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STUDY OF TEMPERATURE DISTRIBUITION IN A STEADY-STATE CONCRETE CHIMNEY.

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Abstract. *The present work has the scope to numerical analysis of temperature in concrete chimney. Since one of the factors responsible for the structural impairment of a chimney is the thermal shock, it is justifiable to know the thermal conditions that they are subjected to, only then begin developing a plan for the proper maintenance such. Thus, the present study was developed over a fireplace rectangular section. By means of an application to calculate the temperature distribution was conducted in the wall of the chimney in order to improve the conditions thereof. The present methodology of this work is the method of finite differences, which in turn is based on the replacement of the differential equation set of n equations for unknown temperatures, selected among n points, and the simultaneous solution of these equations results in the temperature values these discrete points.*

Keywords: *Finite Differences, Matlab, Steady state thermal .*

1. INTRODUCTION

The main function of the chimneys is the provision of good combustion as well as the transport of the gases out of the environment in question. (Jotul, 2014) these, in turn, are classified in residential and industrial, so that the former are usually used for cooking while the latter, exhaust fumes and gases from the boilers of workshops and factories (Costa, 1955). However, (Costa, 1955) points out that the forms of chimneys, regardless of their denominations and situations, differ from each other by virtue of their application and the architectural design of the work.

Although the presence of chimneys is of paramount importance in both residential and industrial environments, (Aguiar, 2006) draws attention to the influence that temperature causes over the years on the structure of the chimneys, relating the shattering of parts of the structure to the thermal shock suffered constantly . Thus, it is extremely important to obtain knowledge about the main processes of heat transfer in which this structure is submitted.

The Falling material from the top of the chimneys is a serious problem within steel mills. Because they are located in a very aggressive atmospheric environment, the chimneys have been deteriorating over the years, with the concrete degradation. Such occurrence compromises the functionality and stability of some structures, putting facilities, equipment and even employees at risk (Aguiar, 2006). As one of the responsible factors for the concrete shattering is the presence of thermal shocks in the structure, the need arises to determine the thermal stresses that it has been suffering. In order to do so, the mathematical numerical simulation tools become indispensable for the correct sizing of these constructions.

With emergence of new generations of computers, the solution of the heat transfer problem by numerical methods has been used with increasing frequency. These techniques allow the resolution of the complete model of the phenomenon, including its multivariate characteristic in time and space (Rodrigues *et al.*, 1998) .

Advances in numerical techniques have been significant. Developments and tests of new temporal and spatial discretization methodologies, pressure-velocity coupling techniques and linear systems solution have greatly improved the performance of the codes for solving the equations that model the fluid flow.

For (Çengel and Ghajar, 2012), one of the reasons for seeking alternative methods for problem solving lies in the limitations of analytical methods. Solution analytical methods are limited to highly simplified problems in simple geometry. The geometry must be such that the entire surface can be described mathematically in the coordinate system by imposing constant values for the variables. That is, it must fit perfectly to a coordinate system without missing or missing anything. However, even in simple geometries, heat transfer problems can not be solved analytically if the thermal conditions are not simple enough.

In addition to the limitations, (Çengel and Ghajar, 2012) also highlight the issue of adequate modeling. The solutions we obtain are those of mathematical models, and the degree of applicability of the solutions to real physical problems depends on the precision of the model. An "approximate" solution to the realistic model of a physical problem is usually more accurate than the "exact" solution of the gross mathematical model. When we try to obtain an analytical solution to a physical problem, there is always a tendency to oversimplify the problem to make the mathematical model simple enough to allow an analytical solution. Thus, it is not surprising that nonlinearities, such as temperature dependence in thermal conductivity and the radiation boundary condition, are rarely considered in analytical solutions.

Within this scope, the present work presents the study of the temperature distribution in a concrete chimney in permanent regime. The objective of this study is to evaluate, with the aid of computational means, the temperature analysis in the most critical regions of the chimney.

The results obtained using the numerical solution using Matlab and ANSYS software were analyzed. Regarding MATLAB software, although this has made the resolution of the problem less time consuming, it still does not exempt the user from resorting to handwriting resolution, since it requires the transcription of the equations of each node in the program. Thus, it is verified that MATLAB is, in fact, a powerful calculator, whose main purpose is to solve complex equations and display the final result.

As far as ANSYS Workbench is concerned, the greatest difficulty in using the Steady-State Thermal tool was linked only to the generation of meshes, due to the infinity of resources offered by the program. However, in a short time it was possible to familiarize yourself with the software interface and its commands.

Although the present study was carried out with two different software, it was verified that the ANSYS Workbench analysis required a greater refinement of the mesh to bring the results closer to that presented by(Çengel and Ghajar, 2007).

2. METODOLOGY

The present study was based on a problem in which combustion hot gases flow steady state through a concrete chimney of rectangular section of 20 cm X 40 cm and wall thickness of 10 cm. In this chimney, the hot gases flow at a temperature of 280 ºC and the average coefficient of heat transfer is 75 W/m^2K. The chimney also loses heat from the outer surface to the ambient air at 15 ºC by convection, with a heat transfer coefficient of 18 W/m^2K, and to the sky by radiation. The emissivity of the external surface of the wall is 0.9 and the effective temperature of the sky is 250 K. The mesh must conform to the condition Δx = Δy = 10 cm. There is no internal heat generation. Considering that the problem is two-dimensional with constant properties in steady state and without heat generation, then the heat equation reduces to:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0 \tag{1}$$

Eq.(1) was discretized using the finite difference method. The nodal network dimensions were previously defined, generating the mesh expressed in Fig.(1).

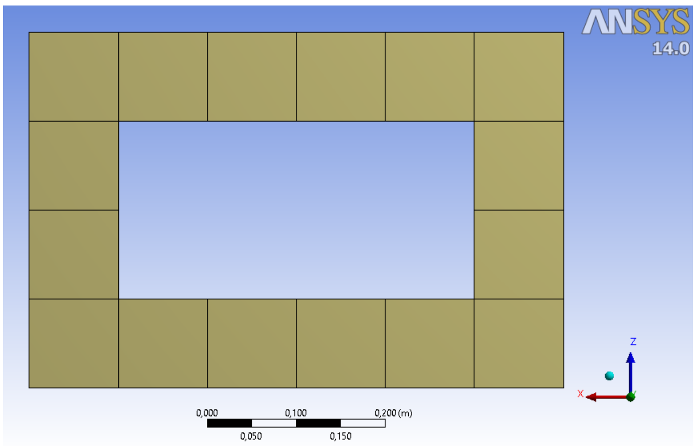

Figure 1. Structure of the chimney section.

Since the geometry of the section is rectangular and there is no heat crossing the line of symmetry, these can be treated as isolated or "mirrors" in the formulation of finite differences. Therefore, it is possible to perform the equation for the fourth part of this geometry and perform the mirroring of the results for the other nodes of the section, without the final result being affected as shown in Fig.(2).

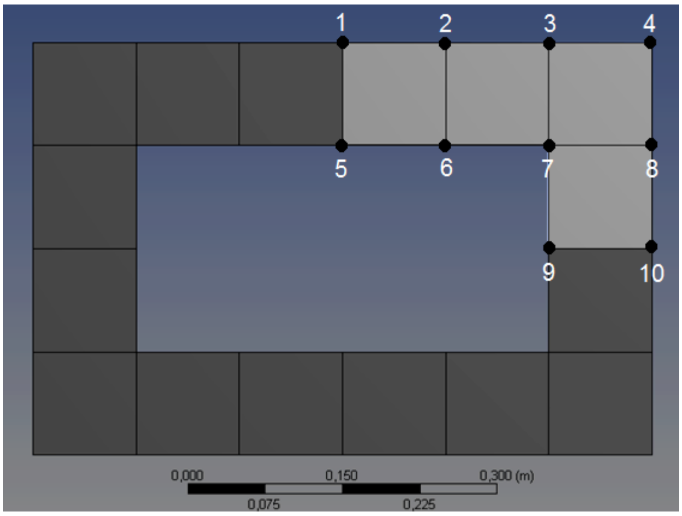

Figure 2. Nodes selected for the equation.

Once the considerations were made, the discretization of the nodal points was developed as shown in Eqs. (2), (3), (4), (5), (6), (7), (8), (9), (10) e (11).(BONILLO,2014)

$$T_1 = \frac{-a_2 {T_4}^4 + T_2 + T_5 + b_1}{2 + a_1} \tag{2}$$

$$T_2 = \frac{-2a_2 {T_2}^4 + T_1 + T_3 + 2T_6 + 2b_1}{4 + 2a_1} \tag{3}$$

$$T_3 = \frac{-2a_2 {T_3}^4 + T_2 + T_4 + 2T_7 + 2b_1}{4 + 2a_1} \tag{4}$$

$$T_4 = \frac{-2a_2 {T_4}^4 + T_3 + T_8 + +2b_1}{2 + 2a_1} \tag{5}$$

$$T_5 = \frac{T_1 + T_6 + b_2}{2 + a_3} \tag{6}$$

$$T_6 = \frac{2T_2 + T_5 + T_7 + 2b_2}{4 + 2a_3} \tag{7}$$

$$T_7 = \frac{2T_3 + T_6 + 2T_8 + T_9 + 2b_2}{6 + 2a_3} \tag{8}$$

$$T_8 = \frac{-2a_2 {T_8}^4 + T_4 + 2T_7 + T_{10} + 2b_1}{4 + 2a_1} \tag{9}$$

$$T_9 = \frac{T_7 + T_{10} + b_2}{2 + a_3} \tag{10}$$

$$T_{10} = \frac{-a_2 {T_{10}}^4 + T_8 + T_9 + b_1}{2 + a_1} \tag{11}$$

The selected method should be simple to implement and at the same time less subject to the accumulation of errors (Asano and Eduardo, 2009). In this way, we could conclude that the appropriate method for this study would be the Gauss-Seidel method. The program was developed in Matlab. Then computational modeling was performed on the Steaty State Thermal,Ansys.

Then, a comparison was made between the two results, the first using the Matlab and the second using Ansys.

3. RESULTS

The study was carried out in two computer software, MATLAB and ANSYS. In the first, the final result can be proved numerically through Tab.(1) and graphically through Fig.(3).

Tab.(1) shows a comparison between the values of the reference and the author temperatures, where the column on the left shows the nodal temperatures, the central column, the values obtained in the reference and the column on the right, the result presented in MATLAB.

Table 1. Comparative table of nodal temperatures.

TEMPERATURE OF THE NODES	ÇENGEL AND GHAJAR,2011	MATLAB	ERROR BETWEEN ITERATIONS	ERROR BETWEEN MATLAB AND LITERATURE
T_1	95.5°C	94.37°C	0.0145%	0.1376 %
T_2	93.0°C	92.81°C	0.0004%	0.2043 %
T_3	82.1°C	81.69°C	0.0036%	0.4994 %
T_4	36.1°C	35.75°C	0.0050%	0.9695 %
T_5	250.6°C	250.44°C	0.0009%	0.0638 %
T_6	249.2°C	248.94°C	0.0232%	0.1043 %
T_7	229.7°C	228.59°C	0.000004%	0.4832 %
T_8	82.3°C	81.42°C	0.0490%	1.0693 %
T_9	261.5°C	247.17°C	0.0001%	5.4799 %
T_{10}	94.6°C	90.71°C	0.0002%	4.1121 %

Analyzing Tab.(1), it is verified that the result presented by MATLAB was satisfactory and that the error presented between the iterations remained below 0.5%, proving that the refinery generated by Gauss-Seidel also met expectations. It is also noticed that the biggest errors presented were at nodes 9 and 10, due to the divergence between the values presented in the literature and the one obtained mathematically.

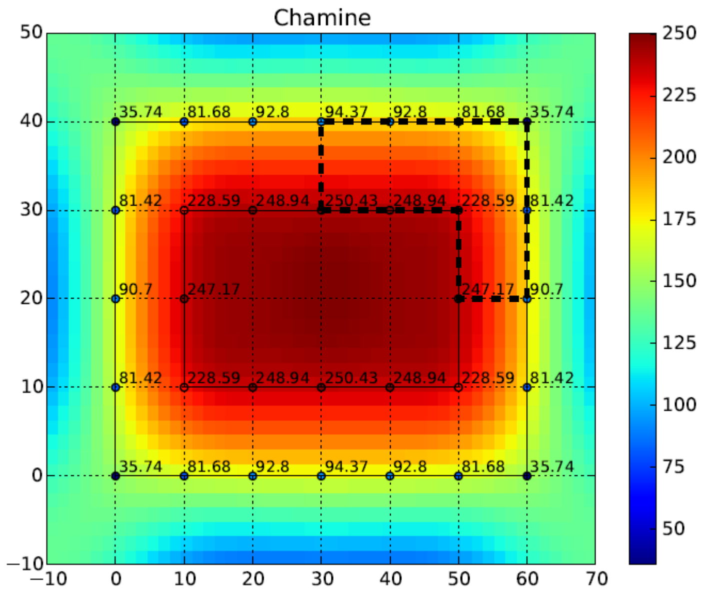

Figure 3. Final result of MATLAB presented graphically.

Finally, ANSYS modeling was performed. Unlike MATLAB, which generates only nodal temperature values, in this program a graphical simulation of the temperature in the element geometry is generated, as can be seen in Fig.(4).

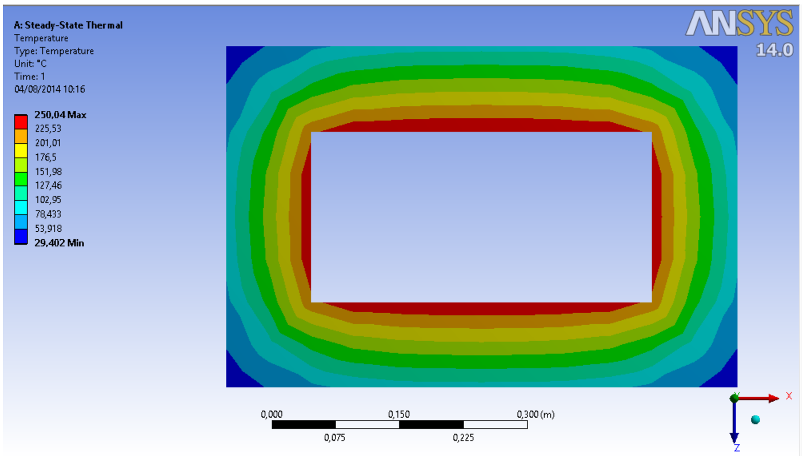

Figure 4. Ansys final result.

Analyzing Fig.(4) and Fig.(5) it is observed that there is a discrepancy between the values presented by (Çengel and Ghajar, 2007) with those obtained in ANSYS Workbench. As a result, a new analysis was carried out with the refined mesh to 5 centimeters, as shown in Fig.(5).

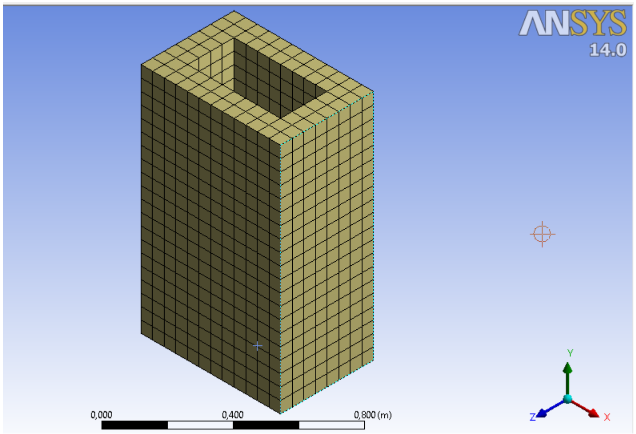

Figure 5. Refining the mesh to 5 centimeters.

The final result can be seen in Fig.(6), where it can also be verified that there was a greater approximation with the results presented in Tab.(1).

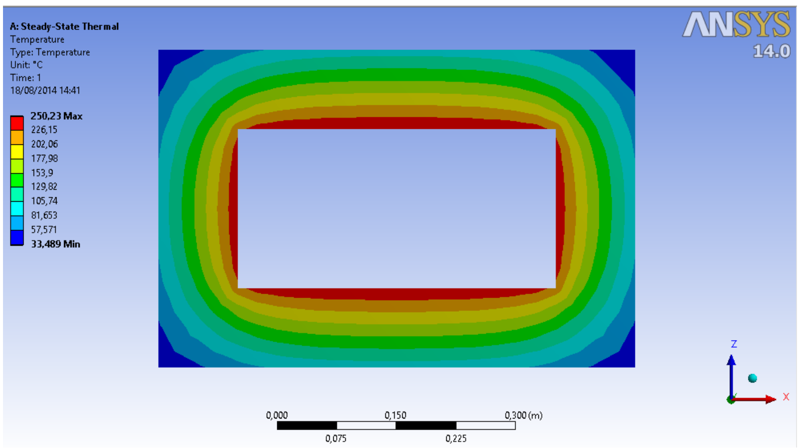

Figure 6. Final result of the analysis after the mesh refinement.

Alternatively, the mesh generation of ANSYS itself was performed in order to compare the result obtained with the others, as shown in Fig.(7).

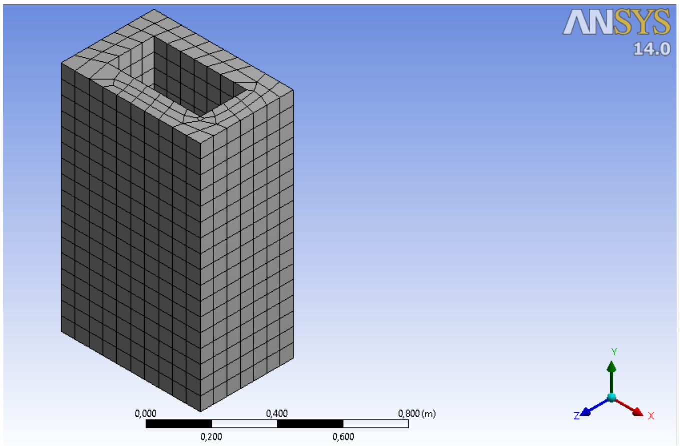

Figure 7. Mesh generated automatically by ANSYS.

The final result can be seen in Fig.(8). It can be seen that the result obtained by the 5 cm mesh was closer to the result of the bibliography when compared to the one obtained by the mesh generated automatically by the program.

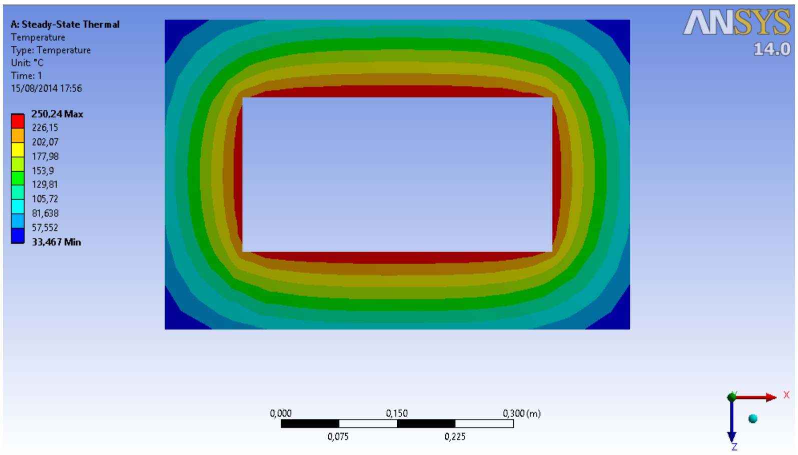

Figure 8. Result obtained by the automatically generated mesh.

After this step, refinements were made for mesh sizes of 2,5 cm and 1,25 cm. as shown in Fig.(9 and Fig.(10.

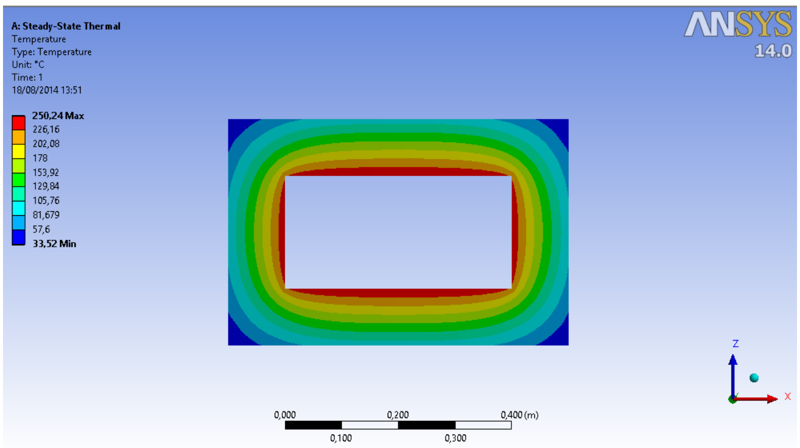

Figure 9. Result obtained for the refinement of mesh in 2,5 centimeters.

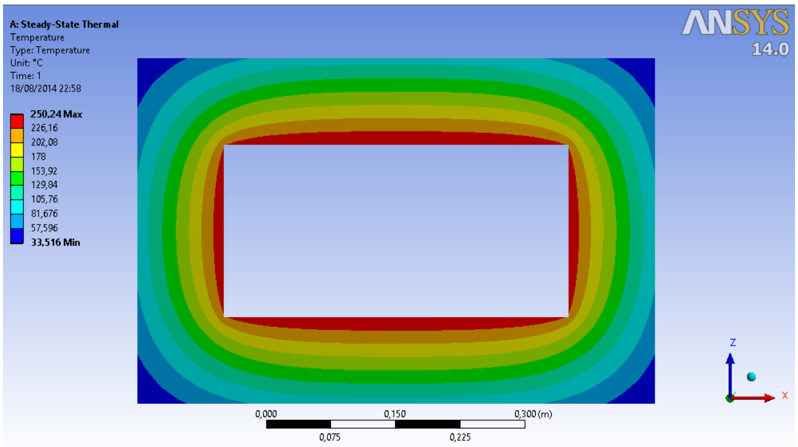

Figure 10. Result obtained for the refinement of mesh in 1,25 centimeters.

According to Fig.(9 and Fig.(10, it can be seen that the final result presented underwent little variation even with the mesh refining. This is because the final results have stabilized, which means that they will suffer few variations with the refining of the mesh. Fig.(11 explains this occurrence through the graph of convergence between mean temperatures.

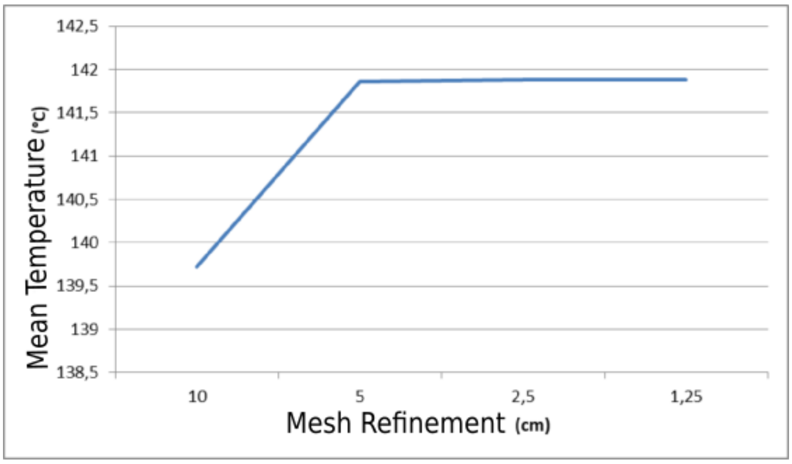

Figure 11. Convergence graph.

According to Fig.(11, the tendency of the graph to remain constant from the mesh refinement equal to 5 centimeters is observed. This means that, for a higher degree of refinement, ie for control volumes smaller than 5 centimeters, the final result will not suffer any relevant variation.

4. CONCLUSION

In the present work a study of the temperature distribution in a concrete chimney in steady state was carried out. As a tool of this analysis, the Finite Differences and Gauss-Seidel numerical method associated to the MATLAB software was used, and later the modeling of the problem was done with the help of Steady-State Thermal, a software program belonging to the ANSYS package.

In view of the whole study, it was concluded that numerical simulation has become a potential tool for solving various problems and in several areas. In the case of chimneys, the numerical simulation of the temperature gives the user which regions of the geometry will suffer most from thermal shock. This allows the engineer to take the necessary measures so that during the design this undesirable factor can be controlled or that even after construction the information obtained is combined with an adequate maintenance plan;

In addition, it is also verified that the solution by numerical methods differs from the others by taking into account the geometric aspect of the element during the resolution of the problem, besides considering, in the case of heat transfer, all variables relevant to the execution of a plausible equation. This guarantees a result that is closer to the real one and less susceptible to errors that may be added to roundings and considerations;

Regarding MATLAB software, although this has made the resolution of the problem less time consuming, it does not exempt the user from resorting to handwriting resolution, since this requires the transcription of the equations of the nodes in the program. Thus, it is verified that MATLAB is, in fact, a powerful calculator, whose main purpose is to solve complex equations and display the final result;

As for ANSYS Workbench, the greatest difficulty in using the Steady-State Thermal tool was in relation only to the generation of meshes, due to the infinity of resources offered by the program. However, it was possible to familiarize yourself with the software interface and its commands;

Although the present study was carried out with two different software, it was verified that the ANSYS Workbench analysis required a greater refinement of the mesh so that the results approximated that presented by (Çengel and Ghajar, 2007).

Finally, it was concluded that in many situations obtaining more accurate results was impossible due to technical factors of the equipment, such as processor and memory. This was a hindrance to achieving results close to reality, but did not prevent them from being accurate.

5. ACKNOWLEDGEMENTS

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