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# NUMERICAL SIMULATION OF DRYING OF POROUS CERAMIC INDUSTRIAL BRICK: ANALYSIS OF PARAMETERS OF TEMPERATURE AND MOISTURE CONTENT

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***Abstract.*** *Several studies on the drying of ceramic materials have been developed in the various engineering and manufacturing sector. Such materials can be used for traditional applications. In many situations, it is common to use theoretical solutions such as numerical simulations that allow, with relative ease and low cost, to change the operational and geometrical conditions of the dryer or object of drying. In this sense, the results of the numerical study on the drying of ceramic bricks are presented. The brick used is a porous medium with 0.287 porosity and a permeability of* $5.75x10^{-15}m^2$*. The conservation equations of mass, momentum, energy and matter were considered. The results of the field of pressure, velocity, temperature and volumetric fraction of the water inside the brick obtained by the commercial package Ansys CFX ®were analyzed. The results of the simulations were compared with experimental data and good agreement was observed, which allowed to analyze and discuss the results of the brick drying.*

***Keywords:*** *Transfer of heat and mass; Ceramic brick; Drying.*

## 1. INTRODUCTION

The drying process employs two study approaches: theoretical and experimental. Mathematical and numerical modeling has some advantages compared to analytical and experimental solutions, such as the possibility of having a detailed distribution of variables (temperature, humidity, velocity, etc.), which in Technical issues, it is often not possible to have experimentally. On the other hand, due to the complexity of the drying process, the study and the optimization require often complex mathematical models, which result in obtaining solutions with adequate physical realism (Silva, 2009). To understand this process, it is necessary to study the distribution of temperature and moisture content of the material and later the various mechanisms that describe mass and heat transfer in its interior (Nascimento, et al (2015), Silva. et al (2012) Batista et al (2008), Batista, et al (2009)). This work aims to make simulations, and to compare with experimental data, on the process of heat transfer and mass in the drying of fused bricks.

## 2. METHODOLOGY

In this section, the results of the study problem which consists of drying a hollow ceramic brick of eight (8) holes via Computational Fluid Dynamics (CFD) are presented.

### 2.1 Geometry and Mesh Definition

In this work, the domain of the eight-hole ceramic brick (porous medium) molded in a controlled oven where there is heat exchange between the medium and the object of study was considered. Figure 1 shows the dimensions of the brick used. These dimensions were based on the work of Silva (2009).

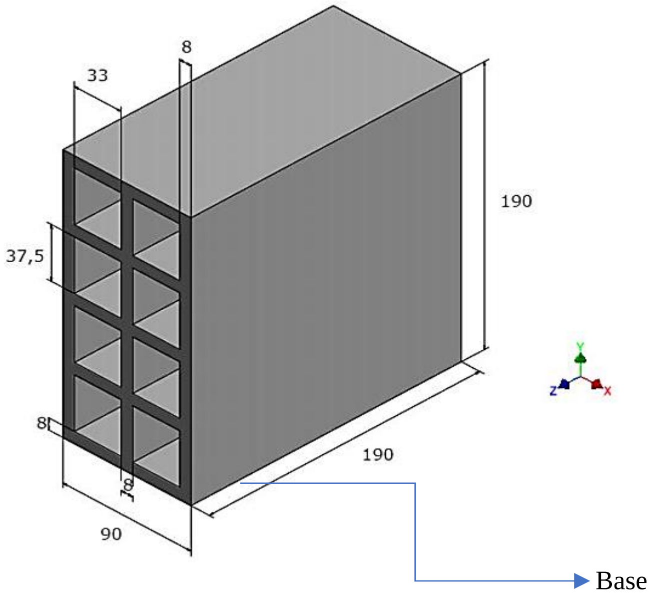



Figure 1. Representative domain geometry highlighted in the 8-hole hollow brick.

Figure 2 shows the numeric mesh of the brick and some details. The mesh was generated by using ICEM CFD. After different refinements and a study of mesh dependence, we verified that the mesh with 568 thousand elements was the one that best fits the experimental data.

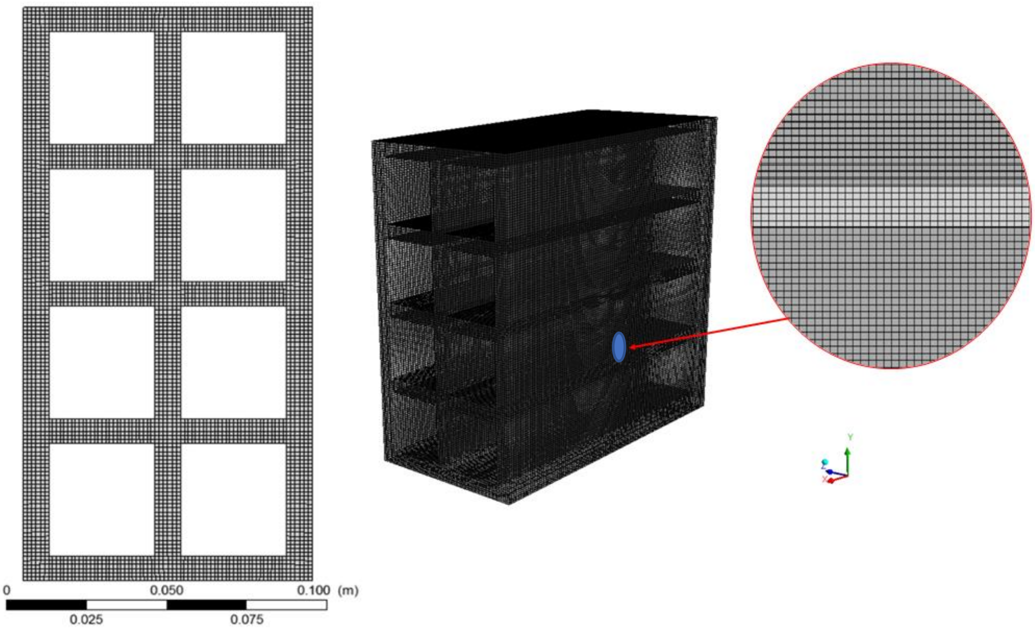



Figure 2. Finite element Mesh in the 8-hole hollow brick.

### 2.2 Mathematical Model

In this work, in the development of the model, the following considerations were assumed:
• Transient, laminar and non isothermal flow;

• No chemical reaction or mass transfer between phases;
• Chemical constant properties;

The equations of energy, mass conservation, linear momentum and transport were considered in mathematical modeling.

a) Mass Conservation Equation

$$\frac{\partial}{\partial t}\phi\rho + \nabla \bullet (\rho \mathbf{K} \cdot \vec{U}) = 0 \tag{1}$$

where $\phi$ is porosity, **K** Permeability, $\rho$ density, U velocity vector and $t$ is the time.

b) Linear Momentum Equation

$$\frac{\partial}{\partial t}(\phi\rho\vec{U}) = -\nabla \bullet (\mu \mathbf{K} \cdot (\nabla\vec{U} + (\nabla\vec{U})^T)) + S_i^M \tag{2}$$

where $\mu$ viscosity, $T$ Temperature and $S_i^M$ is defined by:

$$S_i^M = -C^{R_1}\vec{J} \tag{3}$$

where $C^{R_1}$ is linear coefficient resistance and $\vec{J}$ ¨superficial velocity vector.

c) Energy Equation

$$\frac{\partial}{\partial t}(\phi\rho h) + \nabla \cdot \left(\rho \mathbf{K}\vec{U}h\right) = -\nabla \cdot (k\mathbf{K}\nabla T) \tag{4}$$

where $k$ conductivity.

d) Transport Equation

$$\frac{\partial}{\partial t}(\phi\rho M) + \nabla \cdot \left(\rho \mathbf{K}\vec{U}M\right) = -\nabla \cdot (D\mathbf{K}\nabla M) \tag{5}$$

where $M$ is moisture content, D represents the mass diffusion coefficient.

### 2.3 Boundary Conditions

For the present work, experimental data collected from the article of Silva, et al (2011) were used and compared with the numerical results, and the contour conditions were chosen. The article of Silva, et al (2011) consisted of the study of the drying of hollow ceramic bricks in a laboratory oven at a specified temperature and relative humidity. In the experiment, the initial values of moisture and temperature of the ceramic brick were taken, as well as the moisture content and the temperature values throughout the process.

The simulations were performed applying the conditions of contour, temperature and moisture content to the brick domain in all the walls except for the base that is in contact with the surface, which was adopted as being adiabatic. The condition of temperature (80°C) and moisture content (volumetric fraction Me = 0.00039) was assumed, and with an initial prescribed condition of temperature (21.4°C) and moisture content of the brick (Mo) are seen in Table (1), where Numerical results were generated up to the drying time of 15 h. A transient regime was adopted.

Table 1. Parameters of ceramic brick Silva (2009) and properties used in the simulation.

| Ceramic Brick | | | | |
|---|---|---|---|---|
| $M_o$ (b.s) | $M_f$ (b.s) | $M_e$ (b.s) | $\theta_0$ (°C) | $\theta_f$ (°C) |
| 0.15248 | 0.0 | 0.00039 | 21.4 | 69.2 |

| Ceramic Brick | | | | | |
|---|---|---|---|---|---|
| k (W/m.C) | $c_p$ (J/kg.K) | ρ (kg/m³) | D x$10^{10}$ (m²/s) | $h_m$ x$10^{30}$ (m/s) | $h_c$ (W/ m².°K) |
| 0.8364 | 878.22 | 1775.4 | 8 | 1 | 1.5 |

A statistical treatment was carried out, which allowed to evaluate the best coefficient of heat transfer, and after several adjustments, points to the value of 1.0W / m².K.

In addition to the statistical analysis to obtain the best heat transfer coefficient, a comparative analysis of experimental data collected in literature of Silva (2009) with numerical data was performed. The values obtained were through the minimum square error (MSE), which is the sum of the differences between the estimated value and the actual value of the data, weighted by the number of experimental data, as shown in the following equation:

$$MSE = \sum_{i=1}^{n} \left(\emptyset_{i,num} - \emptyset_{i,exp}\right)^2 \quad (6)$$

where $n$ is the number of experimental data, $\emptyset_{i,num}$ is the numeric value and $\emptyset_{i,exp}$ is the experimental value.

## 3. RESULTS AND DISCUSSION

In order to observe the effects of drying kinetics, an analysis was performed comparing experimental data with the numerical data of the mean moisture content and the dimensionless mean temperature of the brick according to time and a temperature of 80°C. "Fig. 3" shows that the loss of moisture content occurs more slowly compared to the heating of the brick according to time as was expected. From a comparison of the predicted mean moisture content and the experimental data, we obtained a minimum square error of 0.003 (kg / kg) ², using a mass diffusion coefficient of 8x$10^{-10}$ m²/s. For the surface temperature (vertices) of the brick, a minimum square error of 27.1 (° C) ² was obtained when we used a heat transfer coefficient of 1.0 W / m².K. When analyzing the curves, a good agreement between the average moisture contents and average temperatures is perceived. Thus, it is concluded that the proposed model describes both the surface temperature and the average moisture content of the ceramic block under study.

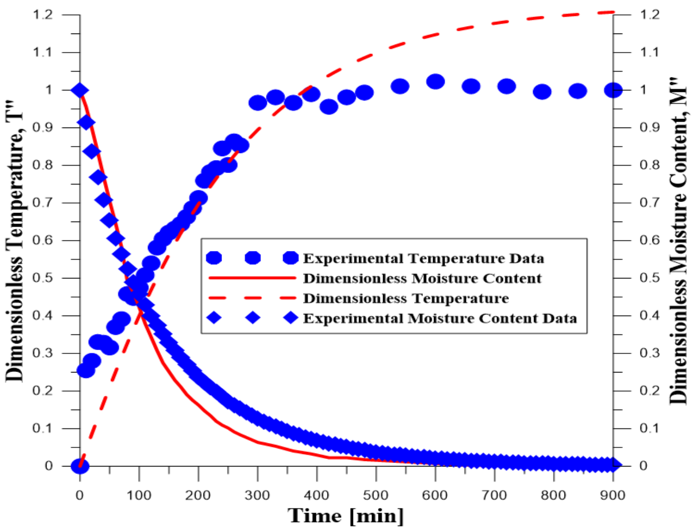
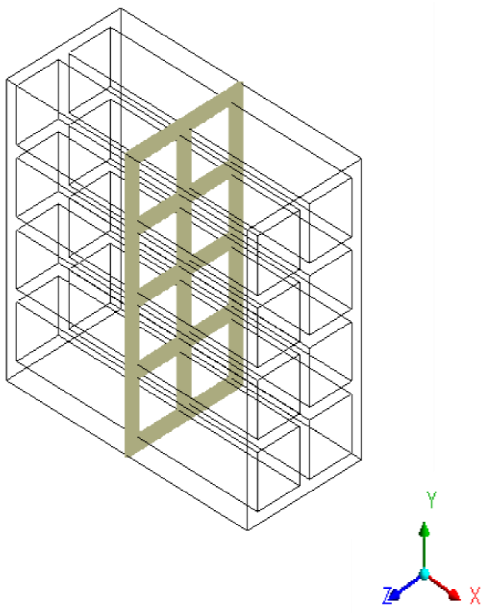
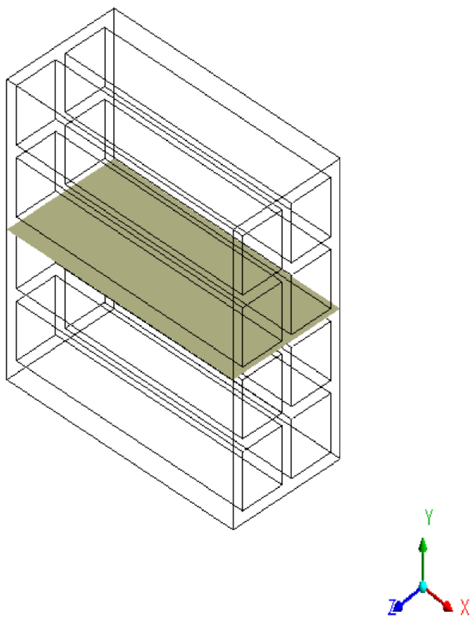



Figure 3. Curves of the average moisture content and the dimensionless surface temperature of the brick based on time for drying at 80°.

In order to analyze the behavior of temperature and humidity inside the brick, the planes yz (x = 0.095 m) and zx (y = 0.095m) were constructed, shown in “Fig. 4”. The temperature fields and the simulation at different instants are shown in “Fig. 5 and 6”. According to “Fig. 5”, which represents the temperature fields, it is verified that the highest temperature gradients are located in the regions near the vertices of the brick, since these regions are in more intense contact with the drying air. With this, they are more susceptible to the appearance of defects in the piece. It should be emphasized that if we take a plane closer to the region that is in contact with the heat flow, it is probable that we will have different temperature fields. That is, the vertices of the brick will be warmer and therefore there may be a contraction. It is noteworthy that, even after a certain considerable drying period, the brick does not achieve uniformity of temperature; there are still small variations in this parameter in the regions within the material. The same behavior is shown in the horizontal plane in “Fig. 6”. This behavior is due to the low coefficient of convective heat transfer.




a)




b)

Figure 4. Representation of the planes a) yz and b) zx

The temperature e moisture content fields "Fig. 5,6,7 and 8" were taken from the yz and zx plane as shown in “Fig. 4”.

In this work, the liquid diffusion theory was used to explain the drying process of the brick. It was considered at the beginning of the drying that a liquid film of the surface was already released and therefore, the surface of the material already reached equilibrium moisture, border conditions. Thus, it can be observed that, in “Fig. 7”, the moisture content at the surface is 0.00039 dry basis (equilibrium condition) at all drying times. And under these conditions, the drying air velocity no longer influences the drying rate of the material. Drying occurs during the drying rate drop period. Another important observation is related to the gradient of moisture content within the material. Unlike temperature, gradients are also observed between the interior of the material and the surface.

It is noteworthy as observed that the higher temperature gradients within the material are concentrated at the vertices, where the moisture content also occurs, and thus may compromise the quality of the brick after drying, increasing the water and thermal stresses of the material, which is directly related to the presence of cracks and deformation of the brick.

Therefore, as a consequence the control of the drying parameters generates the control of the convective heat transfer coefficients and mass at the surface of the solid.

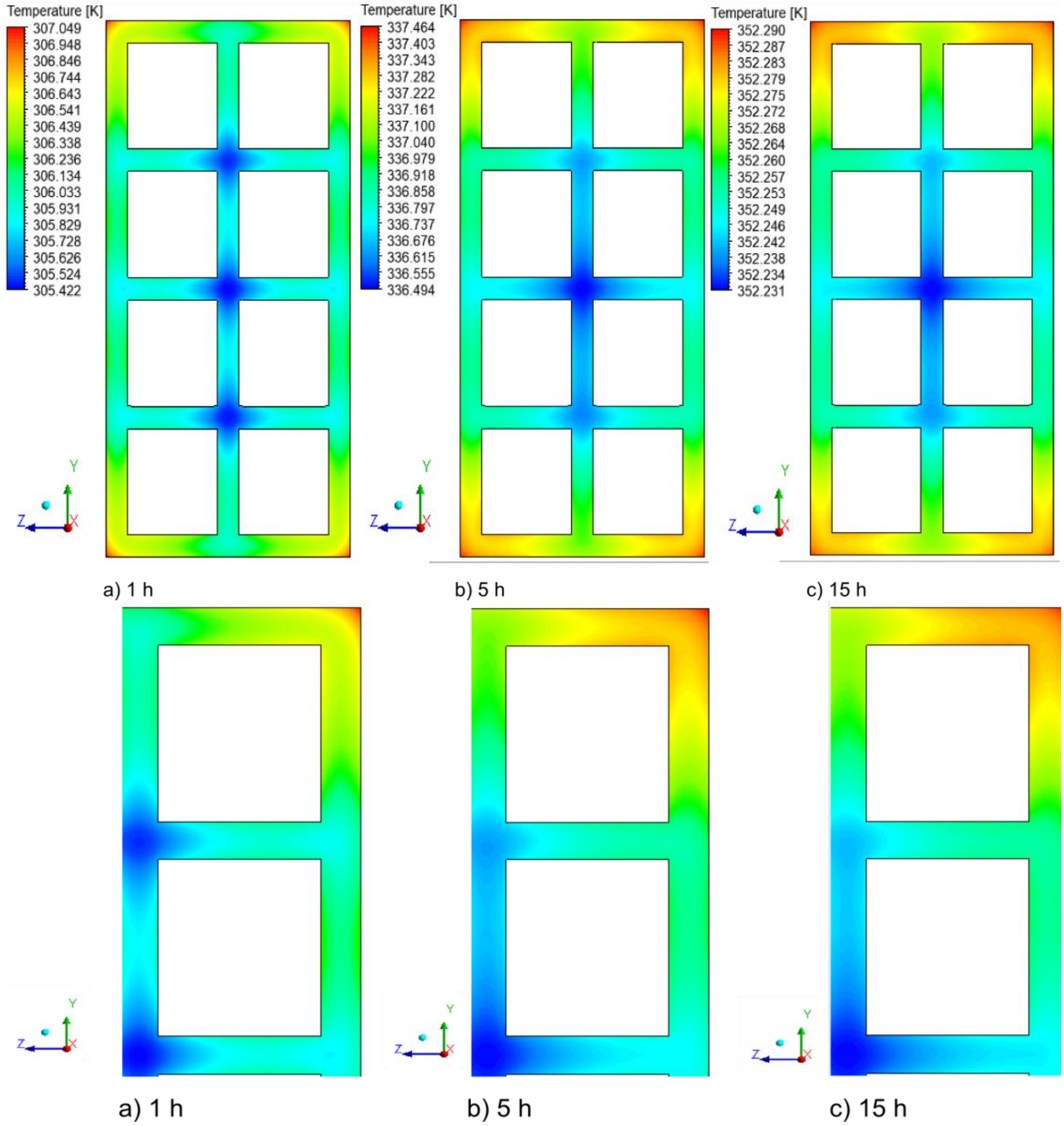



Figure 5. Representation of the Temperature Fields (Plane yz).

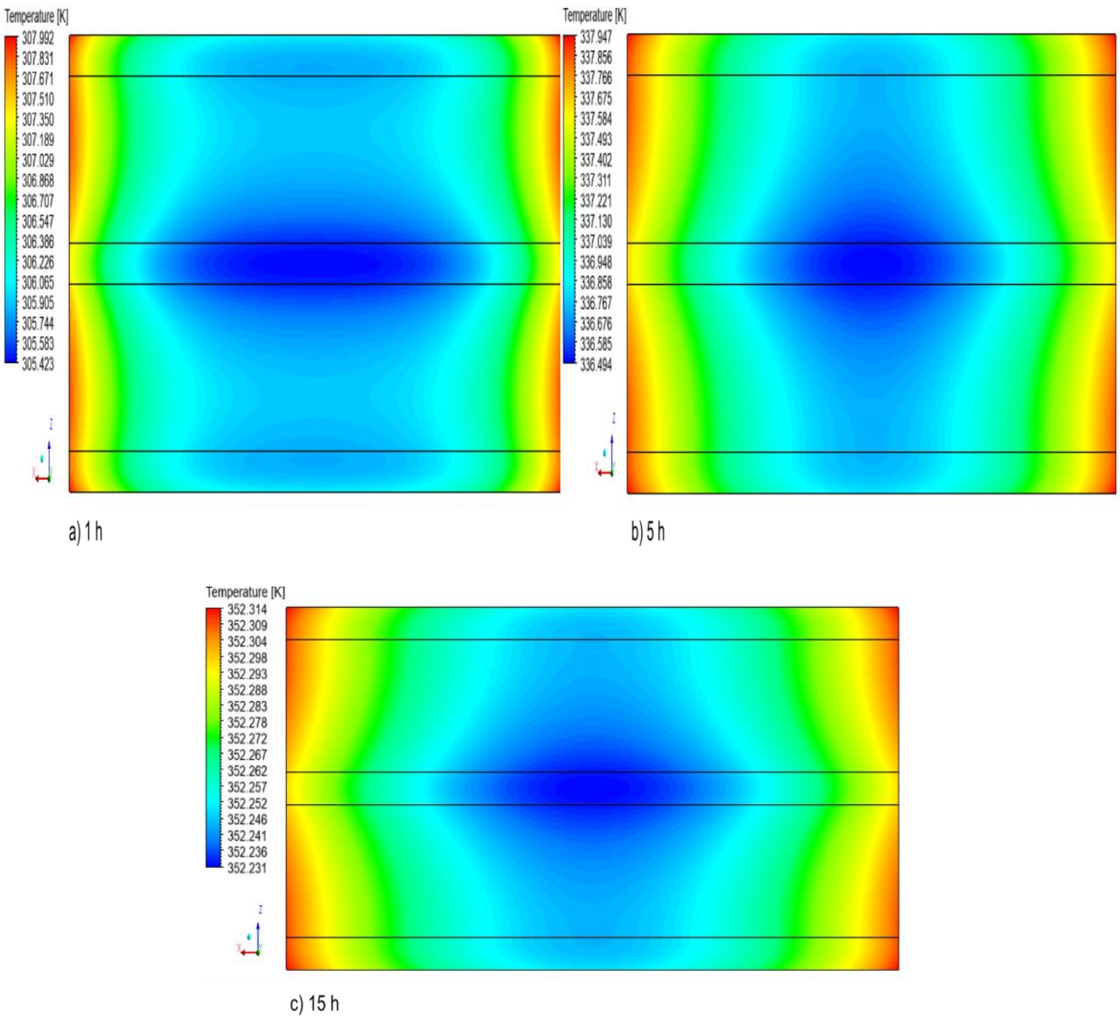



Figure 6: Representation of the Temperature Fields (Plane zx).

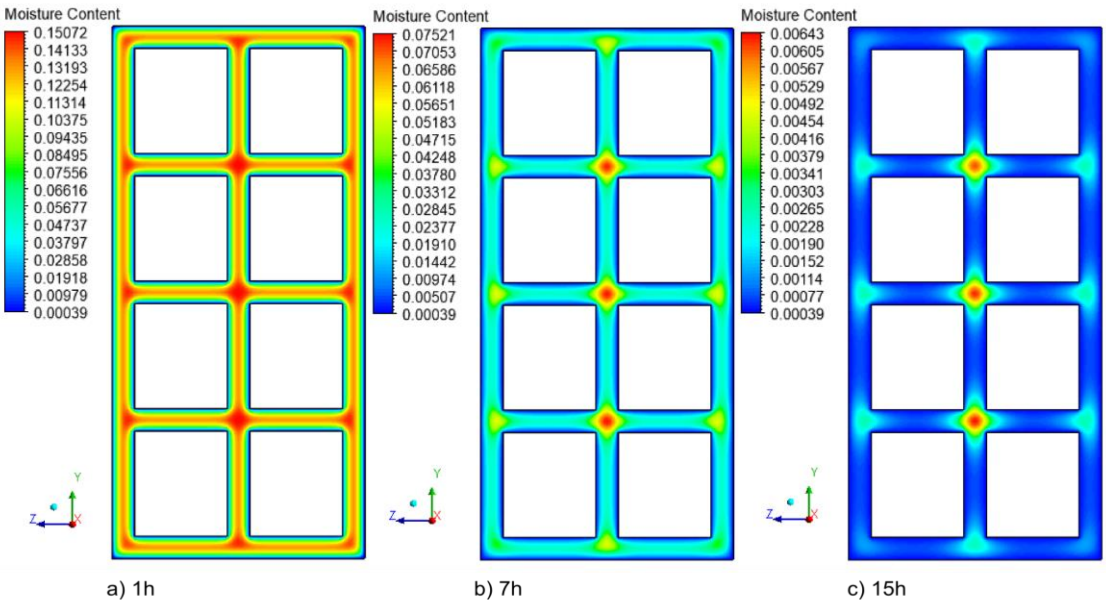



Figure 7: Representation of the Moisture Fields (Plane yz).

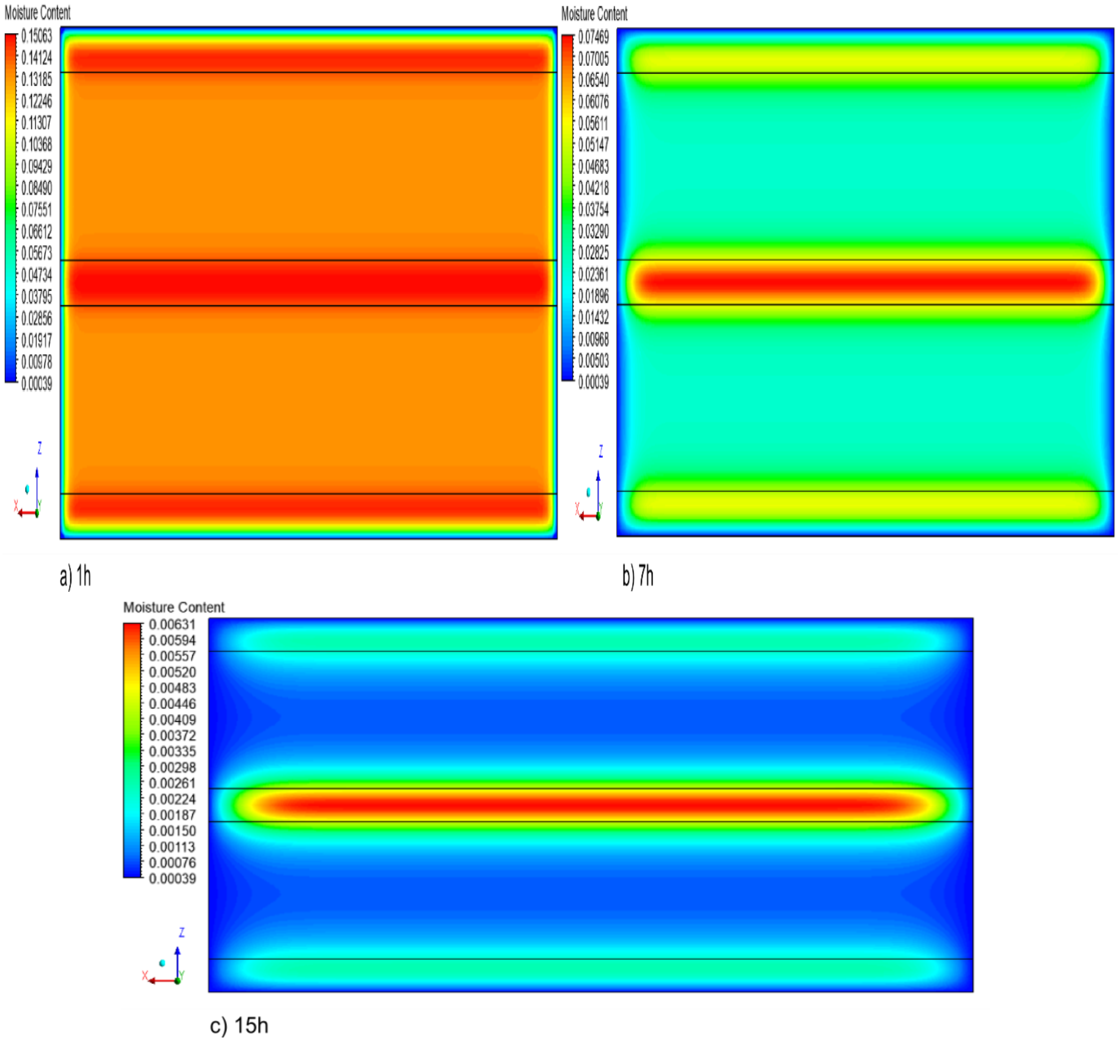



Figure 8: Representation of the Moisture Fields (Plane zx).

## 4. CONCLUSIONS

Considering what was developed in this work, some information about the drying of cast ceramic bricks can be highlighted:

a) A good approximation between the curves referring to the numerical and experimental data is verified, making the use of the applied computational program possible.
b) The humidity and temperature fields indicate that higher temperature gradients are located in the regions near the vertices of the brick and consequently have lower moisture content than in the interior.
c) The humidity and temperature fields allow the verification of the regions of higher gradients, which are the regions where cracks and deformations are most likely to occur, and can reduce the quality of the product after the drying process.
d) With the adjustment of the heat transfer coefficient a better curve compared to the experimental data was obtained.
e) From the obtained results, it is concluded that the adopted model based on the diffusion theory and the solver showed an acceptable behavior to evaluate the heat transfer and the mass of the ceramic brick and relative humidity. This can be used in future works for the optimization and studies of phenomena in the same line of research.

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