

ENCIT-2018-0681 CFD VALIDATION OVER A CABIN-TYPE SOLAR DRYER USING ANSYS FLUENT SOFTWARE

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Abstract. *The purpose of the research is to make an analysis of the air flow through a solar collector air cabin-type dryer and evaluate the numerical solution of the thermal behavior of the dryer which have been already studied in a previous experimental research. To this end, a computational fluid dynamics model was used to describe the transport phenomena that occur inside the empty cabin-type solar dryer under various operating conditions. Then, the mass flow rate of the dryer was varied to identify which condition had the best performance for thermal efficiency and outlet temperature. The numerical results showed that the validation differed by a maximum of 4.79% in relation to the thermal efficiency, and 4.46°C in relation to the temperature at the exit to the air, comparing to the experimental study. Finally, the distribution of temperature in the spaces where a possible material or substance will be placed for drying was mapped. This mapping is of extreme importance for a consumer who wishes to perform the drying under controlled conditions so that his product is in proper drying conditions and does not have its quality impaired in the drying process.*

Keywords: *cabin-type dryer, solar collector, CFD, numerical solution, thermal efficiency analysis*

1. INTRODUCTION

Solar energy is an extremely important source of energy nowadays for people, and its application has been applied since before human existence. Currently, global energy consumption is equivalent to 75% of global energy and contributes to the destruction of the ozone layer. The demand for energy is increasing and, thus, the interest for the sustainable energy gains space for discussions. Every day, the planet Earth receives thousands of times the energy it consumes, that is, this source of energy has enough capacity to meet the needs (Chauhan, *et al.*, 2015). In the world, there are various types of solar drying that vary in shape and size. Each dryer has a certain efficiency, which can be evaluated. Researchers, manufacturers and end consumers are interested in knowing the efficiency or performance that the developed dryer has. Thus, analyzes and tests are made on these devices in order to determine their characteristics and properties

The drying process of the solar dryer is a type of technique that has been modified using several technologies. The drying process is necessary in several factories, being basically in the food industry and chemical industry. Not only in industry, but in the agricultural area, the process is used for drying grains and crops. Humidity is reduced and regulated to safe levels.

The drying process takes place inside a closed chamber. There are three most known types of solar dryers: direct, indirect, and the mixed dryer. The heat transfer in the drying can be by convection (direct dryers), by conduction (dryers of contact or indirect) and radiation. About 99% of the applications involve the removal of water. Drying results in a very complex operation that is indispensable for various sectors of the industry, for example in agriculture, food, pharmaceutical, mineral processing, wood processing industry, chemistry, biotechnology, polymers, etc. There are several types of dryers, which are classified according to the method of heat transfer employed. Solar drying is a clean and inexpensive drying method, where the energy source is renewable and abundant (Ekechukwu and Norton, 1999).

In direct solar drying systems, the crop is exposed directly to the sun in order to dehydrate it. With this type of drying system, a heat absorber surface painted black is used to collect solar radiation and convert it to heat. The crop is positioned on the surface (Pardhi and Bagoria, 2013). The direct dryer uses direct solar radiation for drying, and has its simple format. Generally, it is operated by small producers.

The indirect dryer consists of an air collector, a solar collector, an auxiliary heater, a fan for air circulation and a drying cabinet. Indirect solar drying is more efficient compared to direct drying. In this system, solar radiation is transferred to atmospheric air with the help of collectors which heats it. This can be done with flat plate or solar collector concentrators. Thus, hot air flows into the drying chamber where the product is placed (Ali, *et al.*, 2014).

Finally the mixed dryer, together direct and indirect dryer characteristics. The product receives direct solar radiation and receives a flow of heated air so that the phenomenon combines the characteristic of the direct and indirect dryer. Still, the product is dried indirectly, ie the air is heated first and then it passes through the cabin where the product is stored (Bagheri, *et al.*, 2015).

A drying system was constructed by and tested by Al-Juamily *et al.*, (2007) consisting of three parts (solar collector, solar drying cabin, and an air fan) and the results showed that the most relevant factor in the drying rate is the air temperature inside the cabin; the effect of varying the air speed inside the cabin is small and can be neglected, and the relative air humidity leaving the cabin is small (between 25% and 30%) and therefore there is no need for a high air velocity within of the cabin. A transient analysis of a cabin-type solar dryer was performed by Dutta, *et al.*, (1988) with simplified but practical considerations, and the model predicted instant dryer temperatures, amount of moisture, and drying rates. The analysis was performed without any load, and with loads ranging from 10kg to 40kg of dried product.

An experiment was made by Sharma *et al.*, (1990) to analyze a cabin-type solar dryer, in which transient regime equations were written for the different components of the system and their solutions tested within the framework of the periodic analysis. The model was able to predict the instantaneous temperature inside the dryer, the amount of moisture, the drying rates, and the results obtained from the theoretical and experimental observations that were reported.

Numerical simulations have been growing and gaining space in industries. More specifically, Computational Fluid Dynamics (CFD) is a powerful and powerful tool capable of solving many engineering problems involving heat transfer and fluid flow. A CFD analysis is based on a computational approach to fluid flow, using numerical methods. Due to its ability to predict and describe the behavior of a system, it is a reliable, versatile and workable tool for the industry. Among its advantages are lower cost, reliability and quick analysis of the system.

In CFD modeling, it is required numerical analysis and algorithms to solve and analyze the problem of fluid flow. Calculation performance on the computer is required to simulate the interaction of liquid and gas with the surface. This is better known as the boundary conditions. ANSYS FLUENT software is used to simulate the interaction of flow and air movement within the drying chamber (Akpinar, *et al.*, 2006).

In the drying process, the air flow occurs in a permanent regime, in addition to being considered the average heat transfer in the system. Air movement and transfer phenomena are closely linked with velocity. Under these conditions CFD modeling is used. During the drying process, the air velocity is measured with the aid of an anemometer. The flow of hot air, in different positions of the drying chamber, is determined using sensors (Diamante and Munro 1991).

According to Prakash, *et al.*, (2015) there are three boundary conditions in the simulation of a solar drier. CFD modeling techniques are assumed in these three contour conditions considered in the simulation. The first condition is assumed at the inflow: a fixed mass flow as a boundary condition. The second condition does not restrict flow. The mass is supplied to flow to the outlet. Flow voltage is assumed as the third boundary condition.

Recently Sun, *et al.*, (2016) conducted an experimental and numerical study on the analysis of a two-stage solar air heater collector with an intermediate collector plate. The study brought results of the thermal and dynamic behavior of the fluid of the collector when subjected to monitored operating conditions, for example mass flow and irradiation.

Numerical and experimental results were similar, so that the efficiency and the exit temperature had a difference of 1%. In addition, theoretical results determine that the thermal behavior of the fluid in this intermediate collector plate is similar to most flat-type solar air-heating collectors. That is, as the mass flow rate was increased, the thermal efficiency increased and the air outlet temperature decreased.

Mendonça, *et al.*, (2017) performed a work, where from experimental data of Singh and Kumar (2012), the behavior of the air inside a one-stage solar heating collector was simulated with the ANSYS software, in order to validate the experimental measurements. In addition, the thermal and dynamic behavior of the fluid (air) was analyzed under conditions of maximum mass flow and maximum solar radiation. Finally, three different types of collectors were compared. It was concluded that the model had a very good consistency with the experimental results and it was verified that in the conditions of high mass flow the flow is more uniform, and therefore have values closer to the experimental ones, when compared with conditions of mass flow where the predominant flow is natural convection rather than forced convection. When comparing the three collectors, he concluded that the more steps a collector had, the greater the thermal efficiency of the collector because the air would receive more solar radiation before reaching the drying chamber. The model will be used for thermal and dynamic analysis of the fluid in the drying equipment, as well as for the dimensioning of the solar collector that will be used as a component of the solar dryer to be developed.

The objective of this paper is to numerically model the drying process of the air flow in a solar dryer used in the master dissertation of Gonçalves (2012), using the ANSYS Software, and evaluate it. Then, validate the numerical model of the drying air flow process in an empty solar dryer, comparing the experimental data available with the numerical results. Finally, evaluate the operating conditions and thermal efficiency of the empty dryer for different operating conditions and to make feasible subsequent drying studies with agricultural products within the dryer.

2. METHODOLOGY

The classes of implemented numerical methods vary according to the physical type of engineering problem to be solved. There are some types of methods available, and the one used in this work was the Finite Volume Method (FVM), which performs a property conservation balance for each point, represented by an elementary volume. The lower the volume, the more points will be discretized, and the more precise the final solution. After the discretization, the boundary conditions in the respective mesh are applied defining the system boundary specifications.

In this research, the ANSYS FLUENT, a CFD (Computational Fluid Dynamics) software, which simulates the air flow of a type of solar energy cabin, without load, in a three-dimensional (3D) analysis is used. The software has, as basis of analysis, the finite volume method and has simulated a solar dryer developed in the Materials Engineering Department of CEFET-MG. Figure 1 shows the cabin-type solar dryer.

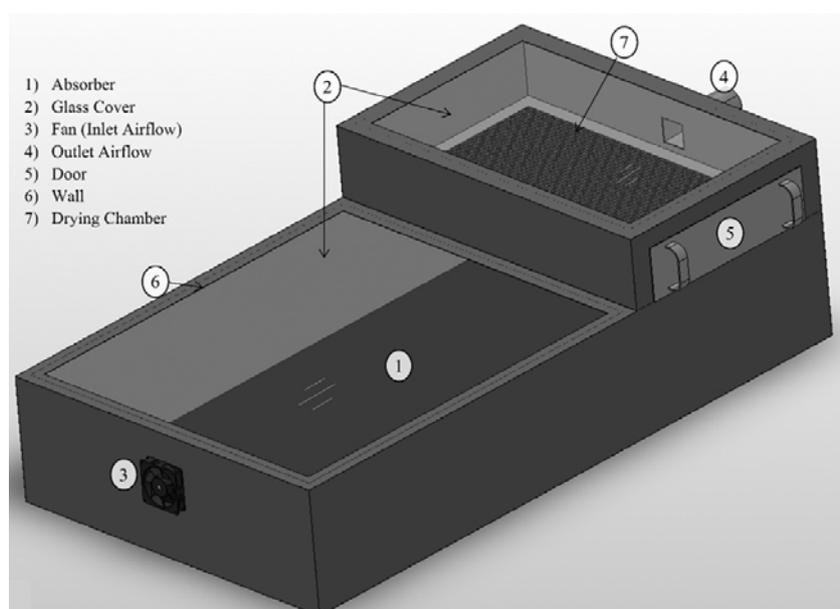


Figure 1. Schematic representation of the cabin-type solar dryer

The fluid domain was created in the ANSYS FLUENT software and is shown in Figure 2.

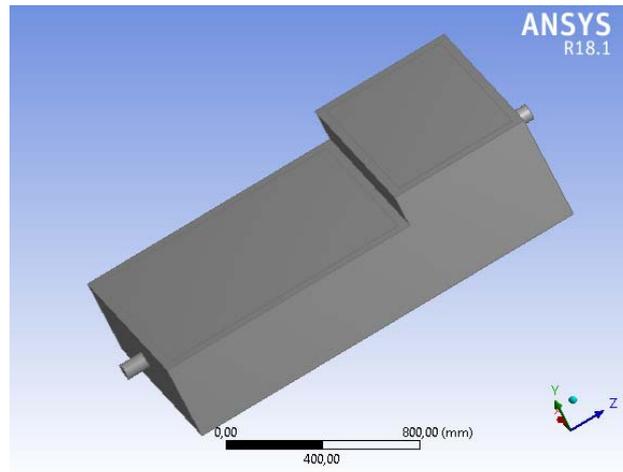


Figure 2. Symmetrical section geometry design.

Structured grid was simulated with standard k- ϵ turbulence model. Figure 2 represents generated computational grid.

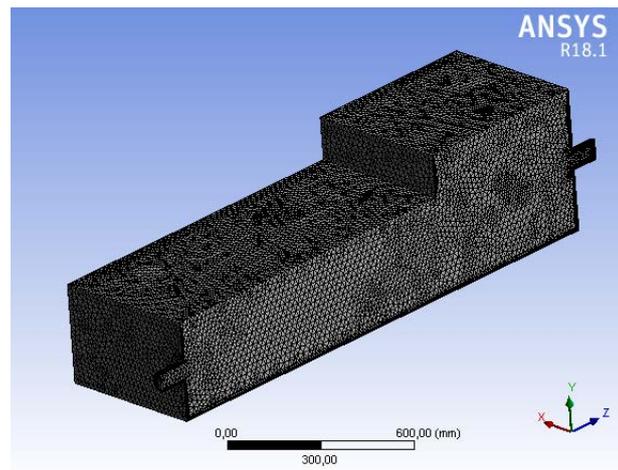


Figure 3. Computational grid - 563,186 tetrahedral elements and 124,303 nodal elements

3. RESULTS AND DISCUSSIONS

This section discusses the numerical results obtained in the application of the CFD model in order to describe the fluid dynamics, the thermal performance of the solar drier and the numerical validation using the experimental results of the Gonçalves' (2012) cabin dryer.

3.1 Experimental Data

The averages of the experimental results of Gonçalves (2012) were used in the eight simulations carried out, which are considered in each of the eight measurement schedules, during four days, that is, for a given schedule the results were measured for four days, and was considered the average of them. The uncertainties were obtained according to the resolution of the instrumentation used during the experimental studies.

Table 1 contains the average of the results of the measurements made by Gonçalves (2012), while Table 3 lists the calculated mass flow rate at each time of the present study.

T_i is the input temperature in the dryer, G is the incident solar radiation flux, T_o is the outlet temperature in the dryer, \dot{m} is the mass flow rate of the dryer and C_p is the specific heat at constant air pressure. Table 1 shows experimental data and calculated by Gonçalves (2012) in his experimental study.

Table 1. Data used and obtained by Gonçalves (2012) in his experimental study.

SCHEDULE	$T_i(^{\circ}\text{C})$	$G(\text{W}/\text{m}^2)$	$T_o(^{\circ}\text{C})$
9:00 AM	(25.8±0.4)	(592.5±10.1)	(50.5±0.4)
10:00 AM	(28.0±0.4)	(762.5±9.9)	(62.6±0.4)
11:00 AM	(30.0±0.4)	(877.3±9.7)	(72.4±0.4)
12:00 PM	(31.8±0.4)	(872.0±9.7)	(76.2±0.4)
1:00 PM	(33.1±0.4)	(805.3±10.1)	(77.1±0.4)
2:00 PM	(32.8±0.4)	(667.9±9.9)	(71.9±0.4)
3:00 PM	(32.6±0.4)	(594.7±9.7)	(63.3±0.4)
4:00 PM	(32.2±0.4)	(532.9±9.7)	(55.6±0.4)

Table 2. Mass flow obtained by experimental data for $C_p=1017\text{J}/(\text{kg}\cdot\text{K})$

SCHEDULE	\dot{m} (kg/s)
9:00 AM	(0.0072±0.0002)
10:00 AM	(0.0070±0.0002)
11:00 AM	(0.0069±0.0002)
12:00 PM	(0.0067±0.0002)
1:00 PM	(0.0067±0.0002)
2:00 PM	(0.0068±0.0002)
3:00 PM	(0.0069±0.0002)
4:00 PM	(0.0070±0.0002)

Gonçalves (2012) used a thermo-hygrometer to measure the inlet temperature, and two type K thermocouples to obtain the outlet temperatures and ambient temperature. He also used a PSP (Precision Spectral Piranometer) pyranometer to measure the incident solar radiation, and finally an ICEL AN-4780 anemometer to measure the air inlet velocity.

3.2 Simulations for validation of the numerical model

Figures 4 to 11, represent the results correspond to the hours of operation of the solar dryer ranging from 9:00 am to 4:00 p.m., relative to the temperature deviation, an important parameter for the evaluation of a dryer.

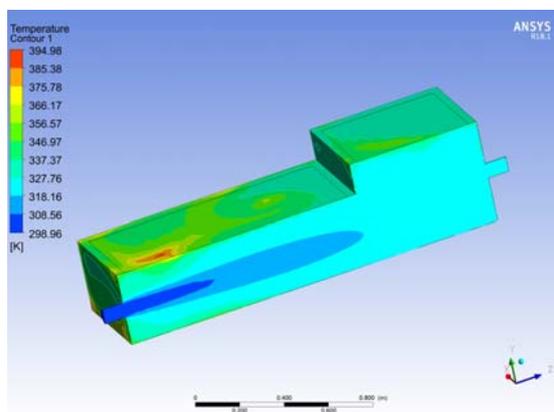


Figure 4: Temperature contour for 9:00 am

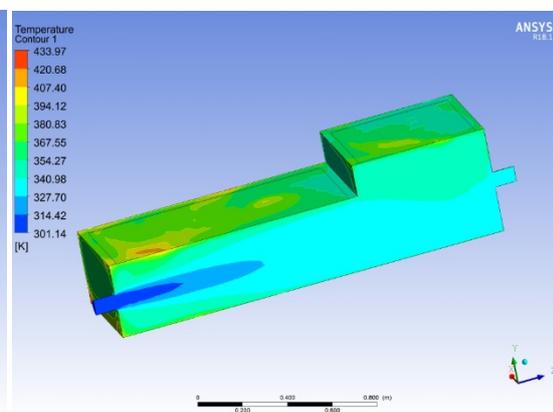


Figure 5: Temperature contour for 10:00 am

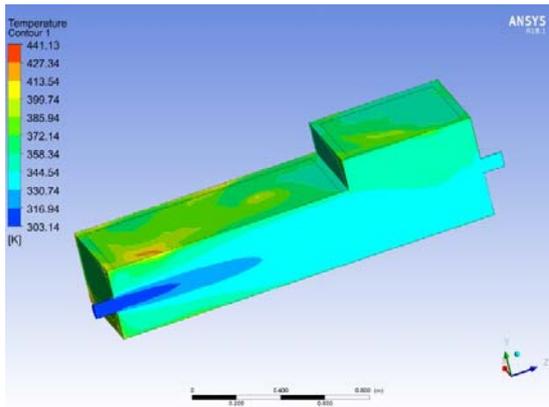


Figure 6: Temperature contour for 11:00 am

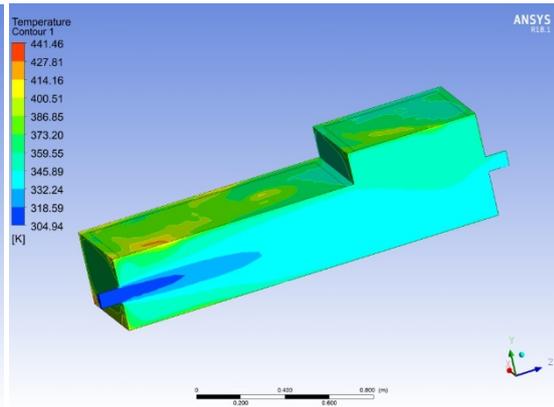


Figure 7: Temperature contour for 12:00 pm

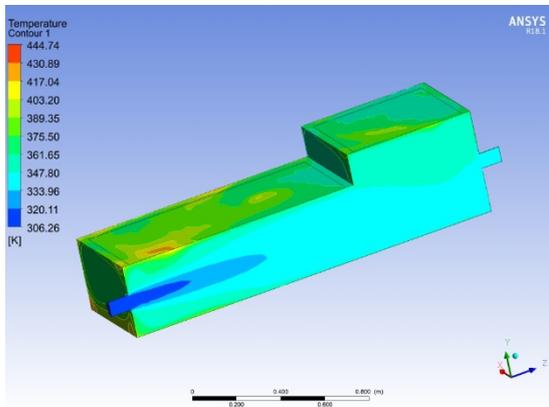


Figure 8: Temperature contour for 1:00 pm

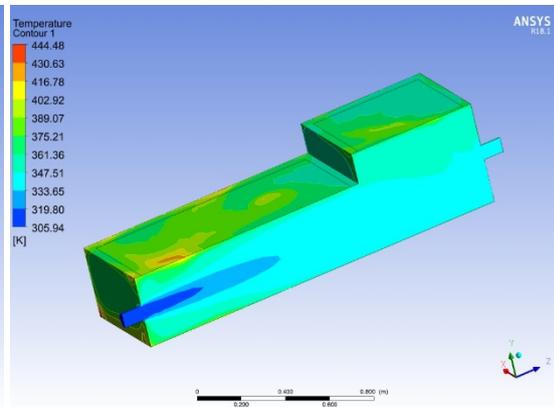


Figure 9: Temperature contour for 2:00 pm

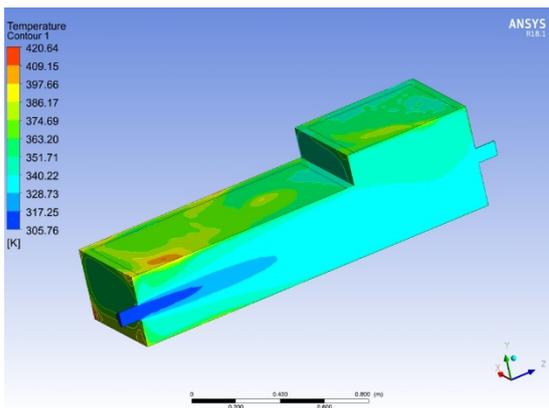


Figure 10: Temperature contour for 3:00 pm

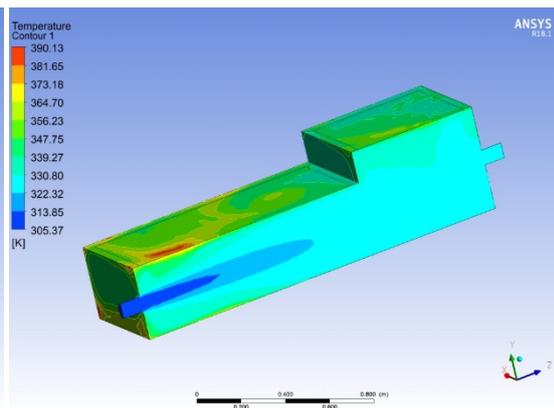


Figure 11: Temperature contour for 4:00 pm

Air gets in at room temperature in the dryer, with a constant flow in the dark blue region. Due to the incident solar radiation, turbulent movement, slope of the device, and recirculation regions, the flow heats up and, by convection, there is mixing of the air into the drying chamber. Thus, the cold air has its temperature and enthalpy increased and, at the output, the flow becomes warmer. From the analysis of 12:00 pm, the time of greater intensity of solar radiation, it is possible to verify the maximum temperature at the exit of the dryer compared to all other schedules. The temperature obtained was 71.74°C . In the central region of the flow, the airflow heats very fast still in the region of the solar collector, and already enters recirculation regions in the middle of the dryer.

Figures 12 to 19 show residual graphs which monitor the balance of a property at the inlet and outlet of the dryer.

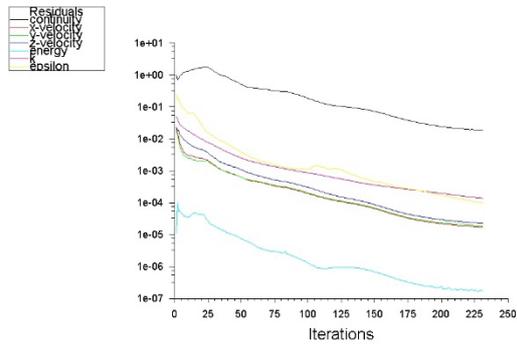


Figure 12: Residuals for 9:00 am

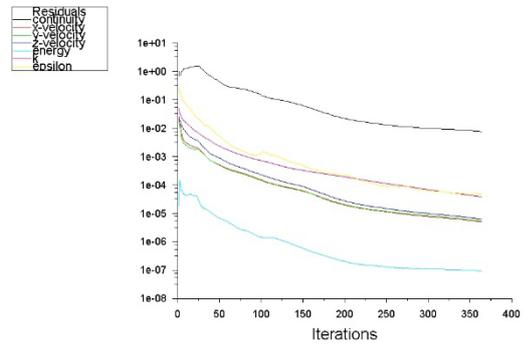


Figure 13: Residuals for 10:00 am

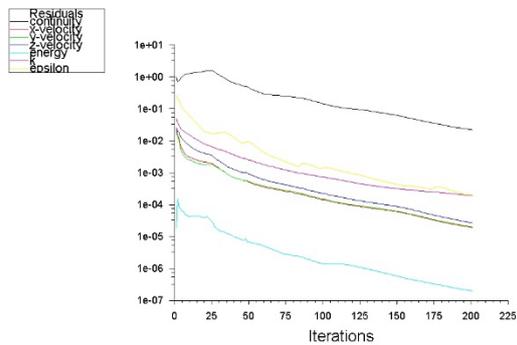


Figure 14: Residuals for 11:00 am

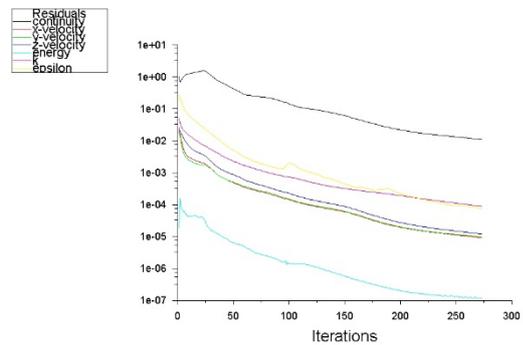


Figure 15: Residuals for 12:00 pm

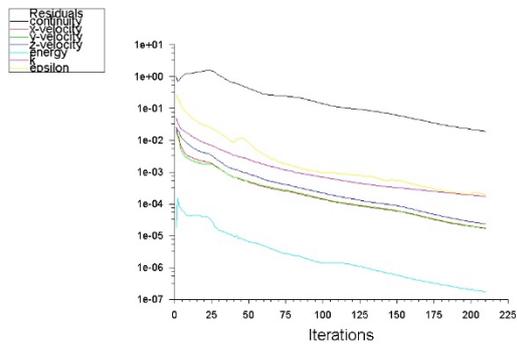


Figure 16: Residuals for 1:00 pm

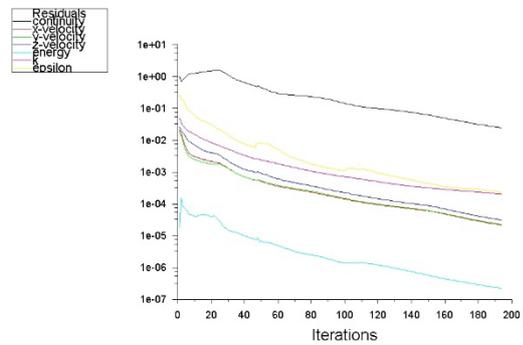


Figure 17: Residuals for 2:00 pm

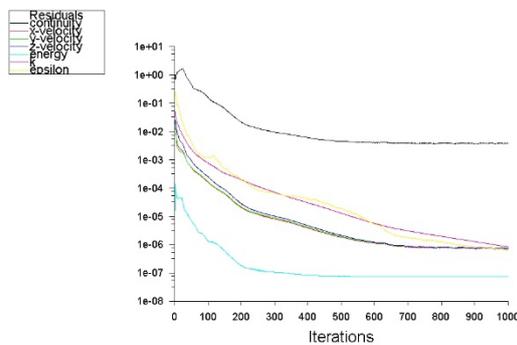


Figure 18: Residuals for 3:00 pm

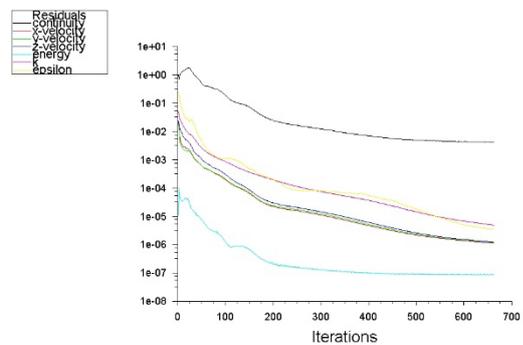


Figure 19: Residuals for 4:00 pm

The residual graphs above help the software user to see if a simulation converged or not, and clarify the inequalities of the properties, i.e.: if the properties were conserved and there was no energy or mass creation. Above, we can see the decay of the residuals over time, so that the solution realizes the balance of the properties of mass (continuity), energy, turbulent kinetic energy (k), and turbulent energy dissipation rate (ϵ) of the way converges to approximate values of the experimental values. The convergence criteria considered were: (1) the mean square root of the residuals had to be less than 10^{-3} ; (2) inequalities in conservation equations had to be less than 1%; (3) the variation of the step-by-step iteration in the magnitudes of the dynamics of the fluids and thermal, like the average mass flow and temperature, had to be less than 1%.

Figures 20 to 27 are graphs of average temperature monitoring as a function of the iterations. A good practice in the simulation is to observe if these graphs tend to have any specific value since this means that the solution has converged, that is, the temperature does not change with the iterations anymore.

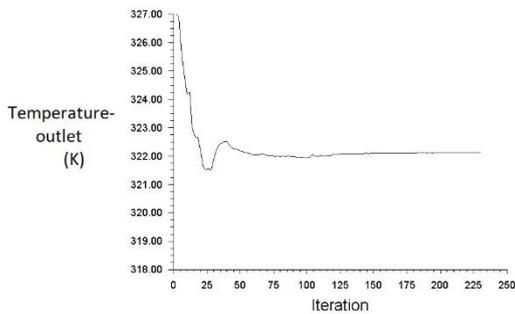


Figure 20: Simulation for 9:00 am

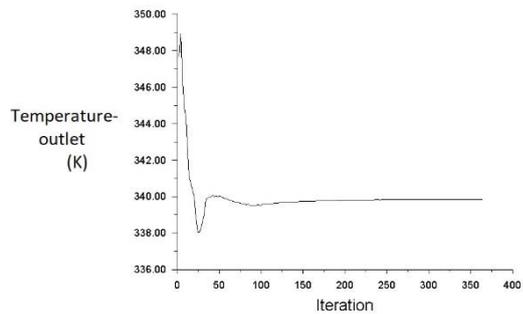


Figure 21: Simulation for 10:00 am

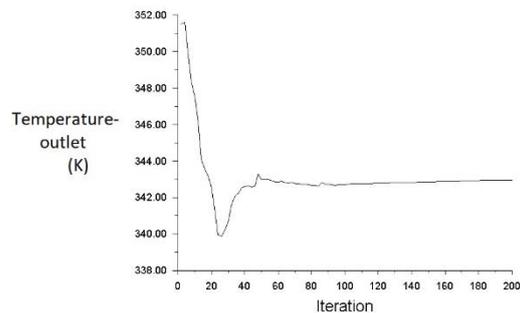


Figure 22: Simulation for 11:00 am

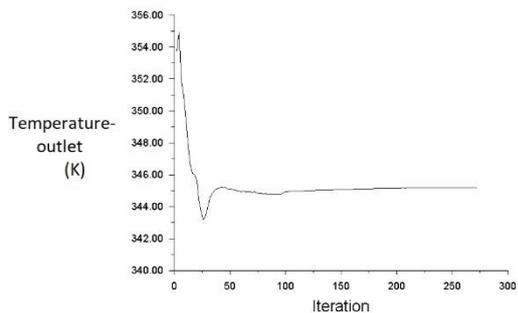


Figure 23: Simulation for 12:00 pm

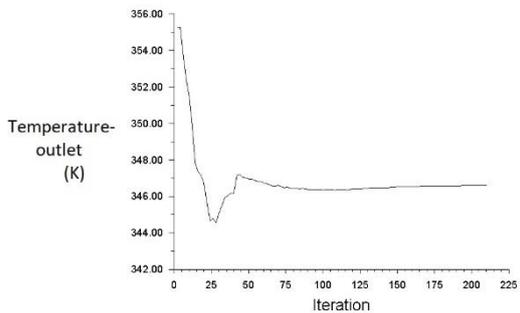


Figure 24: Simulation for 1:00 pm

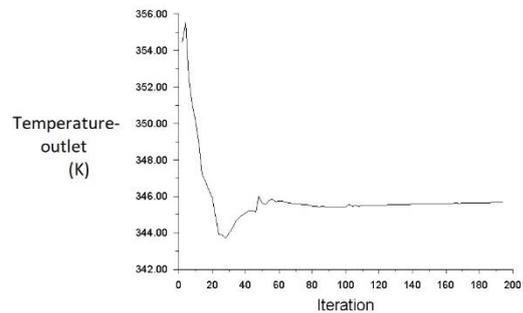


Figure 25: Simulation for 2:00 pm

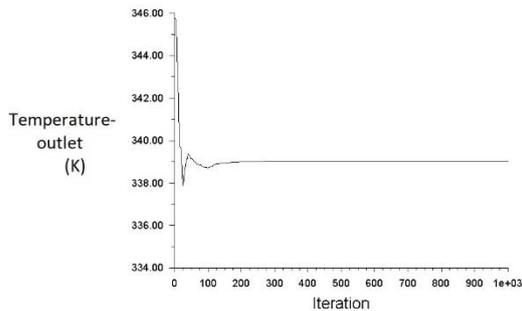


Figure 26: Simulation for 3:00 pm

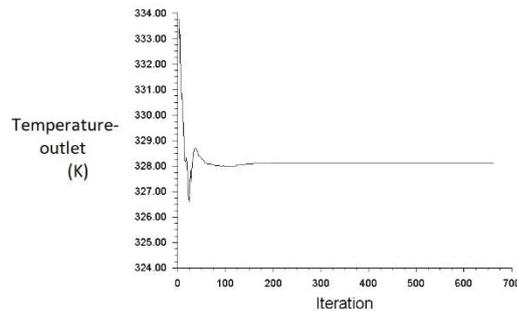


Figure 27: Simulation for 4:00 pm

It is possible to realize by the temperature monitoring graphs at the output that the temperature does not change with the iterations, a fact characteristic of the permanent regime. Thus, according to this indicative, it is assumed that when the properties of a flow do not vary with the iterations, the numerical solution converged. Therefore, when the mean temperature variations were less than 1%, the convergence reached was considered.

Table 3, below, relates the temperature of each simulation according to the number of iterations.

Table 3. Temperature values and their number of iterations

Schedule	Numerical Simulation Output temperature (°C)	Number of Iterations
09:00 am	48.78	231
10:00 am	66.39	364
11:00 am	69.53	201
12:00 pm	71.74	273
1:00 pm	73.18	210
2:00 pm	72.26	194
3:00 pm	65.61	219
4:00 pm	54.79	663

At 9:00 am, the lowest average temperature was observed at the exit of the dryer with a value of 48.78°C, while at 1:00 pm the largest was observed, equivalent to 73.18°C. This is corroborated by the fact that there is a lower solar incidence in the morning, while the highest solar incidence occurs near midday.

The numerical results of CFD compared to the experimental ones were arranged in Tab. 4 for the purpose of validation of the simulation.

Table 4: Comparisons of the output temperature between the experimental results and the computational simulation.

Schedule	Measurements by Gonçalves (2012) Output Temperature(°C)	Numerical Simulation Output Temperature(°C)	Relative error (%)
9:00 am	50.5	48.78	3.41
10:00 am	62.6	66.39	-6.05
11:00 am	72.4	69.53	3.96
12:00 pm	76.2	71.74	5.85
1:00 pm	77.1	73.18	5.08
2:00 pm	71.9	72.26	-0.50
3:00 pm	63.3	65.61	-3.65
4:00 pm	55.6	54.79	1.46

Table 4, above, shows a good correlation of the mean temperature obtained by the numerical and experimental results. In particular, at 12:00 pm and 2:00 pm, they show the highest and the lowest discrepancies in the average temperature. These discrepancies are very slight and do not exceed the value of 4.46°C and it is presumed that, although they are small, they are due to the sensitivity of the instruments used by Gonçalves (2012) to the simplification of the

model. In the same way, Table 5 was drawn which lists the dryer efficiency for each simulation schedule which is compared with the efficiency found by Gonçalves (2012).

Table 5: Comparisons of the instantaneous efficiency between the experimental results and the computational simulation.

Schedule	Measurements by Gonçalves (2012) Instantaneous efficiency (%)	Numerical Simulation Instantaneous efficiency (%)	Relative error %
9:00 am	17.89	19.13	1.24
10:00 am	19.36	24.15	4.79
11:00 am	20.00	21.25	1.25
12:00 pm	21.87	21.17	-0.7
1:00 pm	23.41	22.90	-0.51
2:00 pm	24.46	27.52	3.06
3:00 pm	22.91	26.31	3.04
4:00 pm	21.79	20.18	-1.61

It can be seen from Tabs. 4, 5 and 6 that the simulation reached values reasonably close to those of Gonçalves (2012). Numerical and experimental efficiencies approached significantly, with small discrepancies. According to table 6, the biggest difference between the efficiencies was of 4.79% for the time of 10:00.

3. CONCLUSION

The above study simulated, computationally, by CFD software ANSYS, a cabin-type solar dryer, already studied experimentally, by means of measuring devices, by Gonçalves (2012). The tests were performed both in the Numerical Simulation Laboratory of CEFET-MG, Campus II, and compared with the experimental results.

During the analysis of the model to be implemented, a thorough investigation was made of the operation of the methods and models considered in the problem. The same environmental conditions reported by Gonçalves (2012) were used in the problem. The most important parameters were air inlet temperature, incident solar radiation, mass air flow, outlet temperature and instant efficiency. It operated without any residue or charge inside it, an important condition for the analysis of the fluid dynamics (air) and thermal behavior of the equipment, as well as for dimensioning the solar collector that will serve as a component of the designed solar dryer.

In the analysis of the obtained data, a smooth difference of the results of the simulation in relation to the experimental results was perceived. The discrepancies are mainly due to the existence of truncation errors inherent to the numerical method, due to the fact that a simplified turbulence method (k-ε Standart model) was used in relation to other methods that would be too long and therefore unfeasible, mainly due to simplification such as constant solar incidence, permanent flow regime and no external interference. Even so, it can be said that the study was validated with the use of the simulation, since the errors are small compared with the dimensions and order of magnitude of the problem. The greatest difference in the output temperature compared to the numerical model was 4.46 ° C and the greatest difference in the instantaneous thermal efficiency, compared to the numerical model and the experimental results was 4.79%.

Thus, it can be said that this study will help in the development and analysis of new devices that use solar energy for drying purposes, and more efficient prototype of dryers. Therefore, after these comparisons one can conclude that the model is valid and that the CFD numerical simulation proves to be an extremely powerful tool for engineering.

4. REFERENCES

- Akpınar EK, Bicer Y, Cetinkaya F. Modelling of thin layer drying of parsley leaves in a convective dryer and under open sun. *Journal of food engineering* 2006; 75(3):308–15.
- Al-Juamili KEJ, Khalifa AJN, Yassen TA. Testing of the performance of a fruit and vegetable solar drying system in Iraq. *Desalination* 2007; 209(1–3):163–70.
- Ali MKM, Fudholi A, Sulaiman J, Ruslan MH, Yasir S Md. Sauna technique, drying kinetic modelling and effectiveness on solar drying compared with direct drying in drying process of *Kappaphycus striatum* in Selakan Island Malaysia. *Energy and Power Engineering* 2014; 6:303–15.

- Bagheri N, Nazilla T, Javadikia H. Development and evaluation of an adaptive neuro fuzzy interface models to predict performance of a solar dryer. *Agricultural Engineering International: CIGR Journal* 2015; 17(2):112–21.
- Chauhan P, Kumar A, Tekasakul P. Applications of software in solar drying systems: A review. *Renewable and Sustainable Energy Reviews* 2015; 51:1326–1337
- Çengel Y, Cimbala J M, *Mecânica dos Fluidos - Fundamentos e Aplicações* 1.ed. – São Paulo: McGraw-Hill, 2007
- Diamante LM, Munro PA. Mathematical modelling of the thin layer solar drying of sweet potato slices. *Solar Energy Journal* 1991; 51(4):271–6.
- Dutta G, Garg HP, Ray RA, Prakash J. Performance prediction of a cabinet-type solar drier. *Solar Wind Technology Journal* 1988; 5(3):289–92.
- Ferreira A, Gonçalves L, Maia C. Solar drying of a solid waste from steel wire industry. *Applied Thermal Engineering* 2014; 73:104-110
- Malalasekera, W; Versteeg, H. K; *An introduction to computational fluid dynamics. The finite volume method.* – 2.ed. Pearson Education Limited 1995, 2007.
- Maliska, C. *Transferência de Calor e Mecânica dos Fluidos Computacional.* 2.ed. rev. e ampliada. Rio de Janeiro: LTC, 2010.
- Orbegoso EM, Saavedra R, Marcelo D, La Madrid R. Numerical characterization of one-step and three-step solar air heating collectors used for cocoa bean solar drying. *Journal of Environmental Management* 2017; 203:1080-1094
- Pardhi C, Bhagoria JL. Development and performance evaluation of mixed-mode solar dryer with forced convection. *International Journal of Energy and Environmental Engineering* 2013; 4:1–8.
- Prakash O, Kumar A. Historical review and recent trends in solar drying systems. *International Journal Green Energy* 2013; 10:690–738.
- Prakash O, Laguri V, Pandey A, Kumar A, Kumar, A. A Review on various modelling techniques for the solar dryers. *Renewable and Sustainable Energy Reviews* 2016; 62:396–417
- Sharma S, Sharma VK, Jha R, Ray RA. Evaluation of the performance of a cabinet type solar dryer. *Energy Conversion and Management Journal* 1990; 30(2):75–80.
- Sun, C., Liu, Y., Duan, C., Zeng, Y., Chang, H., Shu, S., 2016. A mathematical model to investigate on the thermal performance of a flat plate solar air collector and its experimental verification. *Energy Conversion and Management Journal* 115, 43-51.
- VijayaVenkataRaman S, Iniyas S, Goic R. A review of solar drying technologies. *Renewable and Sustainable Energy Reviews* 2012; 16:2652– 2670

5. RESPONSIBILITY NOTICE

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