

STATISTICAL ANALYSIS USING MINITAB IN THE STUDY OF NATURAL CONVECTION IN HEATSINKS

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Abstract. *Heatsinks are capable of improving the operating temperature of a wide range of equipment. With the increasing miniaturization of electronic equipment, a greater efficiency in heatsinks is necessary. In this study, the behavior of different geometric parameters in rectangular finned heatsinks was analyzed. Experiments were made to obtain the temperature distribution in the heatsink. Experimental and theoretical analyses were performed to obtain the average heat transfer coefficient \bar{h} , as well as other parameter like Nusselt number. Altogether 16 heatsinks were tested, 8 with 100 mm x 100 mm, and 8 with 50 mm x 50 mm base area. These heatsinks were tested in the horizontal and vertical positions with temperatures ranging between 20°C and 100°C. Analyses were performed with experimental data involving Nusselt number, heat transfer coefficient \bar{h} , the dimensions of the base, the geometric parameters, (height, thickness, space between fins), and positions of heatsinks. Empirical correlations extracted from literature were used to validate the results obtained in this study. Finally, a statistical study was conducted using Minitab software to analyze the influence of the geometrical parameters in the Nusselt number. An analysis of the uncertainties was also carried out. A classification of all heatsinks based on the relation of temperature and supplied power was accomplished. In addition, a new empirical correlation, using Minitab, with experimental data of the present study is proposed.*

Keywords: *Heatsinks, Empirical Correlation, Minitab, Statistical Analysis, Uncertainties Analysis*

1. INTRODUCTION

The application of heatsinks is present in all areas of engineering because they are essential in mechanical and electrical devices, currently widely used in the field of microelectronics. Heatsinks are devices capable of improving the heat transfer rate in equipment, aiming to keep the operating temperature as stable as possible, thus promoting lifespan. Heatsinks consist of fins, which are surfaces where the area is extended, thereby promoting increased contact area between the device surface and the fluid present in the environment, allowing a greater heat transfer rate between the equipment and environment. Some applications, where the use of fins is essential and is part of our daily life can be cited, such as, car radiators, power supply transformers and microprocessors present on mobile devices and computers. Several authors have studied heatsinks and in this work geometric characteristics (height, space and thickness of the fins, heatsink location (horizontal and vertical), different base dimensions were considered. Among the main features of heatsink analysis, the determination of the average heat transfer coefficient by convection \bar{h} which is a function of fluid properties, the surface geometry and flow conditions may be cited. Another feature was the influence of the geometrical dimensions and the position of the base on the Nusselt number. The Nusselt number is a parameter often used to determine the heat transfer coefficient \bar{h} , and is defined as the ratio between the heat transfer of a fluid by convection and by conduction in a given system. In Leung et al. (1985) an experimental investigation of the steady-state rates of heat transfer from an array of vertical rectangular fins of 3 mm thickness and 250 mm length, protruding 60 mm perpendicularly upwards from a 250 mm x 190 mm horizontal rectangular base was reported. The orientation with vertical fins protruding upwards from the horizontal base, was the preferred option because of the relatively high rates of heat transfer that could be achieved. With the progress of technology and microelectronics involved in computers and electronic equipment, Harahap and Rudianto (2005) called attention to the study of miniaturized heatsinks positioned horizontally. Heatsinks were used with dimensions ranging from 49 x 49 mm to 25 x 25 mm. Through adaptations of correlations proposed by Harahap and Setio (2001), using Nusselt number as a dimensionless parameter of comparison, good approximations were reached in the comparisons between experimental and calculated results. Two correlations were proposed, one taking into account the space between fins as the characteristic length and a second correlation involving half the length of the heatsink fin. Harahap and Lesmana (2006) conducted a study in the same line of development as Harahap and Rudianto (2005). Under natural convection conditions, the authors reproduced tests with the same dimension heatsinks positioned vertically. Yazicioglu and Yüncü (2007) conducted tests with 30 different configurations of heatsinks, with lengths of fins ranging from 250 to 340 mm, and thickness of 3 mm. The height ranged from 5 to 25 mm and the spaces between fins from 5.75 to 85.5 mm. Experiments showed that the heat transfer rate by convection is dependent on the geometric parameters of the heatsinks and on the temperature difference between the heatsink base and the room. A correlation for optimum spaces between fins was proposed and the best value was

found between 10.4 and 11.9 mm. Kim et al. (2013) performed numerical and experimental studies involving heatsinks in natural convection. Many tests were performed, in which variations were made in some geometric parameters; also a new correlation for Nusselt number was obtained. Silva (2015) studied the behavior of 12 6063-T5 aluminum rectangular finned heatsinks, which were positioned vertically and also horizontally. The influence of geometrical parameters such as height, space between fins, thickness and number of fins under the influence of natural convection was studied. Two correlations based on dimensionless parameters as Nusselt and Rayleigh numbers were proposed. Several analyses of the behavior of coefficient \bar{h} were performed and the authors concluded that heatsinks arranged vertically have a higher value of \bar{h} compared to those arranged horizontally.

In this work, experimental studies and statistical analysis using Minitab program were performed in order to observe the influence of all the parameters aforementioned in the Nusselt number. A new empirical correlation for the Nusselt number was obtained using Minitab. Additionally, an uncertainty analysis was performed based on the theory of propagation of uncertainty of independent variables. These analyzes made it possible to better compare and to validate the results obtained.

2. EXPERIMENTAL ASSEMBLY AND MATERIALS

2.1 Material and manufacture of heatsinks

The heatsinks used in the experiments were made of due to their essential properties especially those in the heat transfer process, such as high thermal conductivity, low density and corrosion resistance. 6063 T5 aluminum also presents affinity with the welding process by capacitive discharge, which was used to attach the thermocouple on the surface of the heatsinks. The heatsinks were milled to ensure flat and rectangular fins. 16 heatsinks were machined. 8 with base dimensions of 100 mm x 100 mm and 8 more heatsinks with base dimensions of 50 mm x 50 mm. An analysis of the geometric factors was performed using different combinations of fin height H , fin thickness t , fin spacing S , the thickness of the base b and the number of fins n . These factors are shown in Fig. 1.

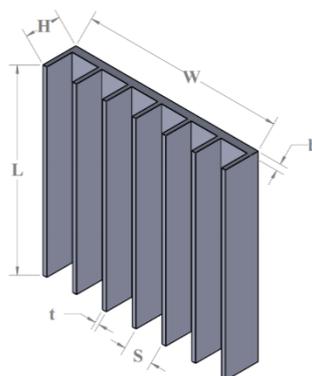


Figure 1. Geometrical parameters of the heatsinks.

The heatsinks are geometrically similar, differing only by the size of the base and consequently the number of fins. The dimensions of all heatsinks are in Tab. 1.

Table 1. Dimensions of the heatsinks.

	S [mm]	t [mm]	H [mm]	L [mm]	W [mm]		S [mm]	t [mm]	H [mm]	L [mm]	W [mm]
Heatsink	Fin step	Thickness fin	Fin height	Lenght of base	Width of base	Heatsink	Fin step	Thickness fin	Fin height	Lenght of base	Width of base
G1	5.55	2.00	7.00	100.00	100.15	P1	5.55	2.00	7.00	50.00	47.30
G2	5.55	2.00	14.00	100.00	100.15	P2	5.55	2.00	14.00	50.00	47.30
G3	5.55	2.00	20.00	100.00	100,15	P3	5.55	2.00	21.00	50.00	47.30
G4	14.35	2.00	7.00	100.00	100.10	P4	14.35	2.00	7.00	50.00	51.05
G5	14.35	2.00	14.00	100.00	100.10	P5	14.35	2.00	14.00	50.00	51.05
G6	14.35	2.00	20.00	100.00	100.10	P6	14.35	2.00	21.00	50.00	51.05
G7	12.00	4.00	7.00	100.00	100.00	P7	12.00	4.00	7.00	50.00	52.00
G8	12.00	4.00	14.00	100.00	99.85	P8	12.00	4.00	14.00	50.00	52.00

2.2 Experimental assembly

The experimental apparatus shown in Figure 2a consists of a MDF (Medium Density Fiberboard) on which the resistive heater and the aluminum heatsink are placed (Fig. 2b). This assembly reduces heat loss through the bottom surface of the heater, but does not provide restrictions to the air flow around the fins. The sidewalls of the heatsink base were insulated with glass wool and MDF was placed beneath the heater in order to direct all the heat flux to the heatsink. Two thermocouples T4 and T5 were welded by the capacitive discharge process on the aluminum heatsink, illustrated in Figure 2a. T4 was placed in the middle of the heatsink on the tip of the fin and T5 was placed in the middle of the base. Capacitive discharge was used to reduce the thermal resistance between the plate and the thermocouples. Three other thermocouples were used in the assembly. Thermocouple T2 was placed on the bottom surface of the MDF insulation; the welded joint of thermocouple T3 was inserted in the middle of the resistive heater. T3 and T2 were used to check the heat lost by conduction in the MDF; and thermocouple T1 was used to measure room temperature. The thermocouples used in this study are of type T 30 AWG except those inside the heaters which are also of type T; however series 40AWG which have a smaller gauge.

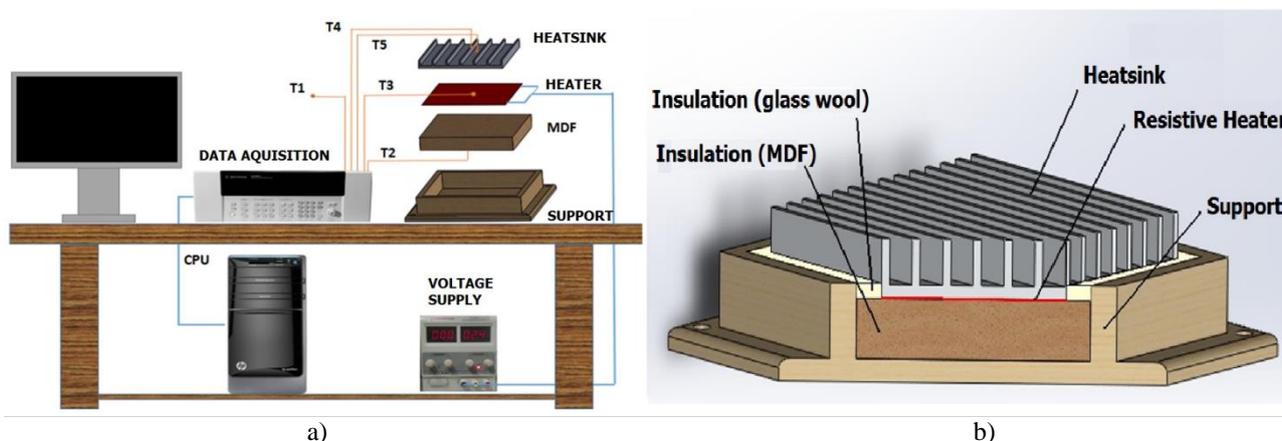


Figure 2. a) Arrangement of experimental bench and b) Sectional view of the heat sink assembly.

The heatsinks were tested in both horizontal and vertical positions. Such arrangements can be best seen in Figs. 3a and 3b. To avoid having a thin layer of air between the sample and the heater, the heatsink is fixed to the heater by means of staples which apply a certain pressure on the assembly, thereby reducing the air between the heater and the heatsink.

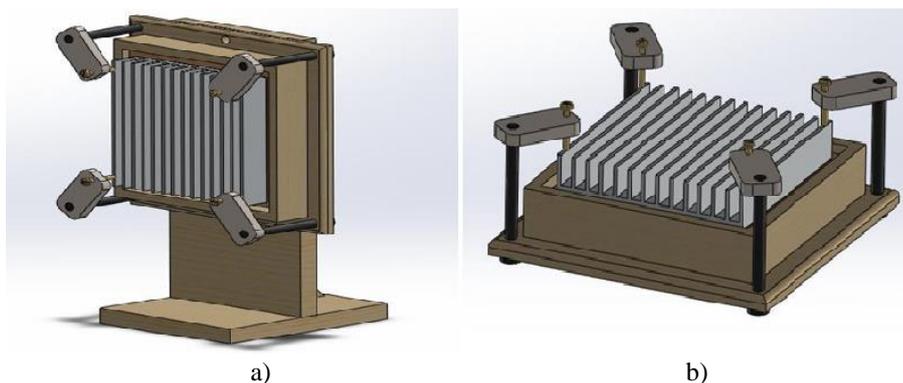


Figure 3. a) Vertical and b) Horizontal settings.

The experimental procedure was performed by heating the heatsinks in a temperature range between 20°C to 100°C until the steady state was reached. Throughout the experiment the temperatures of T1 to T5 were measured at 5-second intervals in a total of approximately one hour and thirty minute. But if after this the steady state was still not reached, the temperature was checked every 10 minutes, until the steady state was reached and then the data were collected. 4 data sequences with approximately 150 points were collected in addition to the transient data so that there was a better repeatability to ensure the steady state. Only the last 50 points, after steady state, were used to obtain the average of the temperatures involved in the analysis and hence the value of \bar{h} . The power used in the assay was obtained from the voltage and current supplied to the heater. During the test, room temperature was controlled by an air conditioner.

2.3 Capacitive welding device

Incorrect attachment of thermocouples to the material to be measured generates high error rates in reading. The thermal contact resistance is caused by materials that may be added during the attachment process. In addition these materials cannot withstand the temperatures that the test body will be submitted and will eventually break through, affecting the measurement. Other problems are generated because of air movement where the local the thermocouples are attached. Figure 4a shows the equipment used in this study for the thermocouple attachment.

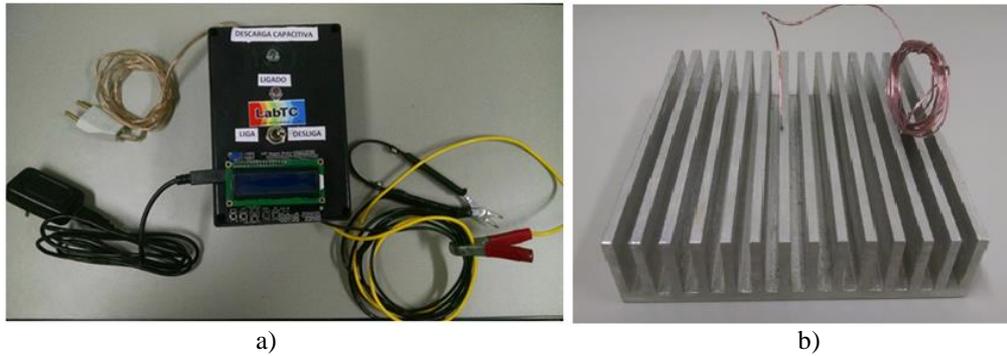


Figure 4. a) Micro controlled capacitive discharge welding device; b) Heatsink with thermocouple welded on.

3. THEORETICAL DEVELOPMENT

3.1 Calculation of average coefficient of heat transfer by convection

The heat transfer by natural convection occurs whenever there is a temperature difference between a body and a fluid medium. Due to the temperature difference, there is a heat exchange between the fluid and the body, causing a change in specific weight of the fluid in the area near the surface. The difference in density creates a downward flow of the heavier fluid and an upward flow of the lighter one. The convective heat transfer that occurs due to the difference between the specific masses of the fluid is called natural convection. The convection with movement of fluid aided by mechanical means receives the name of forced convection. To obtain coefficients \bar{h} theoretically, the authors used the empirical correlations proposed by Harahap and Rudianto (2005) for horizontally heatsinks and Harahap and Lesmana (2006) for vertically positioned heatsinks.

3.2 Empirical correlation of Harahap and Rudianto (2005)

The correlation suggested by these authors use Nusselt number in relation to the dimension l considering $l = L/2$. Experimental data were used and Nusselt number is calculated from Eq. (1)

$$Nu_{H\&R} = 0.203 \left[Ra \left(\frac{nS}{H} \right) \right]^{0.393} \left(\frac{S}{l} \right)^{0.470} \left(\frac{H}{l} \right)^{0.970} \left(\frac{L}{W} \right)^{0.620} \quad (1)$$

where n is the number of fins in the heatsink, S the space between fins and W the width of the heatsink. The average coefficient of heat transfer by natural convection is given by Eq. (2)

$$\bar{h}_{H\&R} = \frac{Nu_{H\&R} k_{ar}}{l} \quad (2)$$

where k_{ar} is the thermal conductivity. The correlation obtained by Harahap and Rudianto (2005) is suitable for a range of values between $3 \times 10^3 \leq Ra_l \cdot n(S/L) \leq 3 \times 10^5$. Using this correlation for values outside the range indicated suggests errors of values of \bar{h} obtained.

3.3 Empirical correlation of Harahap and Lesmana (2006)

The correlation proposed by these authors use Nusselt number in relation to the dimension L and Nusselt number is calculated from Eq. (3).

$$Nu_{H\&L} = 3.350 \cdot (Ra)^{0.153} \left(\frac{L}{W} \right)^{0.121} \left(\frac{S}{H} \right)^{0.605} \quad (3)$$

This correlation given by Harahap and Lesmana (2006) is suitable for values between $2 \times 10^5 \leq Ra_L \leq 5 \times 10^5$. In this case, the average coefficient of heat transfer by natural convection is given by Eq. (4):

$$\bar{h}_{H\&L} = \frac{Nu_{H\&L} \cdot k_{ar}}{L} \quad (4)$$

3.4 Calculation of heat transfer through the insulation

The heat lost through the insulation used in the assembly can be calculated by Fourier's law, given by Eq. (5):

$$q_{isol} = k_{isol} \cdot A_{isol} \cdot \frac{\Delta T_{isol}}{L} = k_{isol} \cdot A_{isol} \cdot \frac{(T_3 - T_2)}{Z} \quad (5)$$

where k_{isol} is the thermal conductivity of the insulation, A_{isol} the insulation surface area, ΔT_{isol} the temperature difference between the upper surface (T3) and lower surface (T2) of the insulation and Z the thickness of the MDF board. The thermal conductivity of 0.14 W/mK for the MDF board was obtained from Lienhard IV and Lienhard V (2006).

3.5 Calculation of heat transfer lost by radiation

The heat rate lost by radiation by the sink can be calculated using the Stefan-Boltzmann's law, given by Eq. (6):

$$q_{rad} = \varepsilon \cdot \sigma \cdot A_{ct} \cdot (T_S^4 - T_\infty^4) \quad (6)$$

where ε is the thermal emissivity of the 6063 T5 aluminum, A_{ct} the total area of the heatsink where the radiation occurs, σ the Stefan-Boltzmann constant, T_S the average temperature between the base and the tip of the fin and T_∞ the environment temperature. The value of the thermal emissivity of 6063 T5 aluminum was 0.23, obtained from Silva (2015).

3.6 Obtaining experimental \bar{h}

To obtain the experimental values of \bar{h} , Newton's cooling law was used, given by Eq. (7):

$$\bar{h} = \frac{q_{pl}}{A_{ct}(T_S - T_\infty)} \quad (7)$$

where q_{pl} is the difference between the power provided by the heater and the rate of the heat lost by conduction on the insulator and the rate of heat radiation lost by the heatsink, given by Eq. (8).

$$q_{pl} = P - q_{isol} - q_{rad} \quad (8)$$

where q_{isol} is obtained from Eq.(5) and q_{rad} from Eq.(6). To consider only the power of the heater, the power dissipated by the wire that connects the heater to the power supply should not be considered, so the calculation of the power P is done by Eq. (9):

$$P = \frac{(V - R_{fio} \cdot I)^2}{R_{aq}} \quad (9)$$

Where V is the power source voltage, I the current power supply, R_{fio} the electrical resistance of the wire connected to the heater and R_{aq} the electrical resistance of the heater.

4. RESULTS

This section presents the results of the comparisons done in some heatsinks tested. A classification between the heatsinks was performed correlating the temperature differences achieved by the power supplied to the heater resistance. A new empirical correlation was also proposed for the Nusselt number based on a statistical analysis involving the geometric parameters of similar heatsinks. Furthermore, a study of the uncertainties involved was accomplished in the determination of the Nusselt number.

4.1 Classification between heatsinks

A classification of the heatsinks was performed based on the relation between the difference of convection and environmental temperature with the power supplied by the resistive heater to the heatsink. For a given power supplied, the heatsink which has the lowest temperature reached, can be considered to be the best heatsink for this analysis. The results of this classification can be seen in Tab. 2.

Table 2. Ranking of heatsinks.

Classification	Horizontal				Vertical			
	Larger	°C/W	Smaller	°C/W	Larger	°C/W	Smaller	°C/W
1°	G3	2.63	P3	7.11	G6	2.56	P6	6.61
2°	G6	2.99	P6	7.64	G3	2.57	P3	6.64
3°	G8	3.03	P2	7.98	G8	2.66	P2	7.89

4.2 Empirical correlation, statistical and uncertainty analyses

The statistical computer program Minitab was used as a tool to propose a new correlation. This program has as one of its applications, the search for correlations for various types of regressions. All the data obtained in the experiments for all heatsinks whose results have been shown previously were used. Different from Silva (2015), in this study, a single correlation was developed for all types of heatsinks, including the position in which they were tested. The following correlation given by Eq. (10) used the parameters Ra , H/S and L/S for a non-linear regression.

$$Nu_{Minitab} = A \cdot Ra^B \cdot \left(\frac{H}{S}\right)^C \cdot \left(\frac{L}{S}\right)^D \quad (10)$$

where the terms A , B , C and D are the regression coefficients found in the process performed by Minitab program to achieve the best fit. After inserting Eq. (10) the program supplies the values of terms A , B , C and D . Thus, by replacing the values provided by Minitab, a correlation was obtained represented in Eq. (11).

$$Nu_{Minitab} = 0.375 \cdot Ra^{0.377} \cdot \left(\frac{H}{S}\right)^{-0.044} \cdot \left(\frac{L}{S}\right)^{-0.542} \quad (11)$$

With the new correlation, a comparison was performed between the experimental data and correlations from literature. The curve related to the new correlation proposed by Eq. (11) presented good results when compared Nusselt number with other empirical correlations used in this work. All the differences were lower than 25% as shown in Fig. 5.

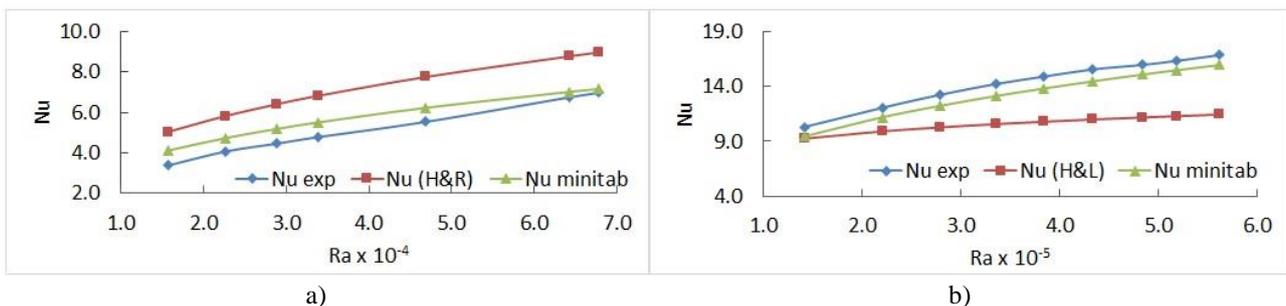


Figure 5. Results obtained with the new empirical correlation a) P3 horizontally and b) P3 vertically.

Altogether 108 different experimental settings were used. Nusselt number was analyzed as response variable and the combinations were made for three different values of fin height (7 mm, 14 mm and 20 mm). 3 values were used for spaces between the fins (5.55 mm, 12 mm and 14.35 mm). Length L ranging between 50 and 100 mm was another geometric feature also used. In addition to these variations, the temperature of the base which was evaluated between low, medium and high was also used. Another parameter used was the position which alternated between horizontal and vertical. DOE (Design of Experiments) tools were used for data analysis. This tool is used in cases where a response is required and it is dependent on one or more variables. An analysis was made concerning the residuals of the data entered and then a histogram was generated. A figure with the residuals is used to analyze the quality of the fit in the statistical analysis. A large amount of residuals means a high incidence of this value in the difference between the actual values and the statistically adjusted values. Figure 6a shows the histogram obtained with the adjusted data. It may be noted

that there is a large amount of residuals equal to zero for Nusselt number, that is, the difference between the actual and adjusted values is close to zero in the center of the graph. In this region, a high incidence of that small difference is seen. It may also be noted that the data behavior approaches the behavior of a normal distribution curve, also known as Gaussian distribution. Another analysis involving the geometric parameters and Nusselt number is displayed. For this, a variance analysis tool (ANOVA) in Minitab was used and an interaction frame was generated (Fig. 6b). This figure shows the behavior of all the parameters involved and the response variable, that is, Nusselt number. The biggest influence noted in $S = 12$ mm, confirms what was mentioned by Yazicioglu and Yüncü (2007) who showed that the best spacing between fins ranges between 10.4 and 11.9 mm.

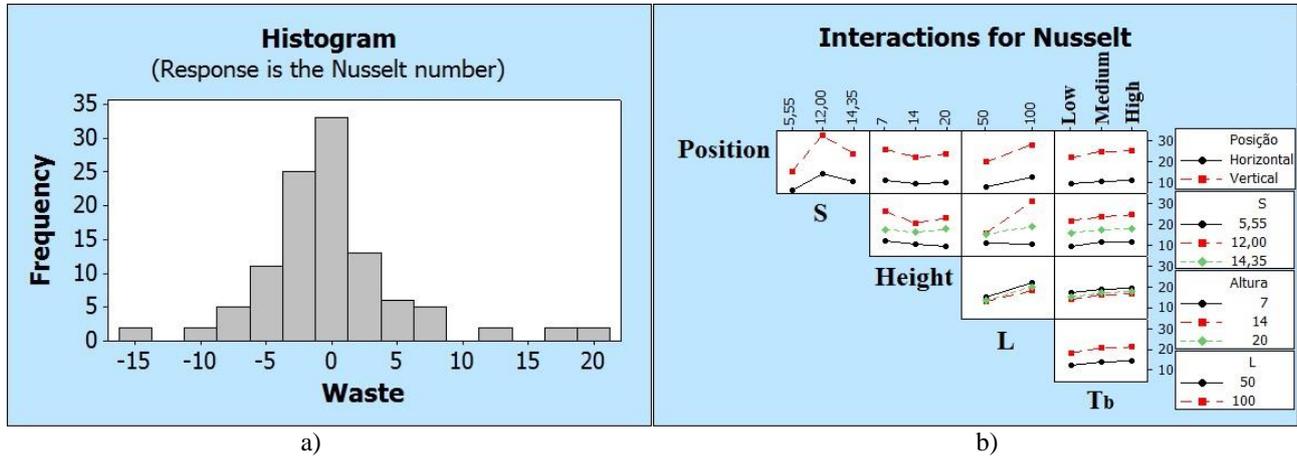


Figure 6. a) Residual histogram and b) Interactions between variables in Nusselt number.

In this work, results were obtained through experimental measurements, and thus an uncertainty analysis is necessary to ensure the reliability of these results. The uncertainty analysis was based on Nusselt number which is the main parameter. For this analysis, the error propagation theory developed, which is based on the uncertainties of the independent variables, was used (Taylor, 1996). The calculation of uncertainty, using the experimental methodology, was done as well as the uncertainties involved in the correlations. The calculation of the uncertainty based on Eq. (3), is according to Eq. (12):

$$\Delta Nu_{teórico} = \sqrt{\left(\frac{\partial Nu}{\partial Ra} \cdot \Delta Ra\right)^2 + \left(\frac{\partial Nu}{\partial L} \cdot \Delta L\right)^2 + \left(\frac{\partial Nu}{\partial W} \cdot \Delta W\right)^2 + \left(\frac{\partial Nu}{\partial S} \cdot \Delta S\right)^2 + \left(\frac{\partial Nu}{\partial H} \cdot \Delta H\right)^2} \quad (12)$$

where ΔNu is the value of the uncertainty of Nusselt number and ΔRa , ΔL , ΔW , ΔS and ΔH are the values of the uncertainty of each variable. Thus, the calculation is given by the sum of the products of the first partial derivative of Nusselt number in relation to each variable multiplied by the uncertainty of each variable; this the product is squared. Similarly, the calculation was done to obtain the uncertainty of Nusselt number obtained experimentally. This calculation took the experimental methodology into account presented in Eq. (13):

$$Nu = \frac{\frac{(V - R_{fio} \cdot I)^2}{R_{aq}} - \frac{k_{isol} \cdot A_{isol} \cdot (T_3 - T_2)}{Z} - \varepsilon \cdot \sigma \cdot A_{ct} \cdot (T_s^4 - T_\infty^4)}{A_{ct} \cdot (T_s - T_\infty)} \cdot \frac{L}{k_{ar}} \quad (13)$$

The uncertainty for Nusselt number is then defined by the combination of all the uncertainties of each quantity involved in their calculation. Therefore, the uncertainty for Nusselt number is given by Eq. (14):

$$\Delta Nu_{exp} = \sqrt{\left(\frac{\partial Nu}{\partial V} \cdot \Delta V\right)^2 + \left(\frac{\partial Nu}{\partial R_{fio}} \cdot \Delta R_{fio}\right)^2 + \left(\frac{\partial Nu}{\partial R_{aq}} \cdot \Delta R_{aq}\right)^2 + \left(\frac{\partial Nu}{\partial I} \cdot \Delta I\right)^2 + \left(\frac{\partial Nu}{\partial k_{isol}} \cdot \Delta k_{isol}\right)^2 + \left(\frac{\partial Nu}{\partial A_{isol}} \cdot \Delta A_{isol}\right)^2 + \left(\frac{\partial Nu}{\partial T_2} \cdot \Delta T_2\right)^2 + \left(\frac{\partial Nu}{\partial T_3} \cdot \Delta T_3\right)^2 + \left(\frac{\partial Nu}{\partial Z} \cdot \Delta Z\right)^2 + \left(\frac{\partial Nu}{\partial \varepsilon} \cdot \Delta \varepsilon\right)^2 + \left(\frac{\partial Nu}{\partial \sigma} \cdot \Delta \sigma\right)^2 + \left(\frac{\partial Nu}{\partial A_{ct}} \cdot \Delta A_{ct}\right)^2 + \left(\frac{\partial Nu}{\partial T_s} \cdot \Delta T_s\right)^2 + \left(\frac{\partial Nu}{\partial T_\infty} \cdot \Delta T_\infty\right)^2 + \left(\frac{\partial Nu}{\partial k_{ar}} \cdot \Delta k_{ar}\right)^2 + \left(\frac{\partial Nu}{\partial L} \cdot \Delta L\right)^2} \quad (14)$$

Because the calculations of the derivatives are large, the mathematical program Maple was used. Table 3 presents the values found for the uncertainties.

Table 3. Experimental and theoretical uncertainties for Nusselt number.

Nusselt number	Experimental		Theoretical	
	Horizontal	Vertical	Horizontal	Vertical
Obtained Value of Nu	5.41	19.23	5.30	20.04
Uncertainty Value	0.18	0.71	0.15	0.06
Uncertainty (%)	3.29	3.66	2.83	0.29

5. CONCLUSIONS

The results obtained showed good concordance with literature for the comparisons between coefficients \bar{h} and Nusselt number. Note that the smaller heatsinks in general the higher values of \bar{h} due to the high temperatures achieved due to the reduced area of heat exchange by convection. It was observed that for heatsinks arranged horizontally, there is a better agreement for Nusselt number and in heatsinks with bigger bases the mean difference was around 10%, when comparing the experimental data with the results of empirical correlations. A classification of the heatsinks showed that the geometric similarity complies with the performance in the relation of maximum temperature reached and power supplied. Results showed similar behavior of heatsinks of different base dimensions with the same geometrical patterns and presented the same performance for both positions in which they were tested. It was verified that a good agreement was achieved when experimental data and the new correlation with respect to Nusselt number were compared. It was possible to find a mean difference of around 12 % for smaller heatsinks and 18.5 % for larger heatsinks. The tools used, like Minitab, can produce satisfactory analyses, provided that a planning of experiments is accomplished beforehand. So a more careful analysis of the statistical point of view was not done because an appropriate planning of the experiments was not performed. The calculations showed a maximum uncertainty around 3.5 %, which is acceptable in literature.

6. ACKNOWLEDGEMENTS

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