BEHAVIOR EVALUATION OF THE FLUID DYNAMICS OF A DRYING PROCESS TO OBTAIN ROOF TILES

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Abstract. Currently, several researches have been developed on the drying of ceramic materials, most of which are carried out experimentally. This process requires high investments and energy consumption, resulting in high costs for companies in the sector. The drying process can be defined as a unit operation that consists of removing water from porous materials through heat transfer. So, aiming at a better cost benefit, it is common to use theoretical solutions that allow, with relative ease of replication and low cost, to change operational and geometric conditions of the dryer or drying object. In this sense, this work aims to predict the drying process of a ceramic tile in a kiln via computational fluid dynamics (CFD). To carry out the simulations, the commercial package Ansys CFX® 22.R1 was used. For a drying temperature of 82,7 °C, the results of drying and heating kinetics, product moisture content, oven air velocity and pressure are displayed and analyzed. A comparison between predicted and experimental data of the average moisture content of the tile throughout the process was performed and a good agreement was obtained

Keywords: modelling; humidity; temperature; speed; heat.

1. Introduction

The fabrication of ceramic roof tiles comprises several phases: the exploration of deposits, the pre-treatment of raw materials, homogenization, drying, and burning. In roof tiles fabrication, water is added to the clay before conformation until a moisture content of 20- 40% is reached. Afterward, this material must be dried and then go into the kiln for the firing process [1].

The drying process is one of the most energy-consuming and complex processes in the production of ceramic materials, second only to the firing process. Its objective is to improve the production process of ceramic roof tiles to obtain a better quality end product. There is a need for the creation of new tools and the advancement of existing tools to reduce energy expenditures and optimize the time needed to obtain the appropriate humidity [2,3,4].

During the drying process, without proper control, high humidity and temperature gradients inside the solid can cause irreversible defects in it, such as cracks, deformations, and warping. This generates a loss of quality of the final product, or its total loss, decreasing the productivity of the process and increasing operational costs [1]. Ceramic materials when manufactured by air-enhanced processes result in shorter production time, less waste, less energy consumption, and thus a high-quality product that can be sold to the final consumer at a lower production cost [5,6].

With the technological development in numerical simulation studies, experiments done in laboratories can be carried out on a full scale, being able to eliminate temperature sensitivity, and higher humidity, thus extinguishing the uncertainties of experimental tests. Simulation can be said to replace the function of dryers and drying processes without having to build a prototype to perform these studies. Several advantages can be cited of numerical simulations, such as:

Possibility of distributing all variables (temperature, humidity rate, speed, etc);

Estimate the heat and mass transport coefficients of ceramic materials submitted for drying;

Hight sensitivity to notice the temperature and humidity changes inside the material, excluding uncertainties from experimental tests;

Predictive potential to model dryer processes with conviction and optimization;

Displacement of the liquid due to capillary forces;

The flow of liquid due to gravity.

In this context, the present research will aim to optimize the drying process of ceramic roof tiles through numerical simulation via computational fluid dynamics.

2. Methodology

2.1 Definition of Geometry and Mesh

To perform the mathematical modeling it was determined to use the commercial package ANSYS CFX® which consists of closed-code software, which contains already partitioned equations used to solve the problems. The package is composed of different programs, for the study of this research ANSYS ICEM-CFD® and ANSYS CFX were used. To create the geometry was used the blocking method with hexahedral elements. Figure (1) illustrates the geometry and its dimensions, and Figure (2) represents the mesh containing approximately 6084 elements and 8000 nodes. Using this method in the mesh construction it is possible to have greater accuracy about the gradients and their greatness.

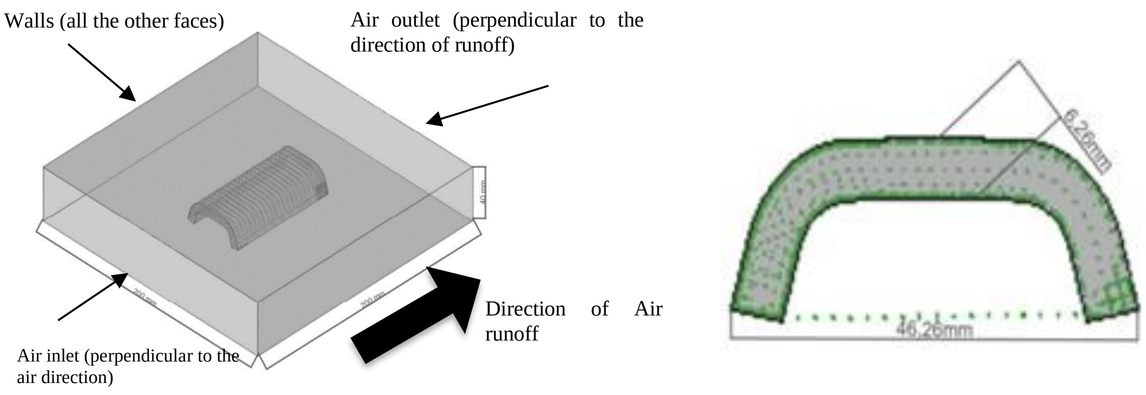

Figure 1. Geometry represents the complete domain and is highlighted on the roof tile.

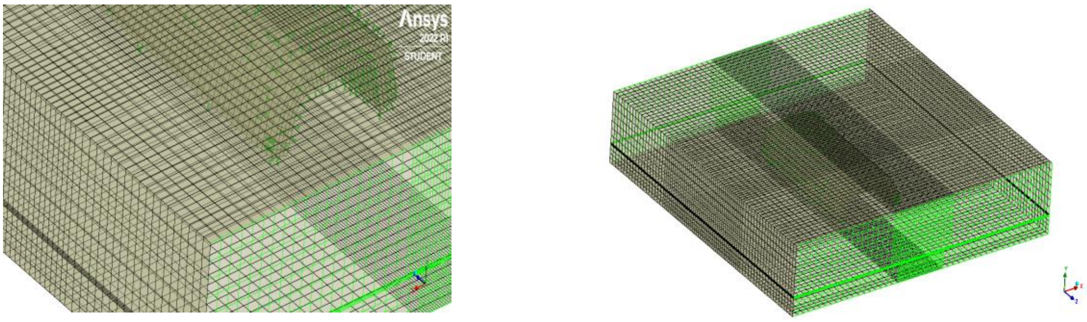

Figure 2. Numerical mesh representation of the domain roof tile/greenhouse.

2.2 Governing Equations

The roof tile drying phenomenon was studied based on the equations of conservation of linear momentum (Equations (1)), mass (Equations (2)), and energy (Equations (3)).

$$\frac{\partial}{\partial t}(\rho\vec{U}) + \nabla\cdot(\rho\vec{U}\otimes\vec{U}) + \nabla p - \nabla\cdot\{\mu[\nabla\vec{U} + (\nabla\vec{U}^T)]\} = 0 \tag{1}$$

$$\frac{\partial}{\partial t} + \nabla\cdot(\rho\vec{U}) = 0 \tag{2}$$

$$\frac{\partial}{\partial t}(\rho H) + \nabla\cdot(\rho\vec{U}H - \lambda\nabla T) = 0 \tag{3}$$

where ρ is the specific mass, $\vec{U}$ is the velocity vector, p is the pressure, μ is the viscosity of air, H is the enthalpy of the air, and λ is the thermal conductivity.

The transfer of energy between the solid surface and the fluid surface occurs through convection, the displacement encompasses the combined effects of conduction and fluid motion. The transfer by convection increases according to the velocity of the fluid. In the case discussed, the fluid is forced to emerge on the surface through external means.

2.3 Contour Conditions

To perform the simulations we used the parameters on the solid and fluid domains. The fluid in which the tile is inserted is composed of air (Table (1)) and it remains at a temperature of 82.7 °C. Because the equipment has the same pressure as the external environment, a relative initial pressure of 101325 Pa* was used. A material, clay, was created whose properties are shown in Table (1). A turbulent regime was adopted because when passing through the roof tile, the air encounters it generating small turbulence. To work with this turbulence, the $k-\varepsilon$ model was chosen because it is the most industrially applicable model.

Table 1. Air and clay properties

Properties	Air	Clay
Specific Heat Capacity [J $Kg^{-1}K^{-1}$]	1004,4	1673
Thermal conductivity [W m^{-1} K^{-1}]	0,0261	1,675
Density [kg m^{-3}]	1,185	1495
Dynamic viscosity [kg $m^{-1}s^{-1}$]	$1{,}831\text{x}10^{-5}$	

* atmospheric pressure

The simulations were performed using the commercial ANSYS CFX 22R1.1 package. This commercial software is responsible for using finite volume methods capable of discretizing conservation equations and simulating fluid flow volume and heat transfer in any geometric shape.

3. Results

Figure 3 illustrates the evolution of the moisture content over the drying time when the roof tile is being dried at a temperature of $82.7°C$. This figure indicates that the numerical results of the roof tile drying adequately fit the experimental data reported for [7,8,9]. A closer inspection of Figure 3 makes it possible to see good agreement between the experimental and numerical data.

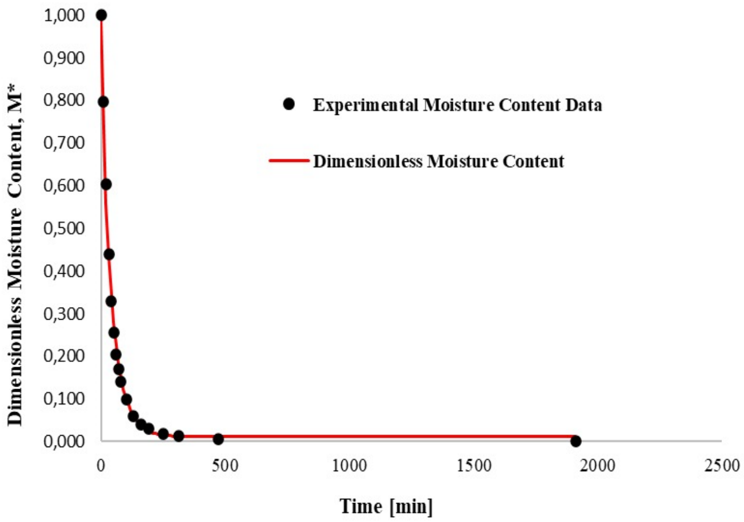

Figure 3. Humidity content of the roof tile as a function of drying time. (T=82,7 °C)

From a comparative study between the predicted value of the average moisture content and the experimental data, a minimum quadratic error of 0,068372 $(kg/kg)^2$ was obtained, using a mass diffusion coefficient of $20 \times 10^{-10}\ m^2/s$. This coefficient was obtained from curve fitting, in which its indication was taken through the smallest value of the variance and standard deviation.

3.1 Temperature field on the roof tile

The results of the analyses directed at the drying phenomena related to ceramic roof tile separately at a temperature of 82.7 are shown below. then it is possible to check the temperature distribution inside the solid that occurred during the process concerning the plane: XY ($Z = 0.04$ m), Observing the figures it can be seen that in the initial instants (t = 10 minutes) the temperature has a low variation, that is, it remains close to its initial value. After 60 minutes it is noted that the temperature has a considerable increase, however, it is not yet its maximum value Plan XY ($Z = 0.04$ m) which, in turn, will be reached only when it exceeds 1910 minutes which is $T = 82.7\ °C$. Figure 4 is represented the temperature field inside the roof tile.

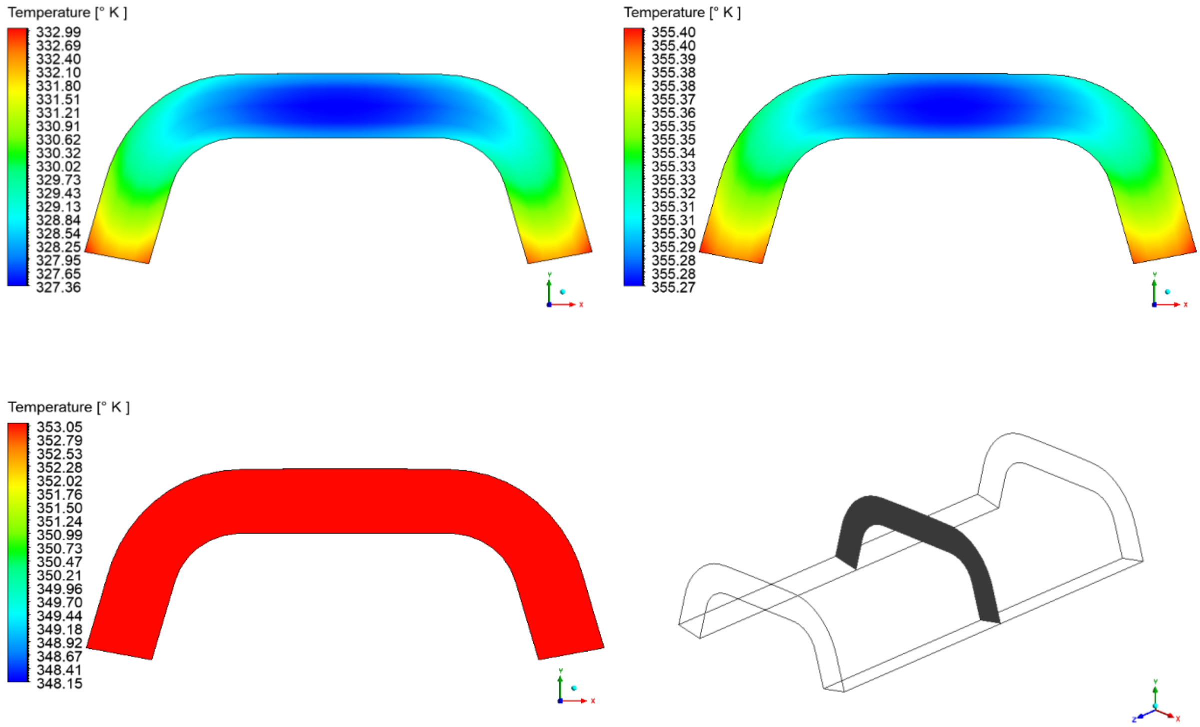

Figure 4. Temperature field on the roof tile.

3.2 Temperature distribution in the air (roof tile/greenhouse)

The air distribution inside the oven is represented below at different drying times and conditions. Based on the analyses performed it is possible to verify the heat transfer that occurs spontaneously between the air with high temperature and the roof tile with less high temperature. Inside the greenhouse, as the air passes through the roof tiles, it experiences a slight decrease in temperature. It is possible to observe that this decrease occurs close to the surface of the tile and within its boundaries. The air temperature has a greater variation in the initial minutes of drying, whereas the roof tile has a greater temperature gradient between the greenhouse roof tile. In Figure 5 it is possible to observe the air temperature distribution inside the greenhouse.

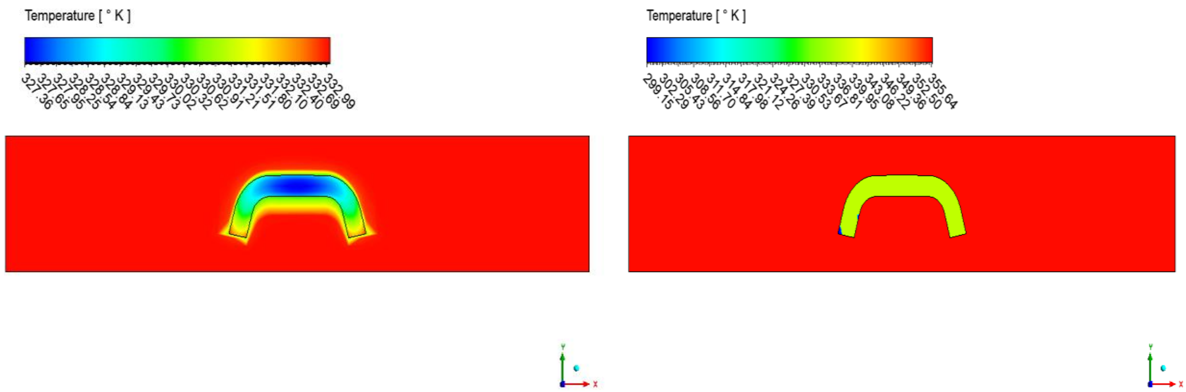

Figure 5. Temperature distribution in the air (roof tile/greenhouse).

3.3 Water mass field on the roof tile

Performing analyses around the created plane, XY axis ($Z = 0.04\ m$), the water mass field is homogeneous in the first few moments ($t = 0$), including only the mass corresponding to the absolute humidity of the drying air. Over time it is observed that as air passes through the ceramic roof tile, the mass of water is transported and is thus eliminated from the material and immediately transferred to the drying air. Figure 6 represented the water mass field oven and Figure 7 the water mass field (roof tile/greenhouse), drying times, and conditions.

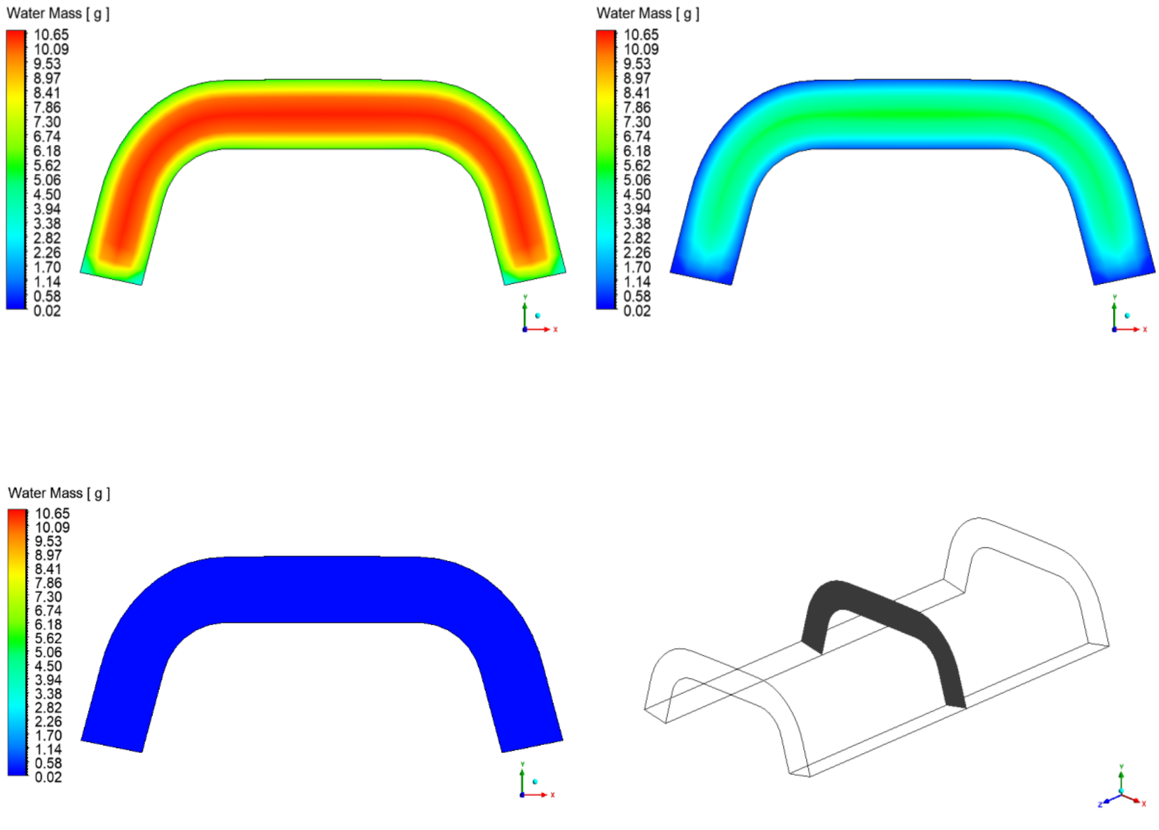

Figure 6. Water mass field on the roof tile.

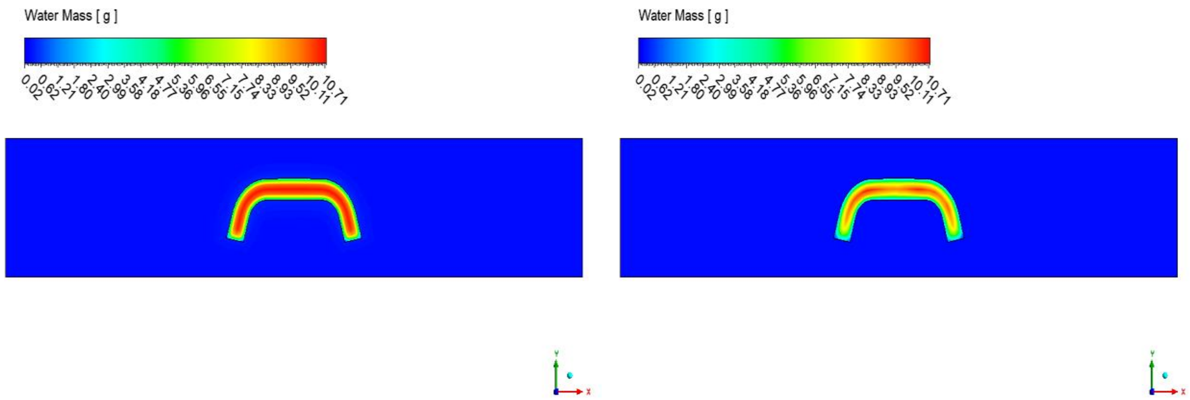

Figure 7. Water mass field (roof tile/greenhouse)

4. Conclusions

In view of the data obtained for the drying of the solid brick, it is concluded:

The suggested mathematical modeling was appropriate and the temperature on the roof tile and the mass of water lost showed a good match with the experimental data.

It has been noticed that the humidity decreases when there are more intense increases in temperature.

You can see the humidity and temperature variations on the surface of the roof tile.

5. References

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