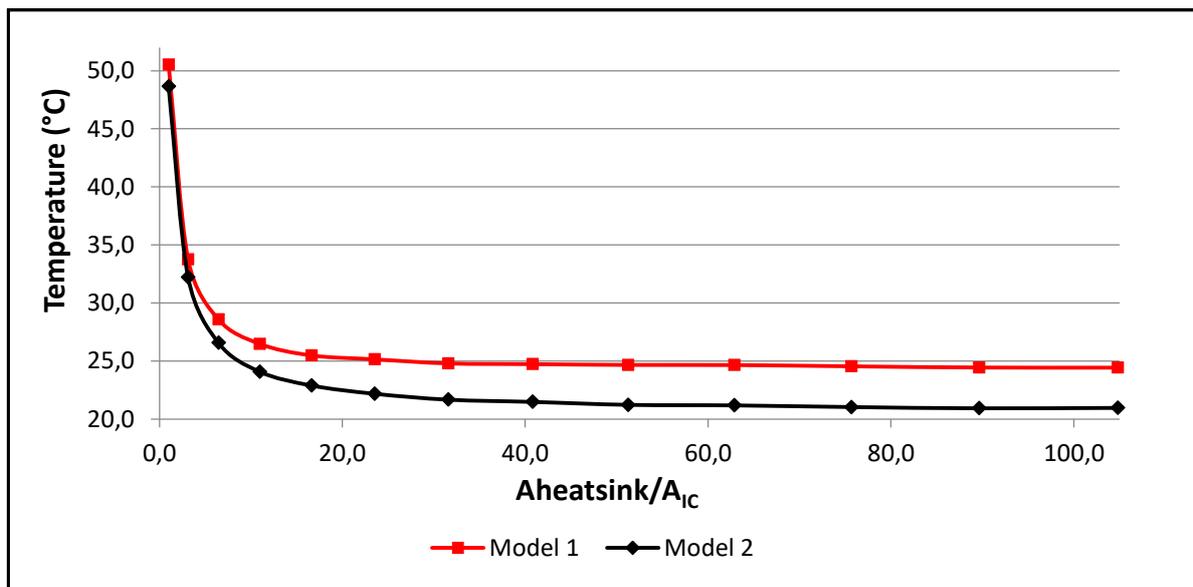


Figure 7. Temperature on the surface of the IC x $A_{\text{heatsink}}/A_{\text{IC}}$.

Table 3. Difference between the temperatures.

$A_{\text{heatsink}}/A_{\text{IC}}$	Model 1	Model 2	Difference between the temperature, %
1.0	50.5	48.6	3.7
3.1	33.7	32.2	4.5
6.5	28.6	26.6	7.1
11.0	26.5	24.1	9.1
16.6	25.5	22.9	10.2
23.5	25.2	22.2	11.8
31.6	24.8	21.7	12.6
40.8	24.7	21.5	13.1

51.3	24.7	21.2	13.9
62.9	24.7	21.2	14.1
75.7	24.6	21.0	14.3
89.7	24.4	20.9	14.4
104.8	24.4	21.0	14.2

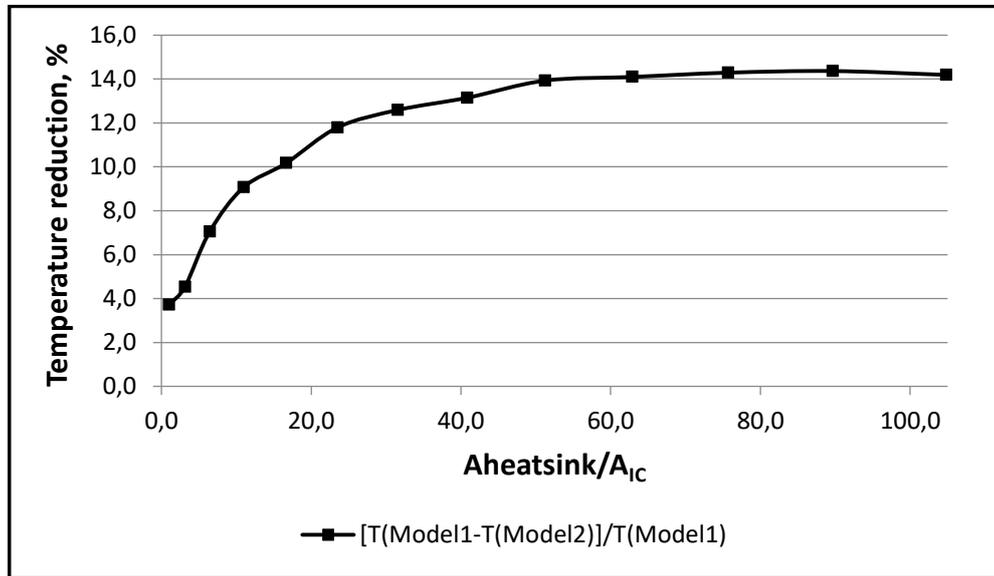


Figure 8. Temperature on the surface of the electronic component x base of the heatsink.

4. CONCLUSIONS

Based on Fig. 5 and Fig. 6, it can be seen that the "heatsink and vapor chamber" set, is more efficient to dissipate heat than when vapor chamber is not used. This is because the entire heatsink area is heated. This is true for situations where the heatsink is larger than the IC.

According to Tab. 1 and Tab. 2, which has their information is summarized in Fig. 7, it can be noted that the two curves have very similar behavior, but the temperatures of Model 2 are lower than those of Model 1. We may also note that from a certain point, increasing the area of the heatsink does not effectively reduce the temperature of the electronic component, thus it is not advantageous to increase the heatsink from this point. This occurs when the base's area of heatsink is approximately 30 times larger than the IC's area for model 1 (without vapor chamber), and approximately 60 times for model 2 (with vapor chamber).

According to Tab. 3 and Fig. 8, it can be observed that when the heatsink base has the same area as the electronic component, the temperature reduction with the use of vapor chamber is less than 4%. As the proportion of these areas increases, the IC's temperature decrease also increases. This process repeats to the point where the base's area of the heatsink is 60 times larger than the IC's area. At this point the temperature reduction is approximately 14%. For area ratios greater than 60, the IC's temperature reduction remains constant.

Taking a general analysis of the results, it can be observed that the lowest IC's temperature is obtained in model 1 (without vapor chamber) is 24.4 °C. This occurs when the heatsink is 90 times larger than the IC. This result repeats when the heatsink is 105 times larger than the IC. For model 2 (with vapor chamber) this result is achieved when the heatsink is only 11 times larger than the heatsink. This result shows that the use of vapor chamber is very interesting.

With the analysis of this work, it can be concluded that by using the heatsink without the aid of the vapor chamber it is advantageous to increase the area of the heatsink up to 30 times more than the area of the processor (which corresponds to heatsink with 21 fins). With the use of the vapor chamber is feasible to increase the area of the heatsink by up to 60 times more than the processor area (which corresponds to the heatsink with 38 fins).

It is also important to mention that this is a numerical analysis that has a qualitative value, so that in order to obtain a quantitative value it's necessary to create the experimental model. This is a stage of research that will be carried out in future studies.

Further analysis is also required for other heatsink models, other vapor chamber models, other air speeds (other convective coefficients), and a natural convection setting.

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