17th Brazilian Congress of Thermal Sciences and Engineering
November 25th-28th, 2018, Águas de Lindóia, SP, Brazil

ENCIT-2018-0653
STUDY OF NATURAL CONVECTION IN HEAT SINKS USING COMSOL

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Abstract. *Heat sinks are usually made of aluminum or copper and aim at maximizing the heat transfer. Heat sinks are used in a variety of devices; mainly electronics that require these devices to keep them in operating temperatures.in this paper the heat transfer by natural convection in transient and permanent regimes was studied in heat sinks with flat rectangular fins. Experimental and numerical analyzes, made in the COMSOL Multiphysics 5.2, were carried out to determine the ideal number and positioning of the sensors used to measure the temperature in the heatsinks. The choice of domains of the simulation faithfully followed what was done in the experimental tests. The main input variable of the simulation was the heat flux generated by the resistive heater. The study response, used to compare the experimental test and the simulation, was the final temperature at the tip of the fin after the state was reached.*

Keywords: *Heat sinks, Natural Convection, Experimental and Numerical Studies, COMSOL.*

1. INTRODUCTION

Fins are extended surfaces from an area where greater heat exchange is desired with the medium in which they are inserted. The use of finned surfaces increases the rate of heat transfer between a hot body and the fluid in which they are immersed through an increase in the area of contact between them. The fins are used in various equipment, whose operation results in the generation of heat, such as motors, transformers, heat exchangers and microprocessors, where heat dissipation occurs in small physical spaces.

In Figure 1, taken from the article by Leung, Probert and Shilston (1985), illustrates the positions of the heatsinks.

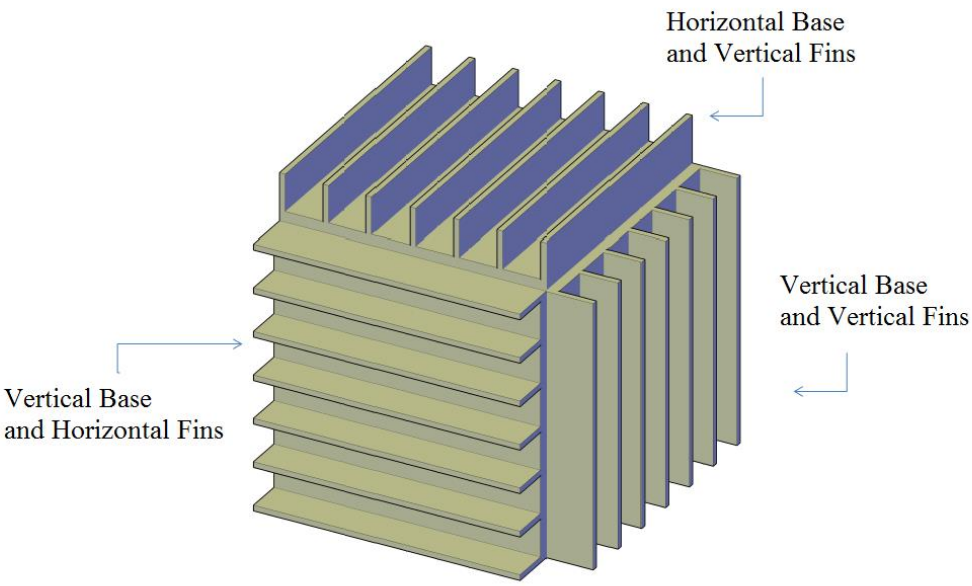


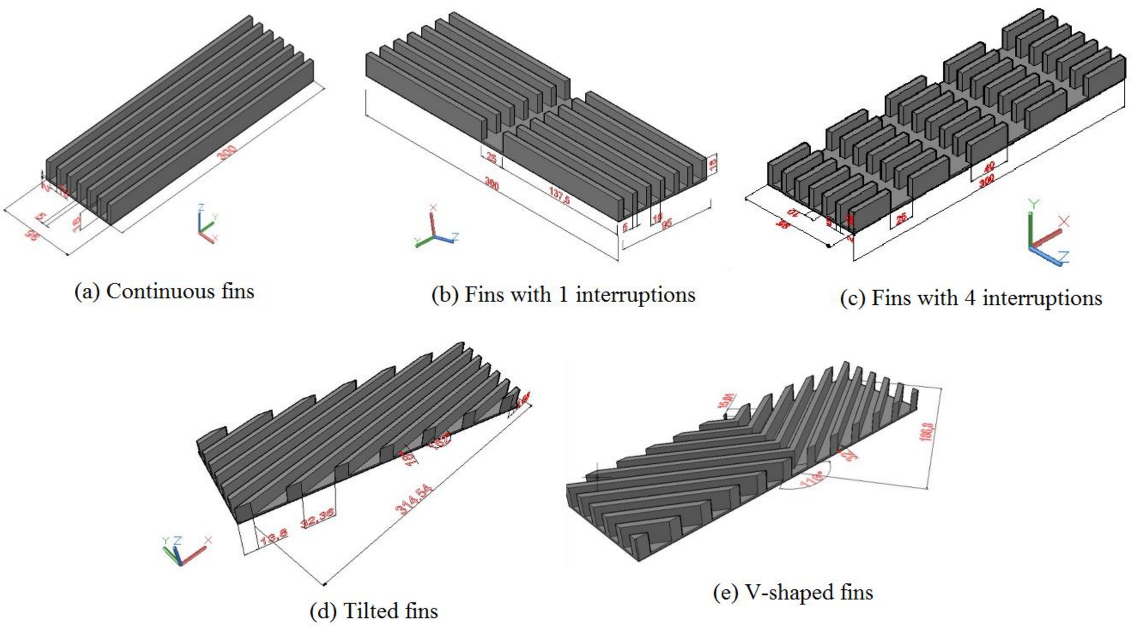
Figure 1. Relative positions of the base and the fins of the heat sink.
Source: Leung, Probert and Shilston (1985).

Numerical simulations carried out by Tari and Mehrtash (2012) changing the heat sink position to investigate the Nusselt number. The direction of gravitational acceleration were varied with the changing of the inclination angles, thus the simulations were done for different inclinations of the heat sink basis. The authors proposed correlations for the Nusselt number, including the angle from the base surface in relation to a horizontal plane, for two ranges of a modified Rayleigh Number. Combined with the proposed correlations the streamlines were presented as a result of the simulations. This helps to understand what happens in the heat sinks during the heat exchange with the environment.

Kim et al. (2013) studied the characteristics of the outflow and the heat transfer in heat sinks vertically positioned using the software FLUENT®. The correlation proposed by these authors used a wider range of Rayleigh number and was considered more accurate than some correlations previously proposed. Kim et al. (2013) concluded that the height of the fins does not have a great contribution to this optimization. Also were observed that the better space between fins depends on their length, on the difference between the temperature of the heat sink and the environment and on the fluid properties.

Heat sinks are widely used to improve the performance of LED applications and wasA studied by Shen et al. (2014). Their experimental bench tested a heat sink in eight different angles positions, varying in 45° in each one. These tests showed that the worst case was the one where the heat sink was at an angle of 270° and the angles of 225° and 315° presented better performance, especially 315°. The computational results show that the mismatch between the heat transfer area and the natural convection flow and the blockage of the convection flow are the two dominant factors that deteriorate heat transfer of the rectangular fin heat sinks

Analyzing fins in different ways Khudheyer and Hasan (2015) used different values of heat flux to perform experiments used to validate their mathematical modeling done in COMSOL 5.0. The five heat sinks were differentiated by the fact that they contained continuous fins, interrupt fins; tilted fins and V shaped fins, as Fig. 2. The authors observed that the heat sink with fins with four interruptions obtained the greatest temperature difference between its base and the environment while fins with one interruption obtained the smallest difference. The authors fixed a set of fins 300 mm long and 18 mm high and varied the spacing between them, reaching an optimal spacing of 10 mm. With another standard measure of with a height of 18 mm and a spacing of 5 mm. the authors observed that the heat transfer coefficient reached its lowest value for fins with a length of 500 mm for a fixed heat flux. Another characteristic analyzed was the thickness of the heat sink base that interfered with the coefficient, reaching its lowest value when its thickness was 9 mm, with fins 18 mm high and 5 mm spacing.



(a) Continuous fins (b) Fins with 1 interruptions (c) Fins with 4 interruptions (d) Tilted fins (e) V-shaped fins

Figure 2. Heat sinks used by Khudheyer and Hasan (2015).

Ong *et al.* (2017) studied the thermal heat spreading effects and determination of the thermal heat spreading resistance. The performance of two conventional heat sinks with flat metal base and an array of cooling fins on top are determined under forced and natural convection and with various heating power input. Their simulations show that the temperature distribution on the heat sink is not uniform and because of this the heat transfer is inefficient. The behavior of the thermal heat spreading is almost imperceptible when the heat sink is under forced convection action.

2. METHODOLOGY

The COMSOL Multiphysics 5.2 computer program was used to simulate the problem studied in this work. This problem has three distinct physical phenomena, the heat transfer in a solid medium, in a fluid medium and the fluid dynamics caused by the temperature difference in the fluid. These phenomena applied to the problem provide a high amount of unknowns and equations that must be solved simultaneously in order to obtain a result. The path followed since the start of the COMSOL Multiphysics 5.2 program to adjust the problem since its dimensioning in the space, physical involved and the type of study to be carried out (transient or permanent regime), as shown in Fig. 3.

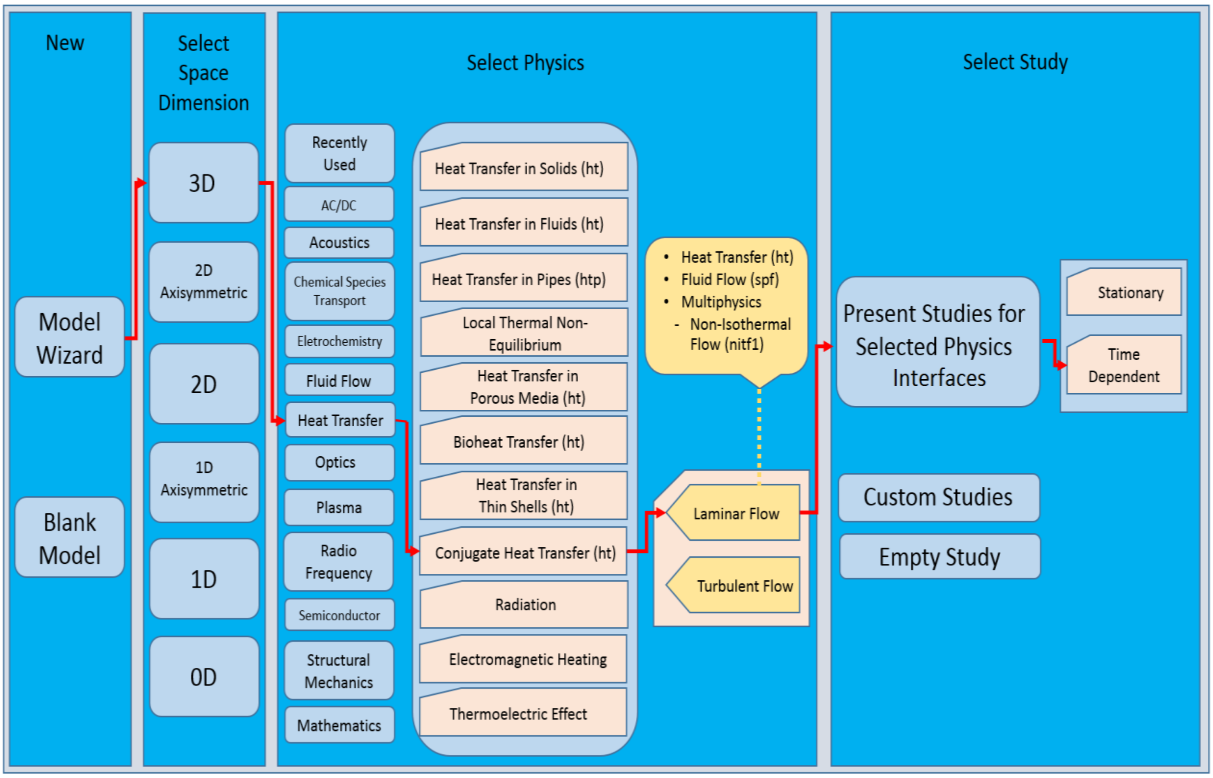


Figure 3. Organization chart of a COMSOL problem.

The simulations reproduce the experimental results that were performed on a stand consisting of a wooden stand on which is placed an MDF board, which serves as an insulator, a resistive heater and an aluminum heat sink. This workbench is exemplified in Fig. 4.

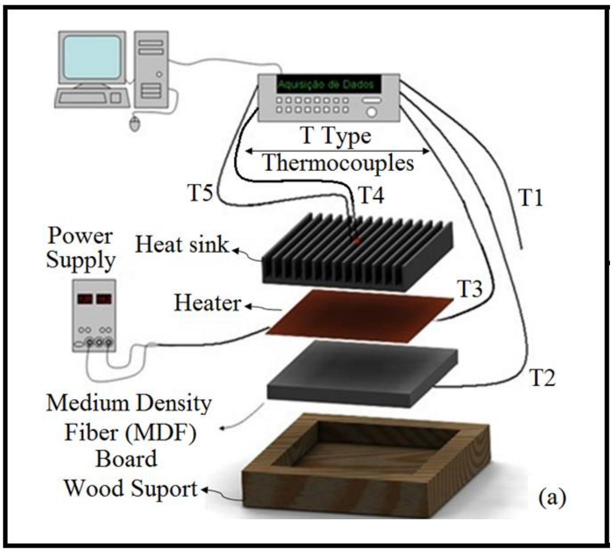


Figure 4. Arrangement of test bench.

The boundary conditions used in the computational is following in Fig. 5. These boundary conditions were defined in order to reproduce what was done in the experimental tests through the computer simulation using the program COMSOL Multiphysics 5.2.

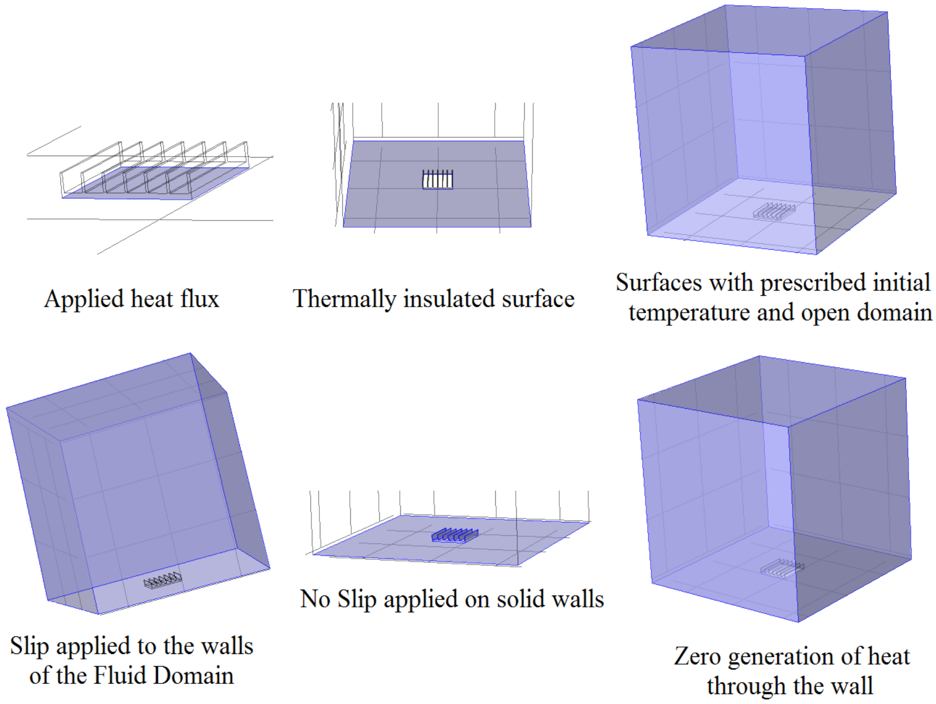


Figure 5. Boundary Conditions.

3. RESULTS

Tests were performed with welded thermocouples at the tips of the fins at different positions in order to observe at the uniformity of temperatures along the heat sink. Figure 6(a) shows the positioning of the thermocouples for the test performed with the heatsink positioned horizontally. Thus, the results obtained in these tests indicated that the heating was uniform, according to Fig. 6(b), and that the temperature gradient between these positions can be neglected. Therefore, only the central position of the heat sink is used to measure the temperatures, as shown in Fig. 6(a2).

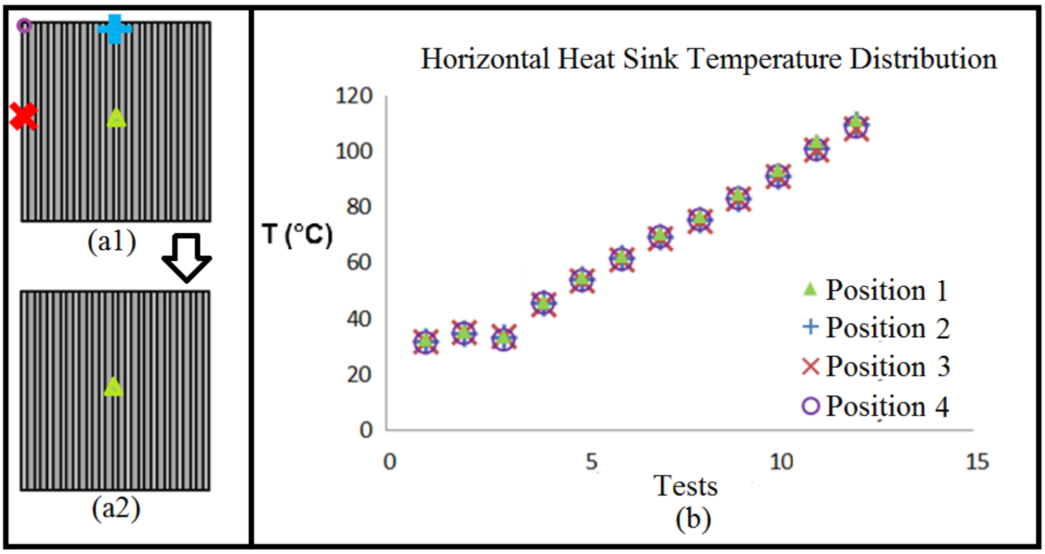


Figure 6. (a1) Thermocouples positioning for the test of uniformity of temperature; (a2) position used in the others tests; (b) temperature distribution to the test of uniformity.

The COMSOL® program was used for some images that show the temperature range on the heat sink in some of your views. In Fig. 7 it is observed that the temperature variation is small between the center and the tip, that is, the same behavior as Fig. 6 (b) shows. Thus, both studies have shown that the temperature gradient in the heat sink, as long as it is in the permanent regime, is small and can be neglected.

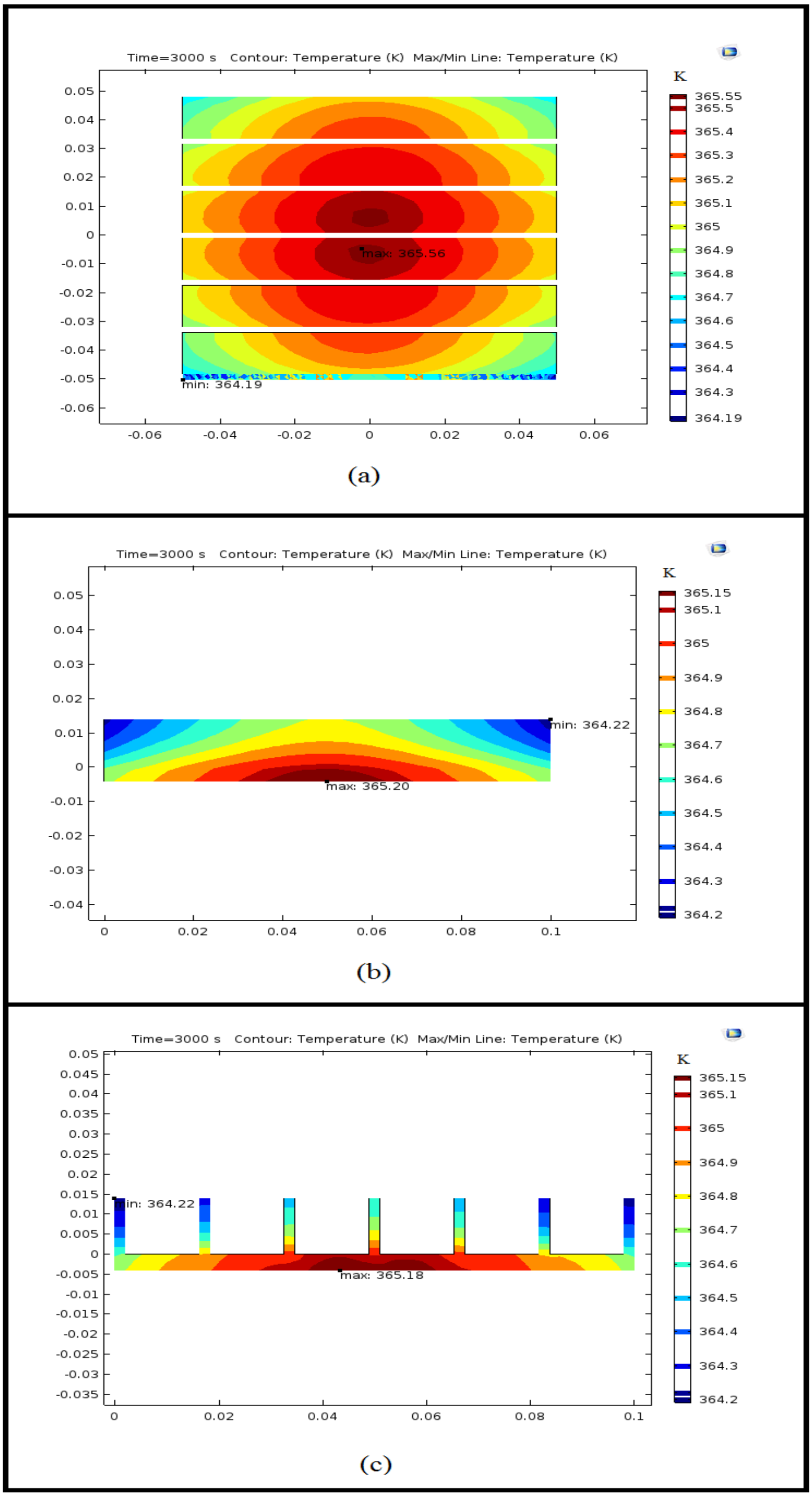


Figure 7. Isotherms obtained by COMSOL (a) from the top view of the heatsink, (b) the outermost fin of the heat sink, (c) from the front view of the heat sink.

Figure 8 shows the meshes chosen in some cases and the number of elements used is shown in Tab.1 The COMSOL® has an automatic mesh generator with options for changing the refining and mesh structure. The tetrahedron mesh was chosen for future simulations with the sloped heat sink. The user can make different meshes for each problem domain, use different refinements such as edge, edge layer refinements, and change shape, distribution, size, and scale of mesh elements.

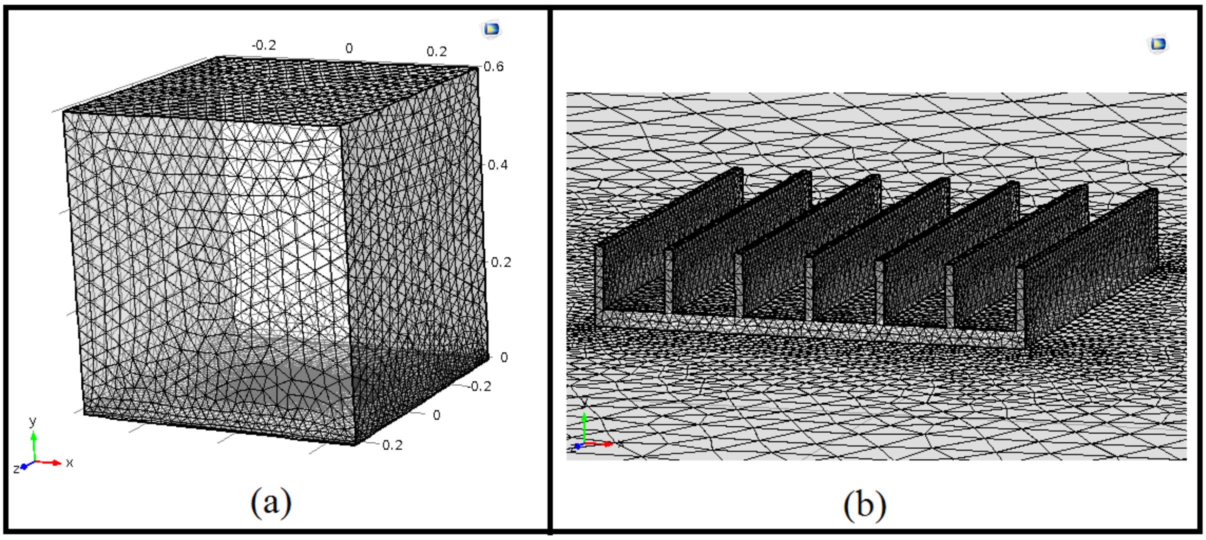


Figure 8. Meshes used in the simulations of Cases 3, 4, and 5 in (a) a complete view and (b) an enlarged view of the heat sink.

Table 1 shows the convergence tests of each mesh used in these simulations, such as the number of elements and the computational time spent, for a better understanding of the choice of meshes. All cases simulate the same experimental test, changing only the refinement of the mesh.

Table 1. Mesh test and time to reach the steady state.

Simulated Case	Total number of Tetrahedral Elements	Temperature with 40% of Simulation Performed [K]	Temperature [K]	Simulation Time
Case 1	84.402	349,31	353,29	20min 39s
Case 2	153.821	354,14	359,69	7h 34min 9s
Case 3	411.135	357,90	365,28	31h 19min 11s
Case 4	411.135	357,85	365,40	41h 27min 45s
Case 5	411.135	357,92	365,67	62h 51min 47s
Case 6	2.128.255	358,76	***	2 weeks to run 40% of simulation

The temperature shown in Tab. 1 was obtained at the same point where the T4 thermocouple was fixed in the experimental tests, as shown in Fig. 5(a2). The same value of the heat flux applied in the experimental tests was applied in simulations in order to make a comparison between the temperatures values obtained at the end of the computational tests. The temperature reached in the experimental tests was 366,97 K, which gives us a difference of approximately 1,3 K between the temperatures obtained in the simulations in Case 5.

In this part of the work, it is possible to observe how the numerical simulations approached the experimental results. Figure 9 shows the heating of the heat sink for 6000 seconds to verify both the computational simulation and the experimental tests reached the steady state. In order to reduce computational time, cases 3 and 4 had the heating time reduced to 3000 and 4000 seconds to define the lowest time to reach the temperature of the steady state in the simulations.

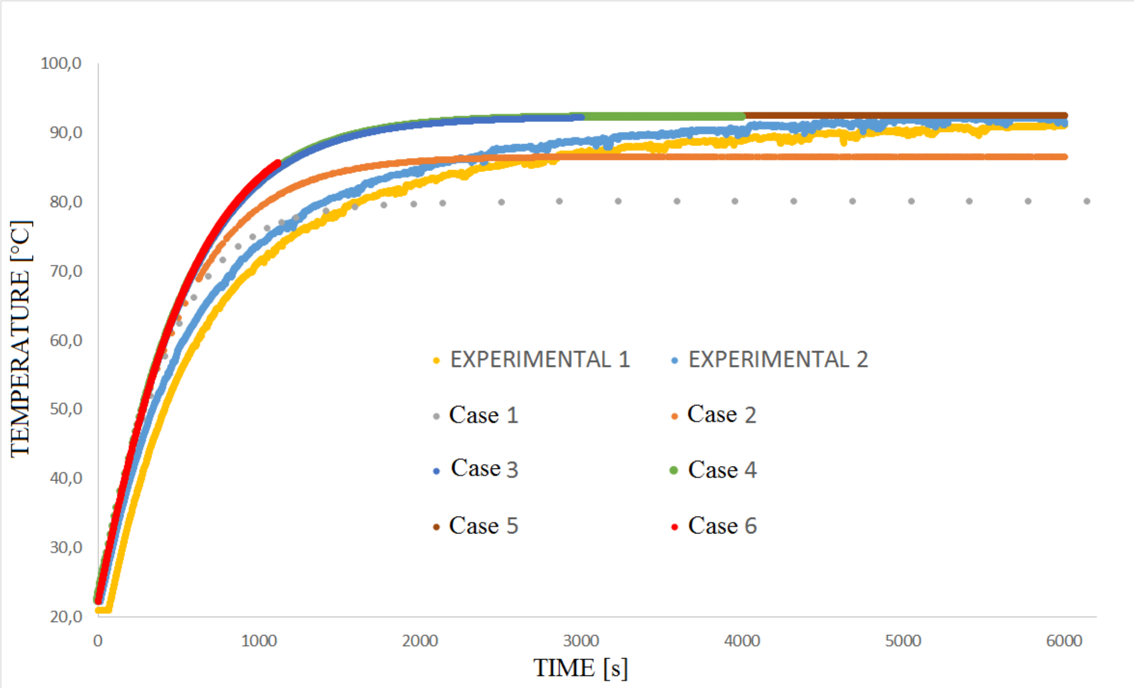


Figure 9. Temperature curves until the steady state.

Figure 10 shows the heat sinks at different times in order to determinate an ideal time for the simulation to reach the steady state without loss of data. Following the work of Kim, Do and Kim (2011), we assume that the temperature difference at the bottom of the heat sink should not be greater than 0,1°C in a period of 2 minutes.

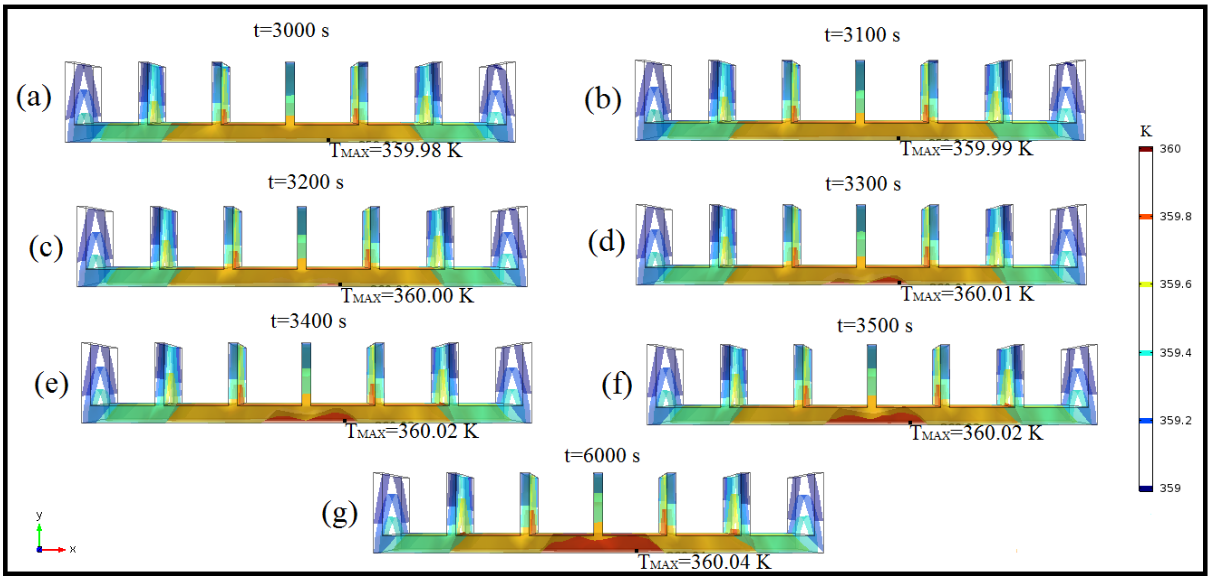


Figure 10. Temperature distribution on the heat sink in (a) 3000 seconds, (b) 3100 seconds, (c) 3200 seconds, (d) 3300 seconds, (e) 3400 seconds, (f) 3500 seconds, and (g) 6000 seconds.

Even after 50 minutes it is seen that the difference between the maximum heatsink temperatures does not exceed 0.06 ° C. Thus, it can be assumed that from the instant 3000 seconds the simulation of the heatsink heating is in steady state.

Figure 11 shows the time evolution of the temperature field in the entire domain of the simulation and an expansion of the heat sink at a different time instants. A thermal plume begins to form and to rise until it stabilizes. Note that this column of air on the heat sink is responsible for the cooling of this, since it is in constant motion due to convection. The air that is closest to the heat sink heats up, thereby decreasing its specific mass and undergoing a rise movement giving room for colder and denser air, which will warm up and thus repeat the process.

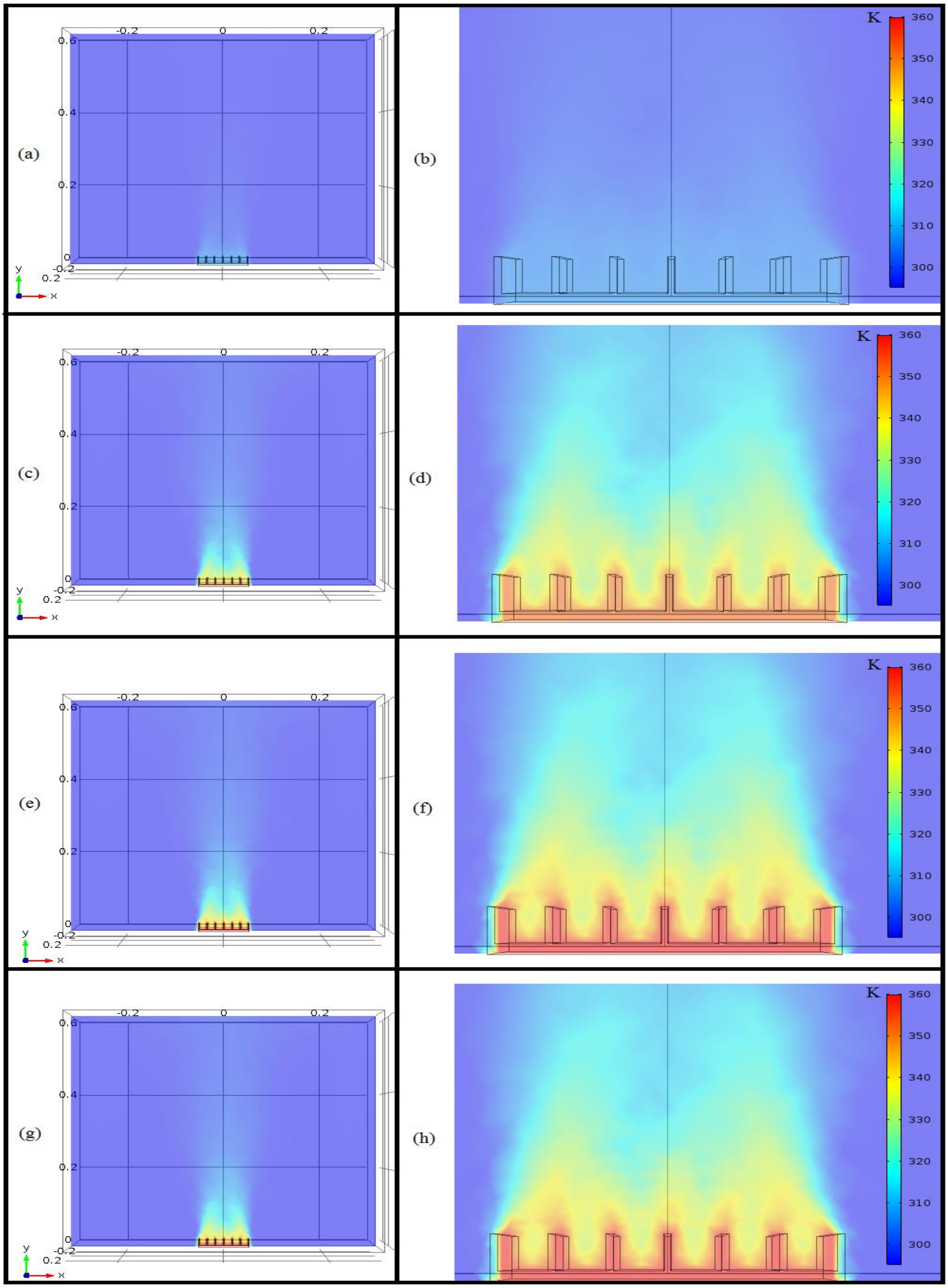


Figure 11. Time evolution of the temperature field in an XY plane in the center of the domain at the instant (a) and (b) 100 seconds, (c) and (d) 1000 seconds, € and (f) 3000 seconds, and (g) and (h) 6000 seconds.

It can be observed in Fig. 10 that the temperatures in the heat sink are practically the same in times of 3000 and 6000 seconds, and this shows that from 3000 seconds the steady state is already reached in the computational simulations, as seen in Fig. 10.

The difference between the temperature obtained to simulation and to experimental tests is showed in Tab. 2. A temperature of 366,97 K was obtained in the experimental tests. As the simulations followed the experimental tests by reproducing their boundary conditions, a small difference between them was expected.

Table 2. Comparison between simulated and experimental temperatures.

Simulated Case	Temperature [K]	ΔT Between Simulation and Experiments [K]	Percent Difference [%]
Case 1	353,29	13,68	3,73
Case 2	359,69	7,28	1,98
Case 3	365,28	1,69	0,46
Case 4	365,4	1,57	0,43
Case 5	365,67	1,3	0,35
Case 6	***	***	***

4. CONCLUSION

A time of 3000 seconds of heat of the heat sink can be used in the computational simulations, because from this point we can consider the steady state. The use of the COMSOL Multiphysics 5.2 program showed us a lot of information that can not be obtained with the experimental tests like the Fig. 11 exemplifies. Thus, the hypothesis of the uniform distribution in the heat sink, after the start of the steady state is confirmed.

A correct physical interpretation is required to model the simulations, in order to use the boundary conditions closest to the experimental tests. Thus, the results will be more faithful to the physical phenomenon. This allowed us to achieve good approximation between the simulations and the experimental tests.

The next steps of this work are to define the best type of mesh to be used, studding the tetrahedron and the hexahedral mesh. Another goal is to define whether the dimensions of the fluid domain interfere with the responses and calculate the Nusselt number directly by COMSOL Multiphysics.

5. ACKNOWLEDGEMENTS

The authors would like to thank CNPq, CAPES and FAPEMIG for their financial support.

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7. RESPONSIBILITY NOTICE

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