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EXPERIMENTAL STUDY OF FORCED CONVECTION HEAT TRANSFER IN A HEATSINK WITH RECTANGULAR FLAT FINS

Vilson Altair da Silva
Instituto Tecnológico de Aeronáutica (ITA)
vilson@ita

Sandro Metrevelle Marcondes de Lima e Silva
Ana Lúcia Fernandes de Lima e Silva
Universidade Federal de Itajubá (UNIFEI)
metrevel@unifei.edu.br
alfsilva@unifei.edu.br

Elisan dos Santos Magalhães
Instituto Tecnológico de Aeronáutica (ITA)
elisan@ita.br

Abstract. Abstract. *Nowadays the effects of the heat in some equipment are a problem to their lifetime. The heat can injure fragile parts, mainly the electronic devices and pieces fixed mechanically. This paper studies one way to control the heat loss in heatsinks. The study consists of putting a heatsink in a computer-controlled subsonic wind tunnel. Heatsinks are positioned horizontally and vertically in the wind tunnel. During the experimental tests, the wind speed was increased. The heatsink base is heated using a resistant heater supplied by a power source. In forced convection, stability was reached in a quarter of the time of the experiments in natural convection. With this study, we can compare the difference between the performance of the heatsinks in these two configurations tested, positioned vertically and horizontally. The methodology can also show how the variation of the wind velocity affects the heat transfer by forced convection in the heatsink. Initially, when positioned horizontally, that is, with the wind flow parallel to the lines of the length of the fins, heatsinks are more effective when exchanging heat by convection. With the heatsink in the vertical position, the cooling system needs more power to keep the system at the same temperature as the horizontal heatsink configuration. However, this configuration takes up more space. Thus, it is not frequently used because the miniaturization of components is a very important factor, especially in electronic equipment. Therefore, the study and understanding of forced convection become essential in this scenario since, when studying this subject, enhancements can be made to the equipment, improving its performance and design.*

Keywords: *Heatsinks, Forced Convection, Experimental Tests, Wind Tunnel*

1. INTRODUCTION

Nowadays, the increase of the computational devices boosts the expansion of all areas of knowledge, including the heat transfer. Heat transfer is very important because it can define the useful life of an equipment that is kept within the operation limits. When an equipment is operating in high temperatures some problems may occur like part take-off or thermal stress (Maschietto, 2018). The speed in which a software works can also be affected by the temperature, because of this, the maintenance of the temperature limits is very important. In the presented study, the heatsink was positioned horizontally and vertically in the wind tunnel. With this configuration, the behavior of the temperature was observed.

Some models of heatsinks have already been studied today, and Bhattacharya and Mahajan (2002) studied heatsinks with metal foam between the fins under forced convection. The authors observed that this kind of heatsink can improve the heat transfer value. But there was an excess pressure drop in the flow. Even so, the performance of these heatsinks was considered superior to other designs reported in literature (Bhattacharya; Mahajan, 2002). The material used in metal foam can affect the heat transfer behavior in these heatsinks by virtue of different thermal conductive (Mancin *et al.*, 2013), and the copper foams, Fig. 1, exhibit better results.

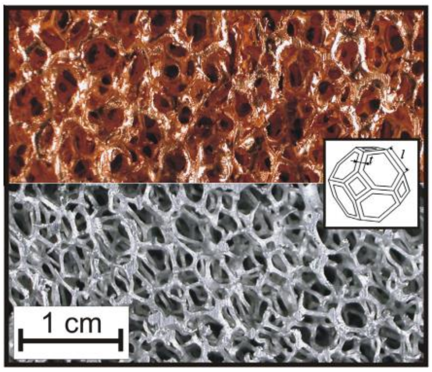

Figure 1. Aluminum and copper foam samples studied by (Mancin et al., 2013)

Another kind of heatsink was studied in (Vijayakumar *et al.*, 2016). The authors analyzed the performance of plate-ellipse and plate-circular pin fin heatsink, for different Reynolds number, fin thickness and base materials. This study showed the plate-ellipsed pin fin heatsink performance is significantly increased when compared to plate-circular pin fin heatsink. The materials used in the base plate were CCC (Carbon Carbon Composite) and copper, which had a worse performance than CCC base plate. In this work a wind tunnel of a rectangular section was used as an experimental apparatus. Another realization was the reduction of the thermal resistance when the wind velocity was increased, and simultaneously increased the pressure drop.

The use of forced convection is the most common tool to improve the heat transfer between the equipment and the environment (Lee; Kim; Kim, 2019) and this tool can help in temperature regulation (Junior; Pasquoto; Bürger, 2007). But the use of fans must be analyzed, because their power consumption could have a significant impact on the overall system and in their working costs. (Christen; Stojadinovic; Biela, 2017).

An experimental study about fins with different perforations, Fig. 2, in a wind tunnel was conducted, and the authors observed that the perforations had an influence on the thermal distribution (Ibrahim *et al.*, 2018). The heat transfer was improved by creating the higher turbulence intensity close to the orifices, thus causing an improvement in heat transfer. The shapes of the perforations cause different intensity of turbulence and different intensity of heat transfer. The best shape of the perforations is the triangular one, followed by the circular orifices, and the fin with rectangular perforations presented results like the ones of a flat plate without perforations.

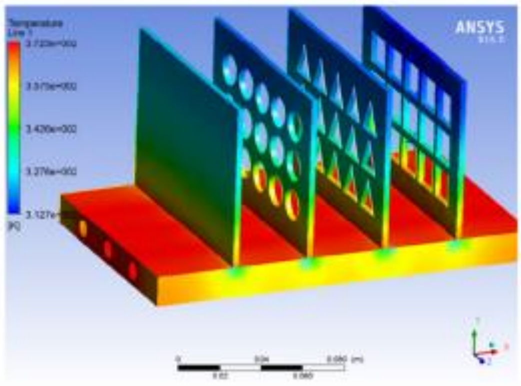

Figure 2. Temperature distribution by (IBRAHIM et al., 2018)

Also in 2018, (Huang *et al.*, 2018) analyzed different pin fin shapes, including circular, elliptical and drop-shaped and reported that these shapes didn’t appear to have a very different heat transfer performance. The experiments, which had a similar setup to the one used in this work, conducted with naphthalene sublimation, showed that performance to local heat transfer on tube surfaces was higher than on pin fins under the certain condition. The authors observed that drop-shaped pin fins exhibited lower pressure loss due to this singular geometry. Thus, they concluded that the drop-shaped pin fins presented a significant effect on the heat transfer, considering both the heat transfer improvement and the pressure drop limit.

The heat transfer by heatsinks is influenced by the change of direction of the fins, and Homod *et al.* (2019) investigated the effect of the direction of longitudinal fins on a tree-dimensional convection, heat transfering a rectangular channel. The authors used a wind tunnel that can be tilted along with the heatsink insides. Different from how it was made in this work, that the heatsink was inclined inside of the wind tunnel. The results showed that the coefficient of the heat transfer is greater when the lateral inclination did not exist, opposed to when an inclination that put the heatsink with the base vertically. The authors also observed that greater coefficient of heat transfer was found on larger longitudinal angulations.

An interesting study was made by Silva *et al.* (2021), that analyzed heatsinks with different shapes and concluded that a best heatsink was one with inverted trapezoidal fins with holes, Fig. 3. Even with the observations made by these authors, we must consider the complexity to scheme a heatsink, the space where it has to be put, because these are also important parameters to consider.

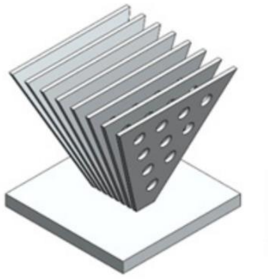

Figure 3. Best fin heatsink studied by (Silva; Sampaio; Pontes, 2021)

To maximize the thermal performance, topology optimization was used in a study about heatsinks (Lee; Lee; Kim, 2021). These authors proposed some shapes of heatsinks, but they emphasize that these shapes must be simplified for manufacturability once these heatsinks are very complex to machine. It is important to say that after these heatsinks are simplified, they are even lighter and less thermal resistive than commercial heatsinks.

An interesting study was made by (Abdullah; Jubear; Al-Bugharbee, 2022) and it studies heatsinks with foam fins of copper. The authors conducted an analysis in experimental and numerical tests, simulating in ANSYS Fluent R19.0 software. The experimental tests were carried out in a wind tunnel and covered the influence of airflow variation on the temperature difference, heat transfer coefficient and Nusselt number. The main finding points in this study are about the decrease in temperature when the airflow velocity increases. Thus, it can be observed the heat transfer coefficient is estimated to be 23,7% higher in the maximum velocity. Furthermore, the authors claim that the use of the six fins instead of one and the positioning of the heatsink, when it is parallel to the airflow, can improve the heat transfer coefficient.

In this work, a way to experimentally test a heatsink using a wind tunnel is presented. Initially these experimental results are used to observe the heatsink's behavior under the action of the forced convection. It is also possible to observe how the positioning of the heatsink influences the heat transfer by forced convection, due to the fact that the tests were carried out with the heatsink positioned vertically and horizontally in the wind tunnel.

2. METHODOLOGY

The experimental tests were conducted in an armfield wind tunnel, denominated C15 – Computer Controlled Subsonic Wind Tunnel, Fig. 4. The studied heatsink was positioned in the work section and connected to some thermocouples to acquire the temperatures in some points.

Figure 4. C15 – Computer Controlled Subsonic Wind Tunnel.

Figure 5 shows how the heat sink was positioned in the work section. The heatsink was studied with its base positioned in a horizontal and a vertical in relation to the flow direction.

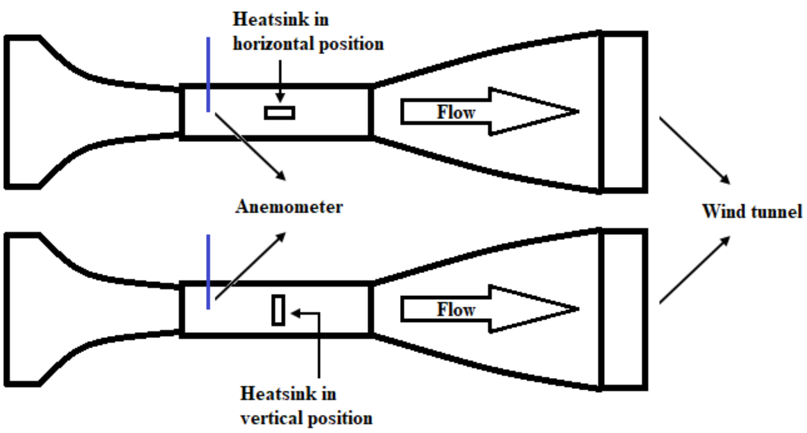

Figure 5. C15 – Experimental bench layout with the heatsink positioned horizontally and vertically.

When the heatsink was positioned horizontally, six thermocouples were fixed on it. On the tests with the heatsink in the vertical position, four thermocouples were fixed to acquire the temperatures. The positions of the thermocouples are represented in Fig. 6. In addition to those shown in Fig. 6, there are still the thermocouples that measure the temperature below the insulator (Ti), of the heater (Th), and the environment temperature before (Teb) and after (Tea) the heatsink, according to the flow. This data was used to calculate the heat conduction to the insulator and to the heatsink.

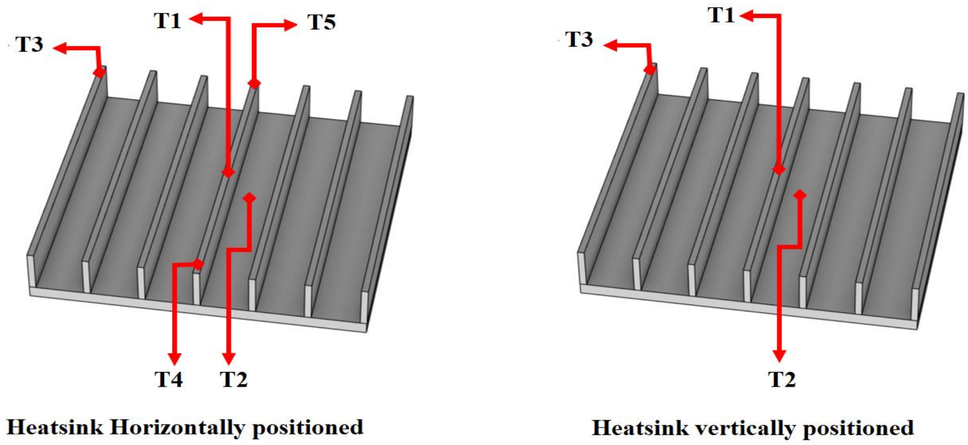

Figure 6. Position of the thermocouples under the heatsink.

The experimental test acquires the temperature of the thermocouples under the different fan power. This method results in different velocities of wind, as opposed to the tests with the heatsink positioned horizontally and vertically. In this study the heatsink was considered cloistered. This hypothesis was designed to observe the behavior of heatsinks responsible for cooling computers and electronic equipment. When used for this purpose, heatsinks are placed inside cabinets, cages, or boxes. Despite enclosing the heatsinks, these parts are responsible for protecting the electronics that make up the equipment.

The average temperature on the fins of the heatsink, and the temperature at the base of the fins were used to calculated the heat transfer coefficient by convection, *h* [W/m².K] Eq. 1, the Nusselt number Eq. 2, and the Reynolds Number Eq.3.

$$h = \frac{q}{A_{cv} \cdot \Delta T} \tag{1}$$

$$Nu_w = \frac{h \cdot w}{k_{air}} \tag{2}$$

$$\mathrm{Re}_w = \frac{V \cdot w}{\nu_{air}} \tag{3}$$

The convective heat transfer coefficient is the ratio of the power supplied to the heatsink (q [W]), by the product of its area under convection (A_{cv} [m²]) and the temperature difference between the average temperature, between the base and the top of the fin $\frac{(Ts=T1+T2}{2}$), which is considered as an average temperature of the surface of the heatsink (Ts), and the environment temperature ($\Delta T=Ts\text{-}T_\infty$ [°C]).

The Nusselt number is calculated by the product of the convective heat transfer coefficient (h [W/m²K]) and the characteristic length of the heatsink (w [m]) and divided by the conductivity of the air (k_{air} [W/mK]).

The Reynolds number is calculated by the product of the velocity flow (V [m/s]), the characteristic length of the heatsink (w [m]) and divided by the kinematic viscosity of the air (v_{air} [W/mK]).

The characteristic length chosen for this study was the width of the heatsink (w [m]). The width was chosen because it is the geometric parameter that is perpendicular to the flow, regardless of the orientation of the heatsink. The geometric parameters of the heat sink are on Tab. 1.

Table 1. Heatsink geometric parameters.

Heatsink						
n	**S [mm]**	**t [mm]**	**H [mm]**	**L [mm]**	**W [mm]**	**b [mm]**
Number of fins	Fin pitch	Fin thicknes s	Fin Height	Fin length	Base width	Base thickness
7	14,35	2,00	14,00	100,00	100,10	4,00

The experimental tests consist of collecting the temperatures required by the thermocouples for four different powers supplied to a Kapton heater. After that, the rated power of the fan varied, and the process was repeated. As the rated power of the fan was a controlled greatness, the velocity of the flow was different from the tests conducted with the heatsink oriented vertically and horizontally. The duration of the experimental tests lasts as long as necessary for the system to enter its stable state. This condition is verified when the temperature difference between the current time and a time in the past, five minutes ago, has a temperature difference less than 0,5ºC. The Figure 7 shows the temperature during a experimental test to heatsink horizontally

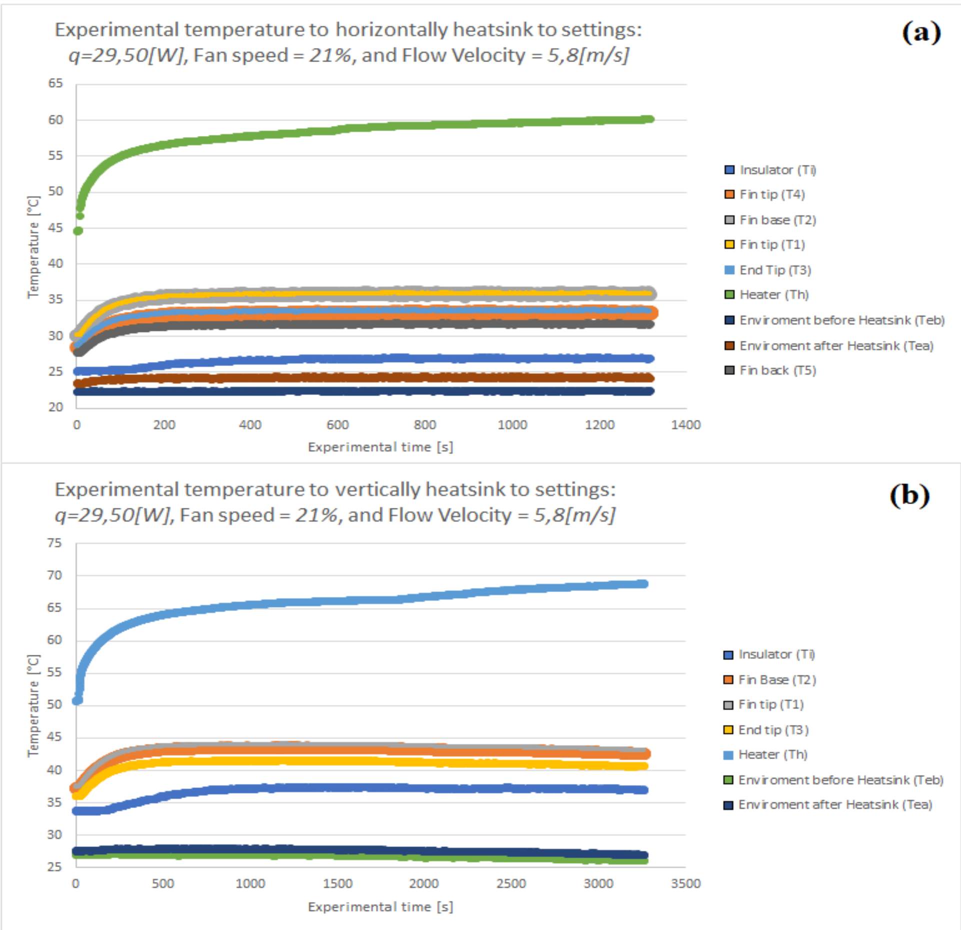

Figure 7. Experimental temperatures until the steady state.

The lines to the Fin base (T2) and the Fin tip (T4), in Fig. 7(a), were modified for better visualization; these lines were made thicker to make this possible. The line drawn for the Fin base (T2), in Fig. 7(b), was also modified to facilitate its visualization. The quoted lines were made thicker strokes because these lines were hidden behind other lines. As the lines behave similarly, the lines end up overlapping one another.

3. RESULTS

The analysis of the results uses some graphs constructed with the data collected during the experimental tests. The first is Fig. 8, and it shows the temperatures reached during the experiments for each power supplied to the heater. These temperatures are related to the flow velocities and the Reynolds number in each case.

In Figure 8 it is observed that the temperature increases as the power of the heater increases or with the decrease in the flow velocity. The flow velocity is directly related to the Reynolds number, so they demonstrate the same behavior.

It is observed that for low values of heater power, there are low temperature gradients and low flow velocity interference. This changes for higher powers supplied to the heater, as the temperature gradient is much greater as the flow velocity increases. Thus, it is observed that for low temperatures of the heated surface, the flow velocity does not interfere much. In this case, the use of natural convection for cooling the system can be studied.

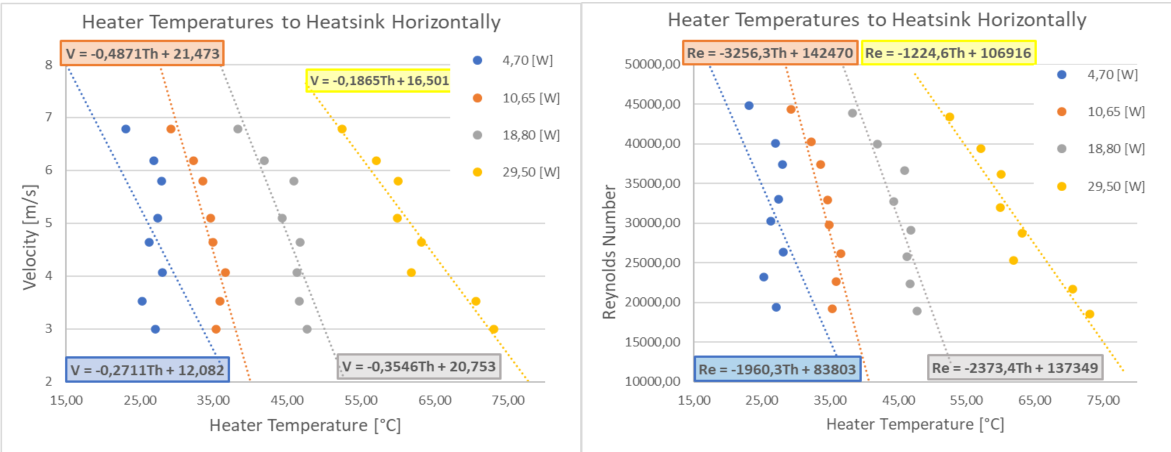

Figure 8. Experimental temperatures to the heater, the flow velocities, and the Reynolds number in the heatsink horizontally positioned.

The same behavior can be observed to the heatsinks vertically positioned, as shown in Fig. 9. An interesting fact to note is that, unlike the case with the horizontal heatsink, there is not much variation in the temperature gradient even with a high value of power supplied to the heater. This indicates that forced convection is not as effective in this configuration. The dashed lines showed that there are distinct groups of data that are divided by power supplied to the heater. Another thing that can be noticed is that the dotted line seems to get steeper when the power supplied to the heater is higher. This highlights the fact that forced convection has a greater influence at high temperatures, causing temperatures to be lower when using a higher velocity flow. Where more vertical dashed lines are observed the flux velocity variation has a lesser influence on the heatsink temperature.

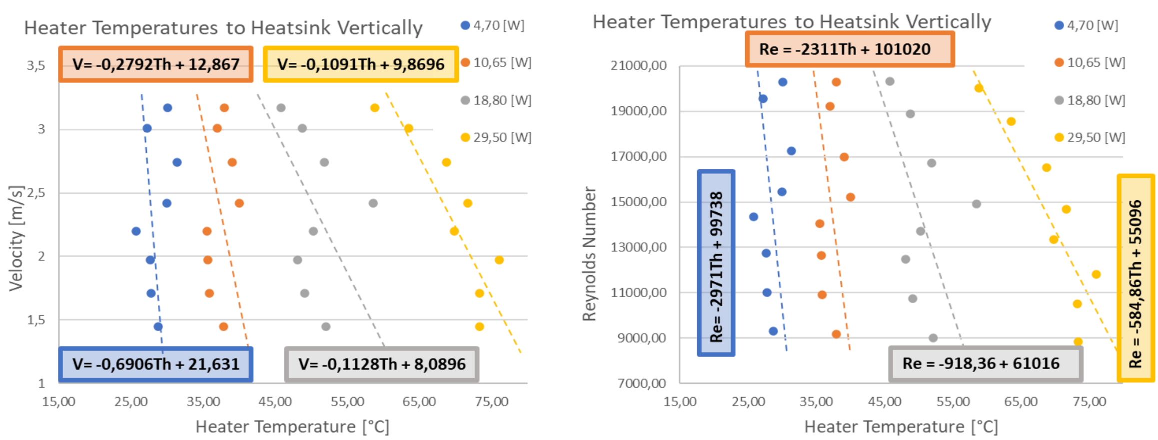

Figure 9. Experimental temperatures to the heater, the flow velocities, and the Reynolds number in the heatsink vertically positioned.

The differences between the flow velocities are best visualized in Fig. 10. These data were measurements taken by an anemometer during the experiments and an average of the velocities was used for each case. This figure shows a graph relating the Reynolds number and the Nusselt number. These admensionals are parameters to study the behavior of a flow and the convection heat transfer. It is also related to the power supplied to the heater and the flow velocity. In most cases, as the Reynolds number increases, the Nusselt number also increases. Therefore, it is also true to state that both admensionals grow with the increase in the flow velocity.

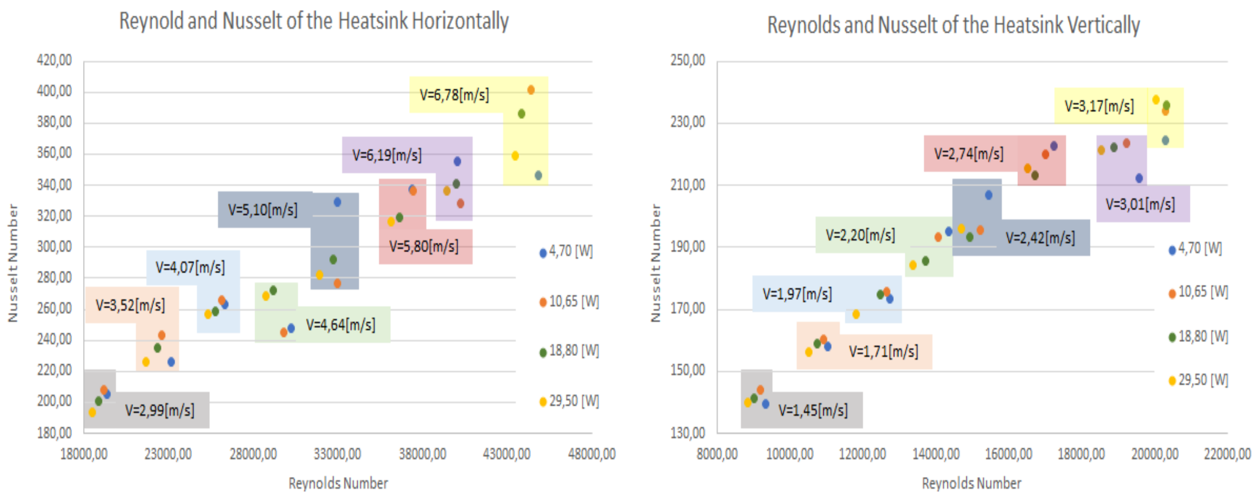

Figure 10. Comparison between experiments with the heatsink horizontally and vertically.

It is also possible to notice that even keeping the fan power constant in each group of speeds, for the experiments with the heatsink horizontal and vertically, the flow velocities varied in each case. This variation is because the positioning of the heatsink causes a different blockage in the flow. When the heatsink is horizontally positioned, the cross-sectional area passing through the heatsink is about 60% greater than in the vertical position.

The convective heat transfer coefficient is observed in Fig. 11. The results for the horizontal heatsink show that for the same power supplied to the heater, higher values of h have a lower convection temperature. This observation also can be seen in the vertical heatsink results, but the difference is lower than observed in horizontal cases.

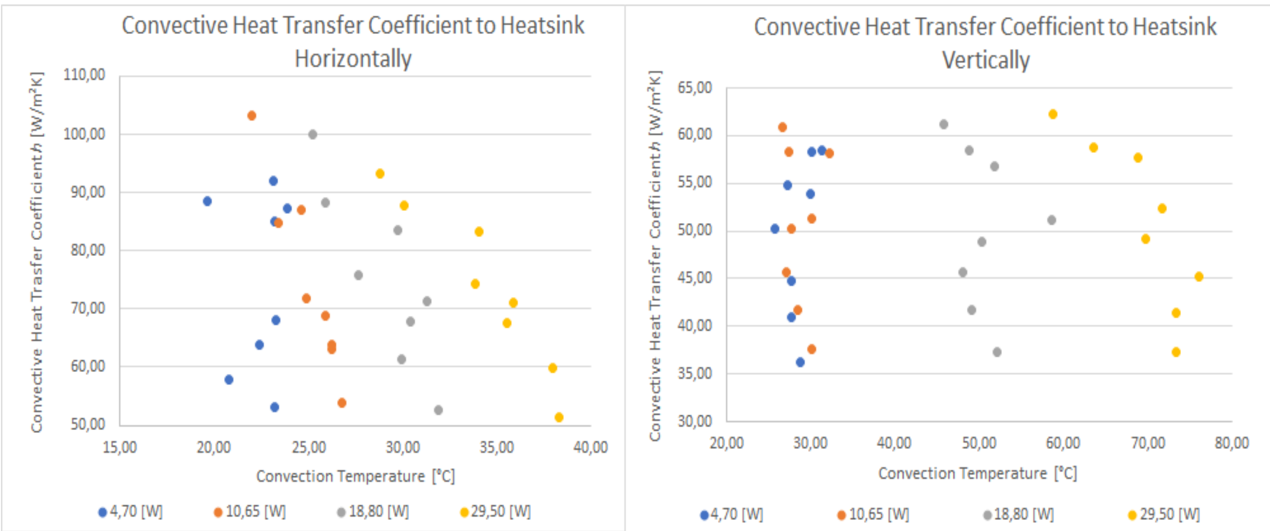

Figure 11. Convective heat transfer coefficient to heatsink horizontally and vertically positioned.

4. CONCLUSION

In this work it was possible to observe that forced convection will not always be advantageous. For example, when the heatsink interferes a lot with the flow, forced convection is less effective. In this case, natural convection can provide approximate results without generating energy expenditure. So, when a cooling system is placed in a closed place, where the heatsink is enclosed, it is very important to study the best placement of the heatsink and the cooler. This must be thought of so that there is maximum benefit from forced heat convection.

As suggestions for future work, some topics are described below:

- A study using smaller heatsinks. This study may provide a better view of the flow, as well as less interference with it. The observation of the flow can provide valuable information for the design of new profiles of heatsinks, as well as a study of the flow velocity generated by the cooler. Such a study can provide data to trace an optimal work curve for the coolers, avoiding oversizing and helping to save system energy.
- A study using simulations in a CFD program. Nowadays, CFD is a widely used tool to study fluid mechanics and heat transfer. A study of this work in a CFD program will unite these two parts of mechanics and will bring computational challenges to researchers, as it is a complex physics.
- New experiments in a wind tunnel, with different speeds and more data acquisition. The most important data to acquire in this new test run will be the flow pressure. This is because with the pressure data, a more detailed study of the flow can be done. And with more data about the flow, future simulations will be closer to reality.
- A study using flow velocity as a parameter of measuring. In this work a parameter that conducted the experiments was a percentage of the fan power. But this parameter did not guarantee an equal flow speed in the two cases studied. The velocities reached by the flow during the tests carried out with the heatsink horizontally positioned were always higher than in the tests carried out with the heatsink vertically positioned. This made it difficult to compare them, which had to be done mainly considering a temperature reference.

5. ACKNOWLEDGEMENTS

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