EXPERIMENTAL STUDY OF DETERMINATION OF DRYING GREAT FLOW IN A DRYER ELECTRIC CABIN TYPE

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Abstract: *Currently approximately 36% of all produced perishable foods are lost before they reach the shelves. Dehydration presents itself as a highly viable method for solving this problem. After the construction of an electric type dryer cabin evidenced a 13.5°C temperature difference underside and upper of the dryer. With the structural changes suggested this temperature difference reduced to 2.9°C. However, tests carried out since the construction of the dryer has shown that the mass flow of the air dryer operating suggested in the literature, it was not appropriate and the thermal efficiency and the drying device may increase. Therefore, this study was conducted an experimental study maximization of efficiency of the dryer as a function of the flow variation and the air temperature within the device. The tests performed showed that the best and most effective procedure must be done with a temperature of approximately 63°C and the speed of entry into the dryer is about 2.5m/s, generating a power consumption of 44.4 kWh. From this method it was obtained a drying efficiency of 11.4% and more economic options dryer use.*

Keywords: *Dehydration; energy efficiency; mass flow; temperature.*

1. INTRODUCTION

Brazil is a bigger global producer of perishable agricultural products, but faces serious problems regarding transportation, storage and conservation of these foods, it lacks the research and development of efficient drying processes that minimize losses and increase shelf life of several products. Dehydration is one of the processes used in the conservation of food products without their significantly lose their biological properties as well as being an economic process compared to others we employ temperatures close to ambient. In practice, the dehydration of a food is the removal of part of its free water to a level at which it can be fed and/or stored at ambient temperature without significant loss of its organoleptic and nutritional properties (FELLOWS 2006).

Among the types of drying that are used currently can be detached natural drying in which foods have more intense color that dried artificially. However, there are more losses than in the drying under controlled conditions and depends entirely on the climatic conditions to obtain a good condition of storage. Another process is the artificial drying which consists of mechanical dryer use to remove the moisture from the fruit through a forced convection.

The artificial drying features as benefits in relation to the natural drying process control and the possibility of continuous use. However, humidity, temperature and drying rate, are variables that must be controlled in order to obtain an efficient drying, with a smooth flow of air, radiant minimum thermal losses and hence increasing efficiency.

Some work on energy efficiency and analysis of variables that alter the process are being analyzed, as Bittencourt (2001), Machado (2009), Holtz et al. (2009), Costa (2008), Lourenço (2011), Furtado et al. (2010), Ferreira et al. (2012), Ozuna et al. (2011), Rezende (2011), Vilhalva et al. (2012), Rocha et. al (2012).

Designed and tested through various trials the dryer type cabin analyzed in the present work should be handled with the use of cross screens that direct the flow of air leaving the more homogenous movement, better distributing the heat in the place where the products are to be put to dehydration, reducing the large differences in temperatures registered in initial analyzes. However, thermal drying test showed that the relative humidity of air in dryer output is much lower than the inlet during the whole test. This fact is a strong indication that the air flow in the dryer was overestimated by the project relationship 0,003125m^3/s air for each 1 kg of moist product to be dried, suggested by Leon et al. (2002).

Therefore, the aim of this study is to identify, by experimental method, the ideal flow of drying air by mass of water contained in the product to be dried, and performing an experimental assessment of thermal conditions (speed, temperature, absolute humidity and moisture relative) of the drying flow and determining the thermal efficiency and drying of the device during different operating conditions.

2. MATERIALS AND METHODS

2.1 Equipments

The tests were performed in a dryer consisting of a wooden structure with small weight and large mechanical strength. Internally the wall of the dryer is composed of a galvanized steel sheet and a glass fiber inner layer. In addition to a fan (whose function is to force the flow of air into the dryer) and an electrical resistance with power 3kW (for the drying air heating). Also galvanized steel trays were inserted with dimensions of 0.7m x 0.5m and useful area of 1.75 m^2 drying fixed on a sheet structure, connected by a steel cable with a load cell to monitor the variation the instantaneous mass of the product (Figure 1). As suggested by Leon et al. (2002), the drying capacity of a dryer is from about 4 kg of wet product for each tray area of $1m^2$. Therefore, the drying capacity is estimated at 7 kg.

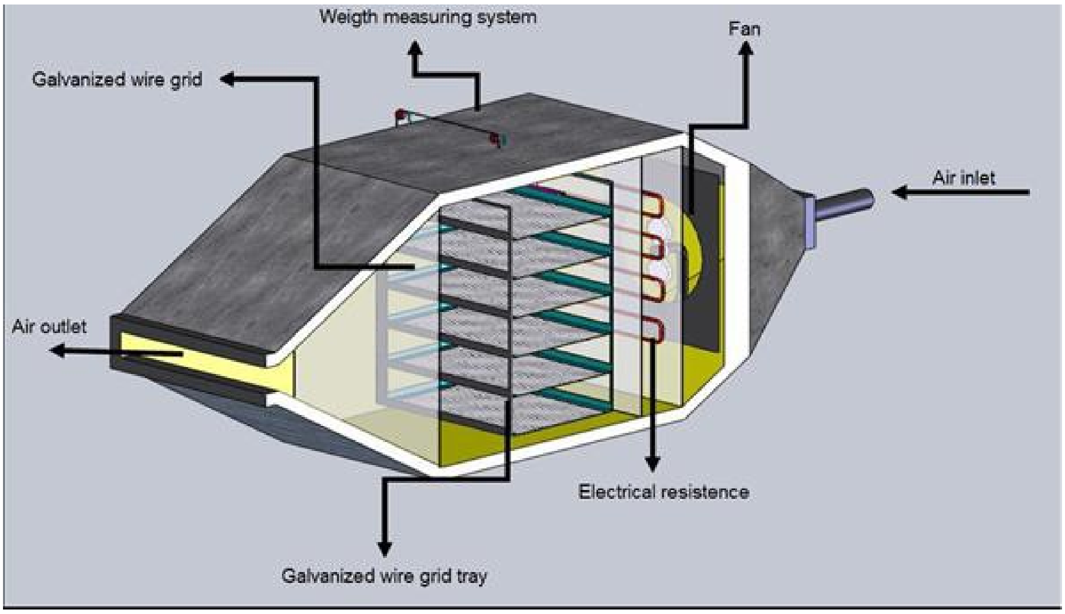

Figure 1 - Schematic representation of the dryer.

2.1 Experimental Procedure

To collect all the necessary data and evaluation of the dryer's performance, we used a digital oven drying and sterilization (New Technique, model 42L) for evaluation of the initial moisture content. A digital scale (Toledo, model 9094; 1g of measurement uncertainty) to collect the mass of bricks. A load cell (with measurement uncertainty of 0.2% of the value read). A thermo-hygro-anemometer for measuring the speed, temperature and relative humidity of the air flow (Icel, AN-4870 model, measuring range air velocity of 0.1m/s to 35 m/s and 3 of measurement uncertainty % of the value read, temperature measuring range from -20°C to 70°C with 0.6°C measurement uncertainty, and moisture measurement range of 0% relative to 100% with 3 measurement uncertainty % to measurement range of 10 to 90% and 5% for all other measuring ranges). Pliers power meter for measuring active energy expended by the dryer during the drying process (Icel, AW 4700 model, active power measurement resolution 0,001kWh, and measurement uncertainty of 3% of the value read). A digital thermometer thermocouple for reading temperatures of type "K" with two channels (Icel, Model TD 880, resolution of 0.1°C and measurement uncertainty determined in the process of calibration and uncertainty analysis). A thermo-hygrometer with datalogger (Icel, HT 4000 model, 3% measurement uncertainty for relative humidity and 1°C for temperature). All measurement uncertainties are set for a probability of 95% framework.

In the experiments, to simulate drying, the raw materials were chosen common laminated ceramic bricks without holes obtained on the spot trade Belo Horizonte - MG, with average dimensions of 20cm x 9.5cm x 4.9cm and without significant variations format, mass and porosity. The brick besides being a hygroscopic material have low cost and easy to purchase. Thirteen bricks were collected previously inserted into containers filled with water for 24 hours to the maximum possible water absorption. Before being placed in the dryer bricks were pre-weighed and calculated mass and initial moisture. Twelve of these bricks have been placed in the dryer so that were arranged in six two columns (Figure 2).

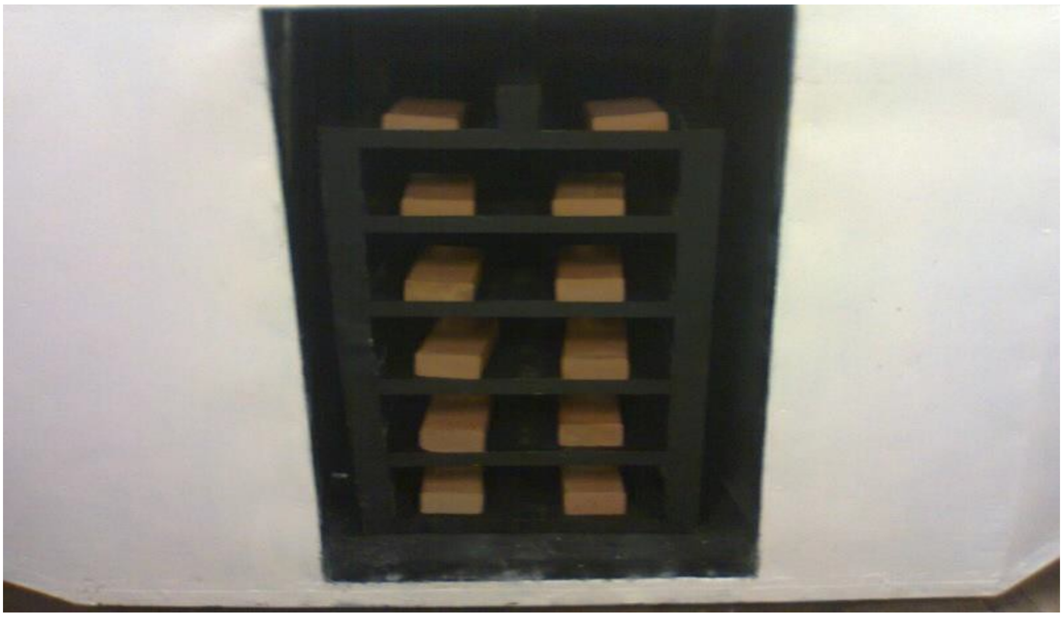

Figure 2 - Arrangement of bricks inside the dryer trays.

The last brick was placed within the sterilizer, a predetermined temperature of 105°C. Four experiments were performed on a permanent basis. The first test with a maximum drying flow and preset temperature 60°C. The second the same flow rate, but with 50°C. The third flow rate with minimal drying and 60°C. On the last trial, flow remains at the third and 50°C. According to the literature, the maximum speed stipulated drying would be 7 m/s minimum speed of 2.5 m/s. Temperatures of 50°C and 60°C were determined to be optimal for the dehydration process under the conditions studied. The required temperature was controlled by a PID controller coupled on the outer upper part of the dryer, causing the heat generated by electrical resistance would supply the necessary demands at every instant. All test were uninterrupted duration of 34 hours.

3. MATHEMATICAL MODELING

The initial humidity test was performed in a drying and sterilizing oven at 105°C for a period of 24 h. According to NBR 9939 (1987) the initial humidity can be calculated using Equation 1.

$$U_{i(B.U)} = \frac{m_i - m_f}{m_i} \tag{1}$$

Where $U_{i(BU)}$ is the initial humidity content on a wet basis, m_i the initial sample mass m_f and the final mass of the dry sample. The instant humidity content of brick in the process, on a wet basis, was obtained from the Equation 2. According to this Equation, it can be seen drying behavior. By means of a load cell, it was possible to determine the instantaneous mass of the raw material.

$$U_{X(B.U)} = 100\% - \left[\frac{m_i}{m_x} \quad (100\% - U_{i(B.U)})\right] \tag{2}$$

Where $U_{x\,(BU)}$ is the instant humidity content on a wet basis, m$_i$ is the initial mass, m_x is the instantaneous mass in gram in a given time and $U_{i\,(B.U)}$ is the initial humidity content of the product in a wet basis.

The useful energy due to the heating of the air flow inside the vacuum dryer ($\dot{W}$) was determined as a function of mass flow rate of the air flow ($\dot{m}$), the specific heat at constant pressure (C_p) at room temperature (T_e) and output (T_s) of the air flow

$$\dot{W} = \dot{m}c_p\,(T_s - T_e) \tag{3}$$

The total energy (E_T) used for dryer operation calculated by the Wattmeter is given by

$$E_T = \int \dot{W} dt \tag{4}$$

According to Leon et al. (2002), the thermal efficiency of the vacuum dryer (η_{hc}) can be evaluated the Equation 5.

$$\eta_{hc} = \frac{\dot{W}}{E_T} \tag{5}$$

The drying efficiency (η_D) can be evaluated from the equation 6.

$$\eta_D = \frac{\int \dot{m}_{H2O} \cdot h_{lv}\, dt}{\int \dot{W} dt} \tag{6}$$

Where h_{lv} is the latent heat of vaporization of water in $\dot{m}_{H2O}$ is the mass flow rate of water removed by the drying air flow.

4. RESULTS AND DISCUSSION

After four tests, the most convenient and effective method for drying speed was with temperature of 60°C. Table 1 shows for each test the drying efficiency. The drying efficiency is low and higher flow temperature of the air flow.

Table 1 - Testing Drying Efficiency

Drying Efficiency	V=2,5m/s	V=7,0m/s
T=50ºC	9,8%	7,5%
T=60ºC	11,4%	8,1%

Figure 3 shows the inlet temperature and dryer air outlet for this test best drying efficiency.

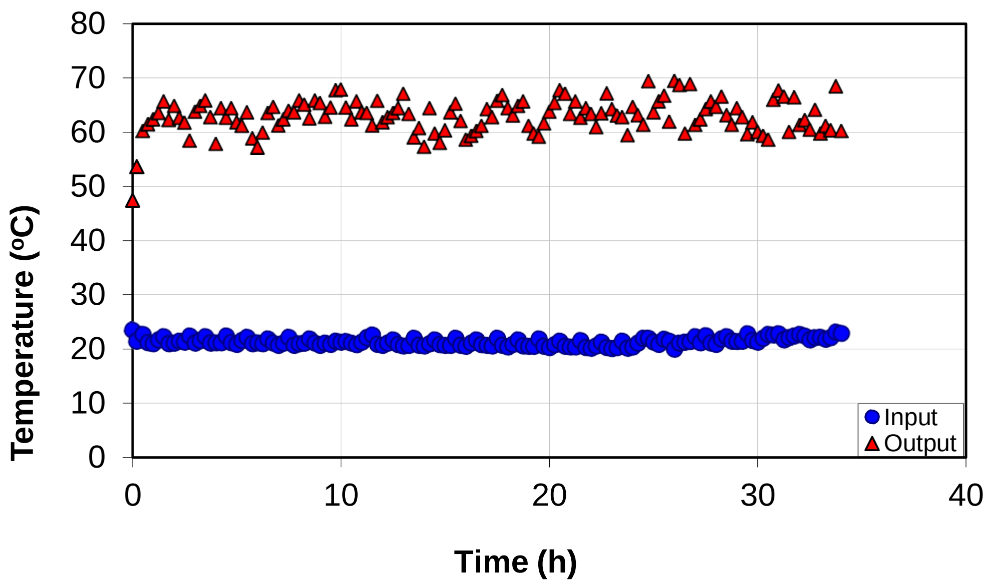

Figure 3 – Temperature input and output of the dryer

Figure 3 shows that the inlet temperature was an average of 21.34°C and an average output of 63.20°C. Note that the input speed does not influence the inlet temperature and outlet during the drying process. Figure 4 is the mass flow rate that maintained an average 0.01 kg/s mass intermanente fluid flowing in the dryer.

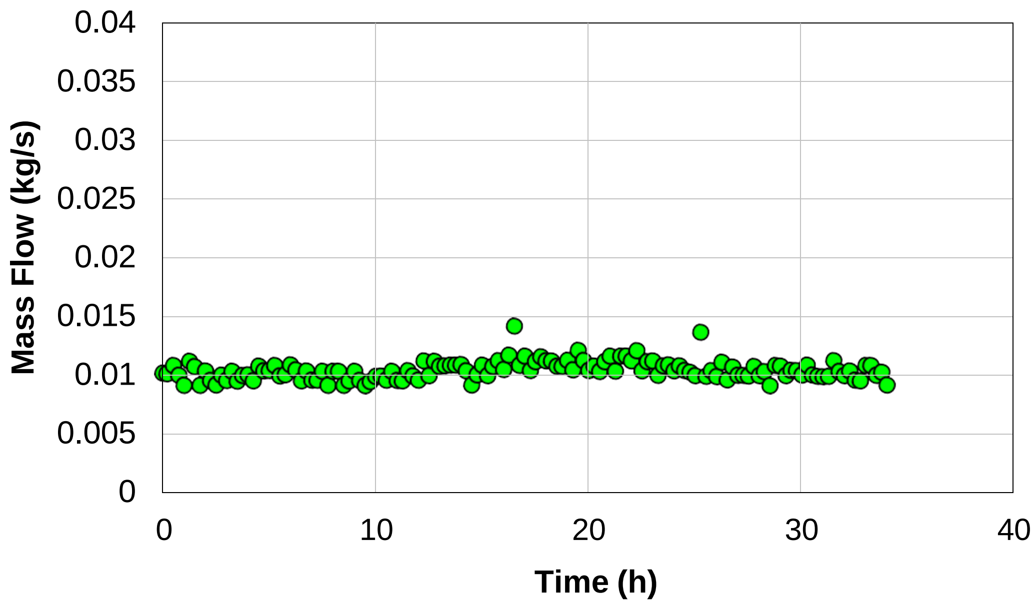

Figure 4 - Mass flow at 60°C minimum speed

It is observed in relation to mass flow, compared to the rest of the tests varying speed and temperature that is in the same speed the higher the temperature will be lower mass flow. This is because the mass flow varies depending on the density and this in turn is inversely proportional to temperature. Thus, this flow rate is lower compared to the flowrate at temperature 50°C. A Figure 5 shows the energy consumed during the drying process in 34 hours.

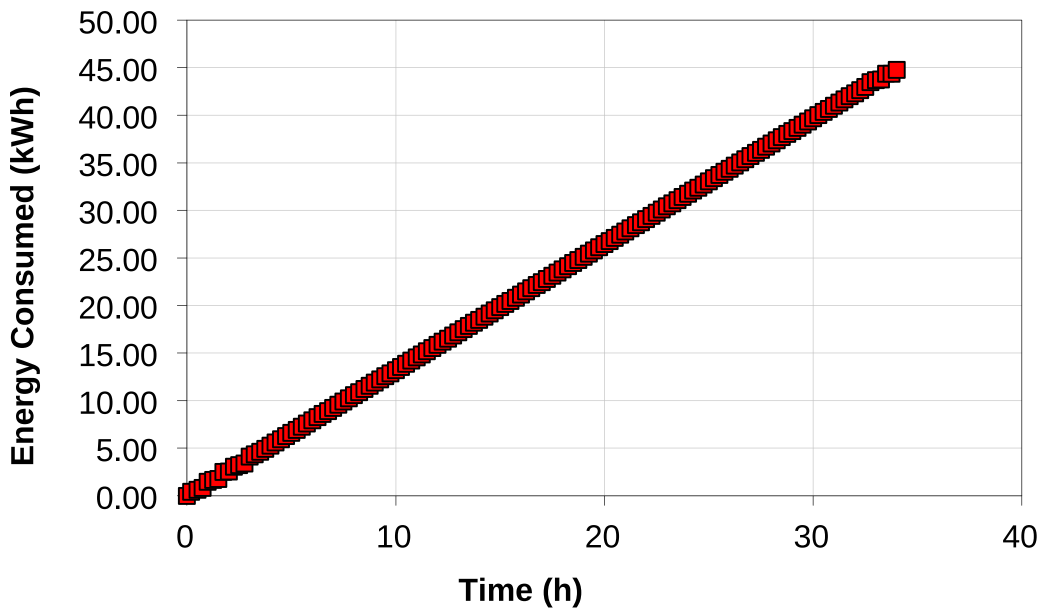

Figure 5 – Energy Consumed minimum speed and temperature of 60°C

In Figure 5, note that the power increases linearly with the time variation. For this test the energy consumption was 44.4 kWh in 34 hours analyzed. This was expected due to the temperature increase.

In all tests the relative humidity in the system input varied inversely proportional to the decrease in temperature controlled during the drying times. Figure 6 shows the graph of relative humidity for the test at 60°C and a minimum speed.

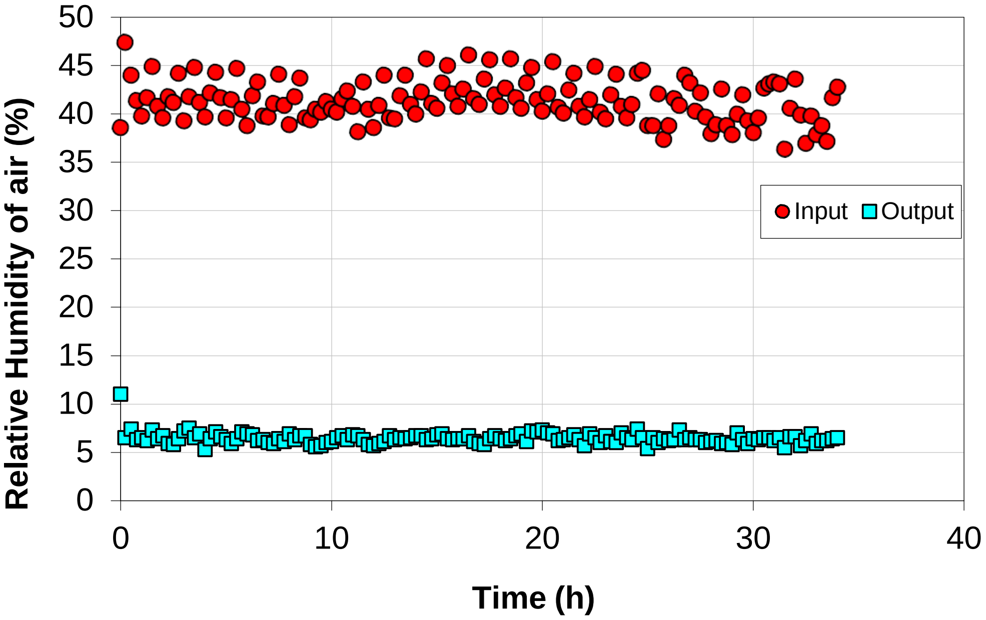

Figure 6- Relative Humidity of air to 60°C and minimum speed.

The inlet air relative humidity ranged from 36.4% to 47.4%, and an average value of 41.4%. Since the output of relative humidity ranged from 5.3% to 11% with an average value of 6.43%.The Figure 7 is the absolute humidity that is the mass of steam per unit volume of water or steam density of water.

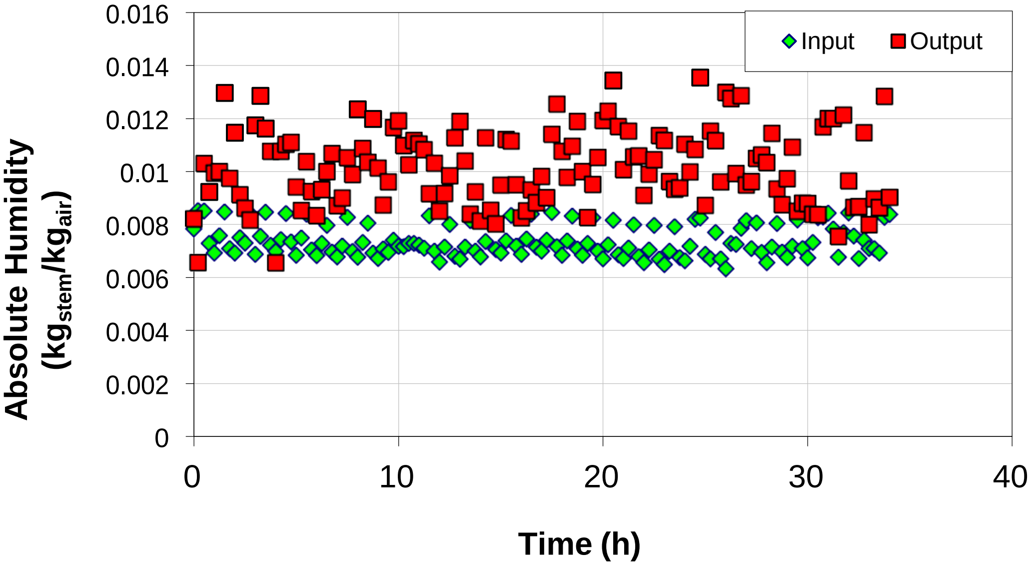

Figure 7 – Absolute humidity to temperature of 60°C and minimum speed.

Figure 7 represents the test performed at 60°C with minimum speed, this absolute humidity in the dryer ranged from 0,0063 kg_{H2O}/kg_{air} to 0,0082 kg_{H2O}/kg_{air} having an average value of 0.0072 kg_{H2O}/kg_{air}. The output of absolute humidity ranged between 0,0061 kg_{H2O}/kg_{air} to 0.0139 kg_{H2O}/kg_{air} and their average value was 0.011 kg_{H2O}/kg_{air}.

Another analysis which may be obtained from drying processes are drying curves, which have the humidity content on a wet basis as a function of drying time for the four tests. Analyzing a 5% reference content for a maximum period of 34 hours and that this level is common to the three operating temperatures only in different. A Figure 8 following times shows the moisture content to a temperature of 60°C and minimum speed.

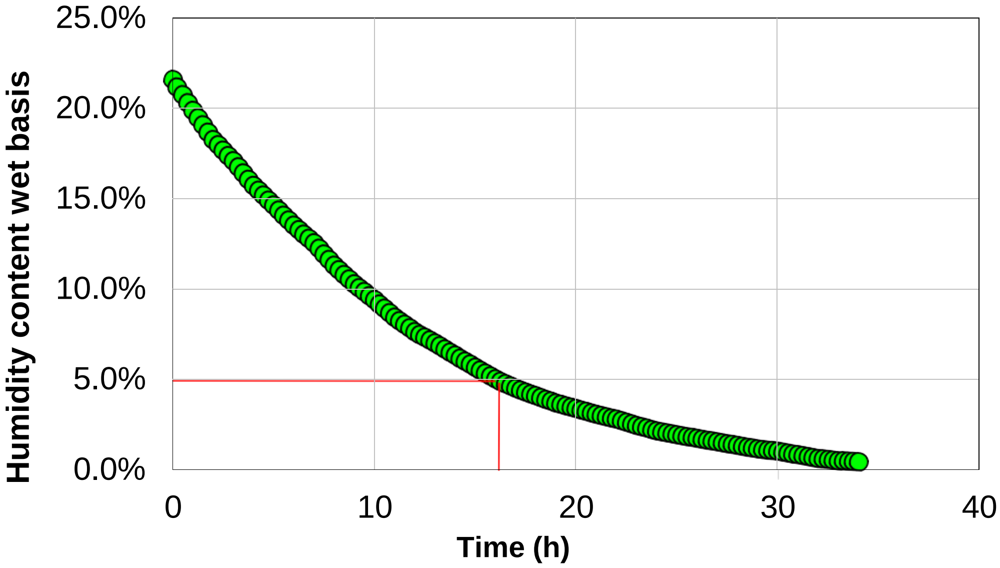

Figure 8 – Humidity content wet basis Temperature of 60°C and speed Minimum.

From Figure 8 it is observed that the time taken to reach the humidity content base set at 5% was 16h, indicating that this regime and conditions the preferred method for drying is at a speed of 2.5 m/s and temperature to 60°C. It Figure 9 presents the instantaneous thermal eficiênica air these operating conditions.

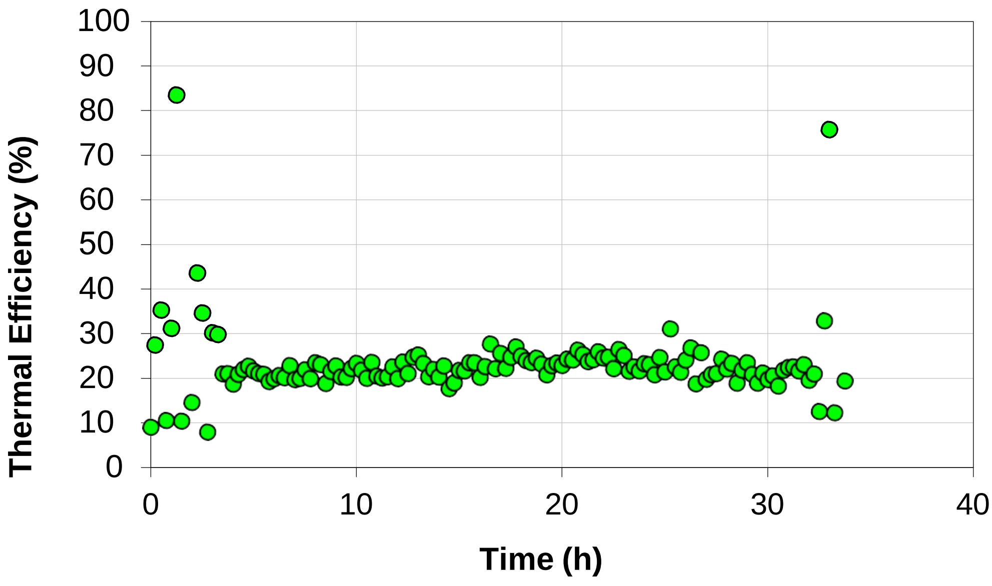

Figure 9 – Thermal Efficiency in the drying operation

According to the Equations (3) and (4) relating to the useful energy due to the heating of the air flow in the dryer and the total energy calculated by Wattmeter given by equation (5) can calculate the thermal efficiency in the four tests performed and It will provide us with the most important information of all variables during drying. Drying performed with speed minimum and 60°C showed 11.4% efficiency, as shown in Table 1.

5. CONCLUSIONS

This work was presented an experimental thermal analysis in a dryer cabinet type trays in the drying laboratory of the Department of Materials Engineering, on Campus I, at CEFET-MG. After internal correction of large differences in temperatures that had the underside and upper of the dryer, a study to investigate the best drying condition that minimizes heat loss there was a need for an increased process efficiency by generating better quality product be dehydrated.

The main variables analyzed in this study were temperature and speed, both input and output of the dryer, as well as mass flow, humidity and energy consumption. Assays were performed under the same ambient conditions, with the same instrumentation and duration of drying time. Twelve bricks, hygroscopic materials to be dried, kept for 34 hours without interruption within the dryer. Another reference brick with shape and weight similar to the others was dried in an oven at 105°C for comparative analysis of data collected.

Therefore, after the structural changes that minimized temperature differences within the drier and then conducting various tests, we reached the following result: for performing a drying expected to be more efficient it is necessary that the procedure is done with a temperature of 60°C and the speed of entry into the dryer is about 2.5 m/s. Ideal parameters to obtain an efficient drying with more economic options dryer use.

6. ACKNOWLEDGEMENTS

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