PERFORMANCE EVALUATION OF A DRYING EQUIPMENT OF FRUITS AND VEGETABLES FOR FAMILY FARMERS USERS

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Abstract. *In Brazil, agribusiness is a strong component of development, but the rural population is unable to use or store your entire production of fresh fruits and vegetables which causes post-harvest losses of more than 50%. Process would be a possibility of reducing losses but the availability of small equipment is reduced because big companies have no interest in developing them. A team of engineers met their specialties to establish as objetive the evaluation of the efficiency of an equipment for vegetable drying, but small capacity. To adapt it to users in rural areas the design was a simple design equipment. The performance evaluation was done by drying 1000g of sliced eggplant. Measurements of temperature were made and the sections evaluated include the dryer external surface, the trays, exhaust air, drying air and ambient air. The drying air speed and the total drying time were also measured. The results allowed concluding that the dryer of fruits and vegetables has a low energy efficiency. However, simple adjustments such as replacing the exhaust system and the addition of proper insulation can greatly improve the equipment efficiency.*

Keywords: drying, fruit preservation, energy efficiency.

1. INTRODUCTION

Most of the food that supply the Brazilians, nowadays, comes from small properties (CONAB, 2012). Hoffmann (2014) confirms the importance of Brazilian small producers that in 2006 participated with 83.2% of cassava production, 69.6% of bean production, 33.1% of rice in shell production and 14.0% of soybean. In addition, data of the second Brazilian Agricultural Census 2006 show that 29.7% of cattle, 51.2% of chickens and 59.0% of pigs belong to family farm, where work 12.3 million people.

However, the conditions in countryside do not favor the processing of fruits and vegetables, and losses of over 50% in post-harvest are frequent. Some other limiting factors are the distance between production and market and the lack of products, which are perishable. During harvest, the prices of fruits and vegetables fall; so, producers are forced to seek other markets. One alternative could be process the products on site, such as production of energetic bars, as reported by Silva *et al*. (2013), who developed energetic bars by using Brazilian cassava flour as caloric base, added dehydrated fruits or vegetables by using osmotic dehydration, nuts, honey and others. In order to enable this production with competitiveness, should be available technologies adapted to reality of family farmers, i.e., to develop efficient equipment and adjusted to the countryside conditions (Cereda *et al*., 2015).

This paper describes the work of a multidisciplinary team in order to optimize a commercial dryer by improving its performance. The dryer will be used by two regional associations of family farmers involved in the project. The most efficient machine can dehydrate various fruits and vegetables that can be used for making sweet and salt energetic bars, which formulation replaces cereals by cassava flour. The bars were chosen because of their global aspect and provide good nutritional profile. For the efficiency test, eggplant (*Solanum melongena L.*) was selected as one of the characteristic product of family farming. The dehydrated eggplant is one of the supplies of salt bars formulation.

Like other vegetable raw materials, eggplant is perishable because of its high humidity and requires preservation techniques to ensure their nutritional and organoleptic characteristics (Andrade et al., 2003). Thus, drying process is suitable to reduce costs, preserve fruit characteristics (Moreira et al., 2007) and increase its life with consequent reduction in percentage of losses (Andrade et al., 2003).

The drying technique is used for removing free water present in a damp solid (Foust *et al*., 1982). In addition, it is possible to drag other organic substances on the liquid state (Geankoplis, 1992). The importance of drying techniques stands out with the increasing in agricultural production and other production sectors. It is a technique applied to food preservation, which reduces the enzymatic reaction speed such as rancidity, hydrolysis, enzymatic transformations and non-enzymatic browning (Pecora, 1985).

A moist solid, placed in a drying gas at a fixed temperature and humidity, exhibits a typical drying behavior. Figure 1 presents the curve that relates the moisture content as a function of time, which is the curve that is obtained during drying process. Initially, the solid temperature adapts after contact with medium drying up to a steady state, represented by AB segment on graph. The segment BD is a constant rate period, where the solid temperature is equal to the wet-

bulb temperature of drying medium and, once such temperature is attained, it remains stable and the drying rate remains constant. This period is called drying at constant rate (Foust *et al*, 1982).

The drying period at constant rate ends when the solid reaches the critical moisture content. From this point, represented by segment DE, it starts a period of decreasing drying rate, in which the solid temperature increases and the drying rate decreases quickly. The value of this drying rate approaches to zero, the less tangible moisture content in the drying process, called equilibrium moisture content (Foust *et al.*, 1982).
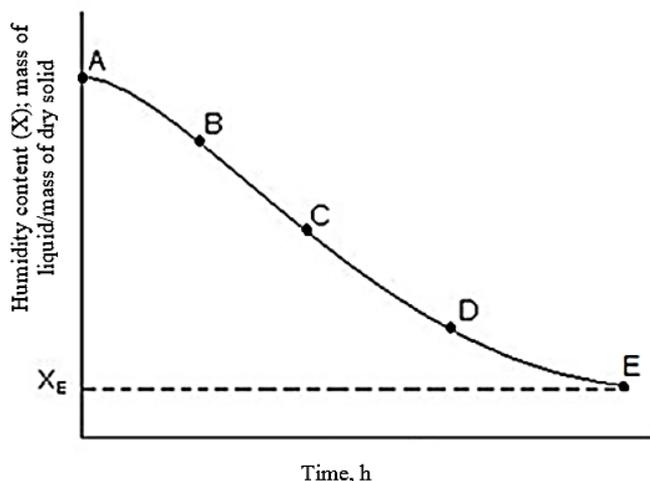

Figure 1. Characteristic drying curve (Foust *et al*, 1982).

3. MATERIALS AND METHODS

3.1 Feedstock

Eggplants were used (*Solanum melongena L.*), which were selected according to the quality, uniformity and degree of ripeness. After cleaning and washing, the fruits were peeled and manually cut into slices with a thickness of 2 mm, and immediately placed in trays for drying.

3.2 Drying system

The evaluated dryer was manufactured for a small capacity, since the objective was to meet the family farmers' needs. The dryer is equipped with a gas burner fed by liquefied petroleum gas (LPG), a hot gas filter, two trays of 35x38 cm with screens, distant by 20 cm vertically, in which material to be dried is placed, two fans that promote the movement of hot air from trays and a thermometer for measuring the air temperature as shown in Fig. 2.
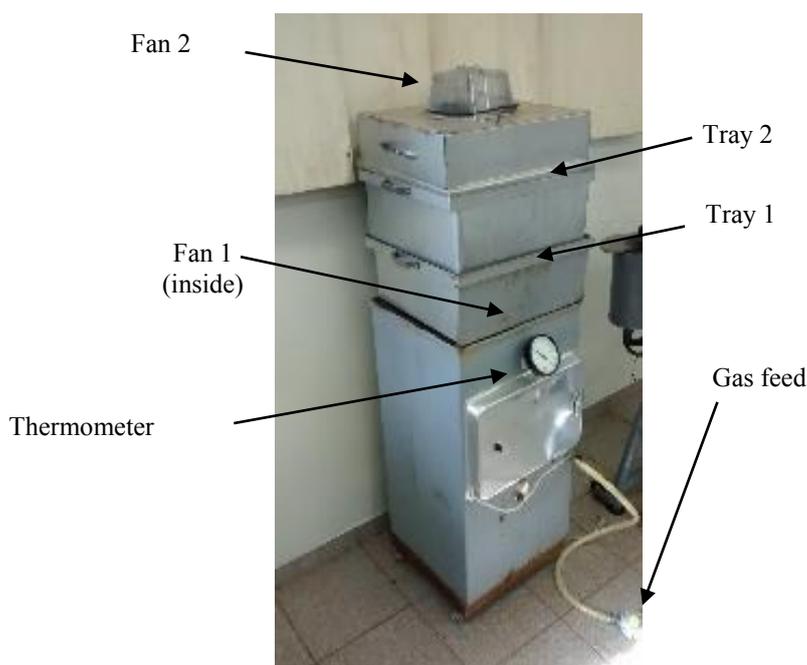

Figure 2. Description of the drying system used.

The procedure used during drying process consisted of loading the trays with 0.5 kg of sliced eggplants. After loading the trays, the system was turned on and measures, initially, were taken every 5 minutes. After the first 20 minutes, the measures were made every 20 minutes, which allowed us to observe the transient and steady state during the drying process.

3.3 Analysis of drying systems.

The variables used for analysing the drying system were: material moisture variation (during the drying process); temperature distribution, heat losses, and air flow in the dryer; LGP consumption; heat transfer rate to the air and system energy efficiency.

3.3.1 Variation of moisture of the material

The moisture content of water from eggplant samples were measured in an oven with forced circulation, meeting standards set by the Association Analytical Chemists (AOAC, 2000), i.e., 105 ± 2 ° C for 72h. Samples were taken from the trays every 20 minutes of exposure in the dryer, weighed on a precision scale and transferred to drying oven to evaluate the moisture content on dry basis (d.b.). The moisture content, expressed on dry basis, is determined by the ratio between the mass of water and dry mass (kg of water/kg of dry mass), given by:

$$X = \left(\frac{m_i - m_f}{m_f} \right)$$

(1)

Where the moisture content (X) is the relation between the evaporated water mass, given by the difference of the original mass (m_i) and the final dry mass (m_f) divided by the final dry mass.

3.3.2 Temperature distribution into the dryer

To assess the distribution of temperature in the dryer and room temperature, a penta thermometer (FullGauge) was used. The sensors were placed inside the dryer as shown in Fig 3, and positioned in the following manner: T1 sensor positioned after Fan 1; T2 sensor positioned immediately before Tray 1; T3 sensor in Tray 2; T4 sensor positioned at the exit of Fan 2; and T$_\infty$ sensor measured the environment temperature.
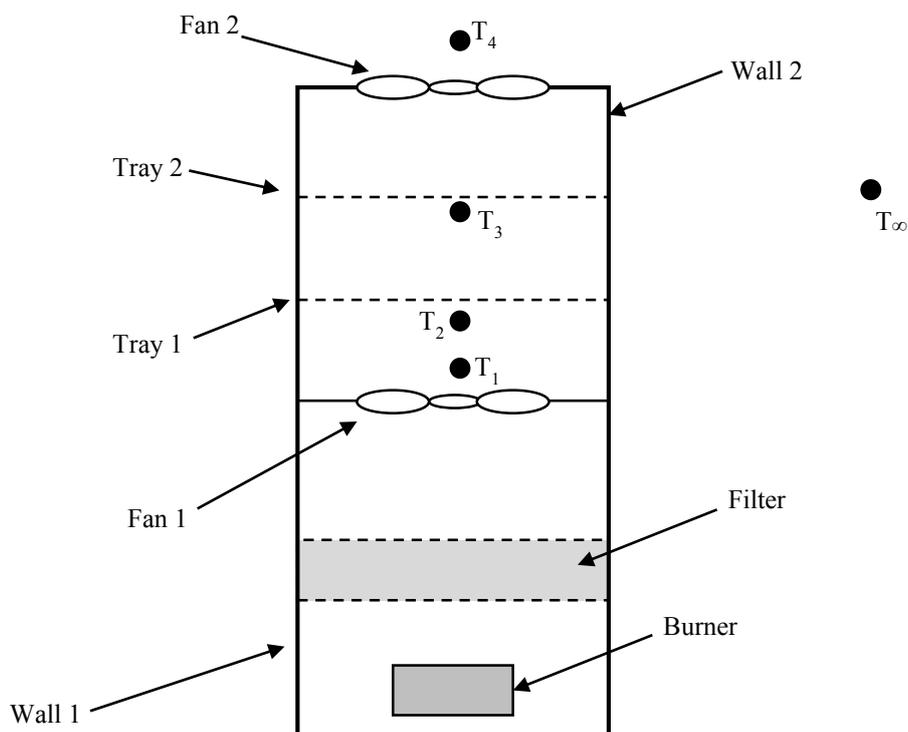

Figure 3. Schematic drawing of the dryer and positioning of temperature sensors.

3.3.3 Heat losses in the dryer

The dryer heat loss was measured by monitoring the surface temperatures outside, along vertical length; each measurement were made at 7 vertical point (20 cm apart of each other) by using an infrared thermometer (Minipa, MT360) in the walls 1 and 2 (Fig. 3). The convection heat transfer coefficient is determined by Churchill and Chu's correlation (1975) to average *Nusselt* ($\overline{Nu}$), according to Eq. (2):

$$\overline{Nu}_L = \left\{ 0,825 + \frac{0,387 Ra_L^{1/6}}{\left[1 + \left(0,492/\mathrm{Pr}\right)^{9/16}\right]^{8/27}} \right\}^2 \tag{2}$$

Where numbers of Rayleigh (*Ra*) and Prandtl (*Pr*) must be evaluated from the air film temperature surrounding the dryer. The average convection heat transfer coefficient was determined by:

$$\overline{Nu}_L = \frac{\overline{h}L}{k} \tag{3}$$

Where *L* is the vertical length near the wall temperature (T_w) and *k* is the thermal conductivity of air at the film temperature. The total estimated heat loss ($\dot{Q}_{loss}$) was calculated by:

$$\dot{Q}_{loss} = \overline{h} \cdot A\left(T_w - T_\infty\right) \tag{4}$$

where area (*A*) is the area of the walls and T_∞ *is* the environment temperature.

3.3.4 Airflow rate in the dryer

The air mass flow rate ($\dot{m}_{air}$) inside the dryer was measured by using a hot wire anemometer (Instrutherm, Tafr-180) for measuring the outlet average velocity of hot air (v_m) of Fan 1 and Fan 2. The airflow was determined by:

$$\dot{m}_{air} = \rho A_s v_m \tag{5}$$

The air density (ρ) was determined at outlet temperature (T4 sensor) and the area (A_s) used was the circular cross section of the dryer exit region of the fan 2.

The air velocity was taken in 12 different positions on the rectangular section (35 x 38 cm), after Fan 1 (Fig. 4a), and in 5 positions on the circular section (D = 20cm), after Fan 2. (Fig. 4b).
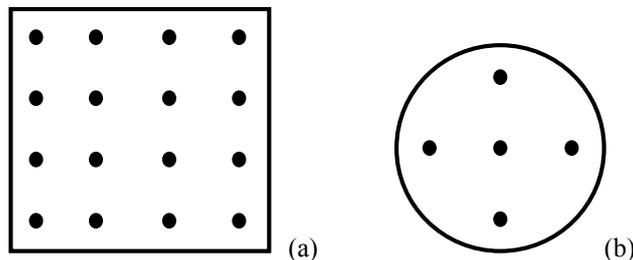

Figure 4. Measurement position of air speed on rectangular cross section to evaluate Fan 1 (a) and on circular section (b) to evaluate the average flow rate of air in the dryer.

3.3.5 LPG consumption, heat transferred to the air and dryer efficiency

The estimate of LPG consumption was carried out by weighing the LPG cylinder before and after the drying, using a semi analytical balance with capacity of up to 30kg. The heat transferred to the air was determined from the energy balance in the system, given by:

$$\dot{W}_{vc} + \sum \dot{m}_s \left(h_{tot_S}\right) = \dot{Q}_{vc} + \sum \dot{m}_E \left(h_{tot_E}\right) \tag{6}$$

The energy efficiency of the dryer was evaluated by the ratio between the energy estimated by combustion of LPG and heat transfer rate to air, as in Eq. (7).

$$\eta = 100 \cdot \left(\frac{\dot{Q}_{ar}}{\dot{Q}_{GLP}} \right) \tag{7}$$

4. EXPERIMENTAL RESULTS

4.1 Drying rate of the material

The dried eggplant showed initial mean moisture content of 9.6 kg water/kg dries mass (90% w.b.). The drying curve obtained during experiment is shown in Fig. 5. The final moisture content of material was about 10% (w.b.) for a total drying time of 200 minutes. The dried eggplant showed characteristics expected to be used in salty cereal bars.
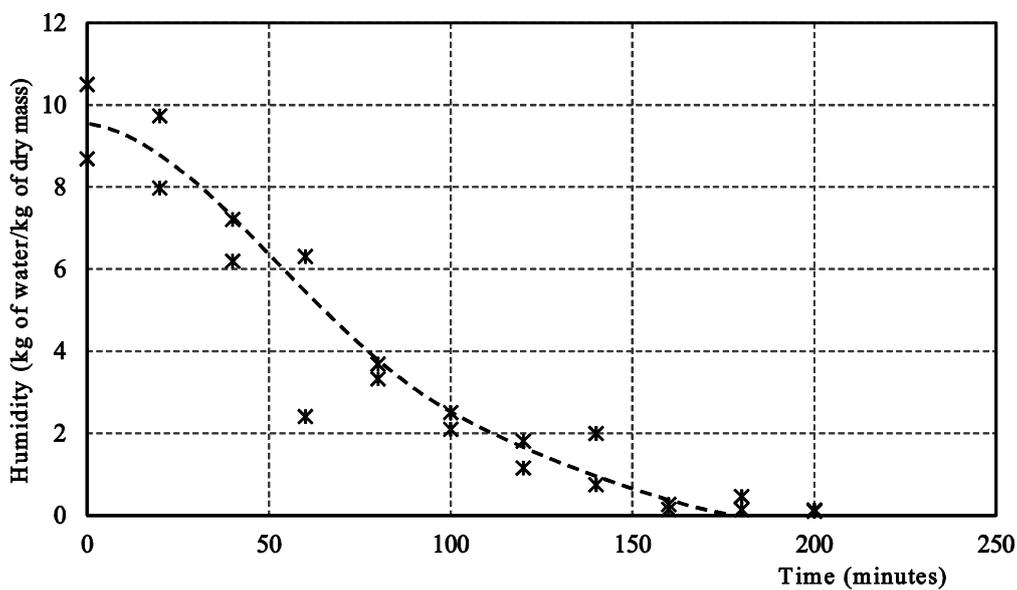

Figure 5. Drying of the eggplant in the dryer

The curve (Fig. 5) resembles that given by Foust *et al* (1982) in Fig. 1, indicating that measures were consistent. In the first 30 minutes, the product adapts to the drying means above the steady state. Between 30 to 100 minutes drying, the solid temperature is equal to the wet-bulb temperature of the drying medium drying period characterizing the constant rate. From 100 minutes, the solid reaches critical moisture content and rate back to vary until the moisture content equilibrium.

4.2 Temperatures in the dryer

From the sensors positioned into the dryer it was possible to evaluate variation in temperatures over time, as shown in Fig. 6.
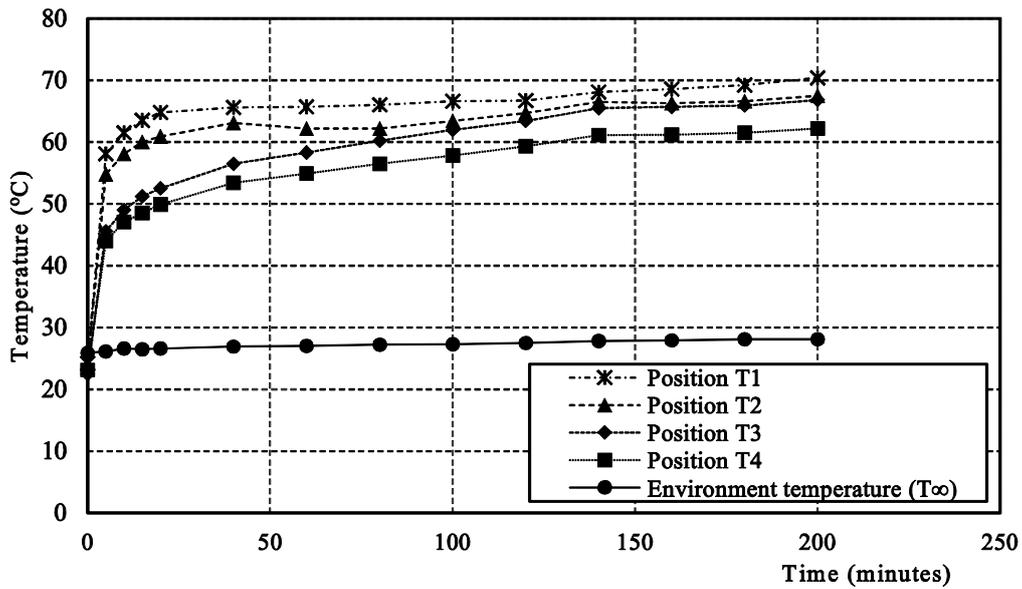
Figure 6. Variation of temperatures inside the dryer during drying period.

The temperatures measured in positions T2, T3 and T4 varied more than the other over time in the dryer, probably due the moisture loss of the material for the drying air. The heating system showed a temperature uniformity after about 30 minutes of operation, close to the time that the material began to have constant drying rate according to drying curve (Fig. 5).

4.3 Heat losses in the dryer

Graph of Fig. 7 shows the temperature variation outside the dryer along vertical position and each curve represents variation over time of drying. From the average value of each temperature, depending on the position, it was possible to evaluate the heat loss from the surface of dryer.
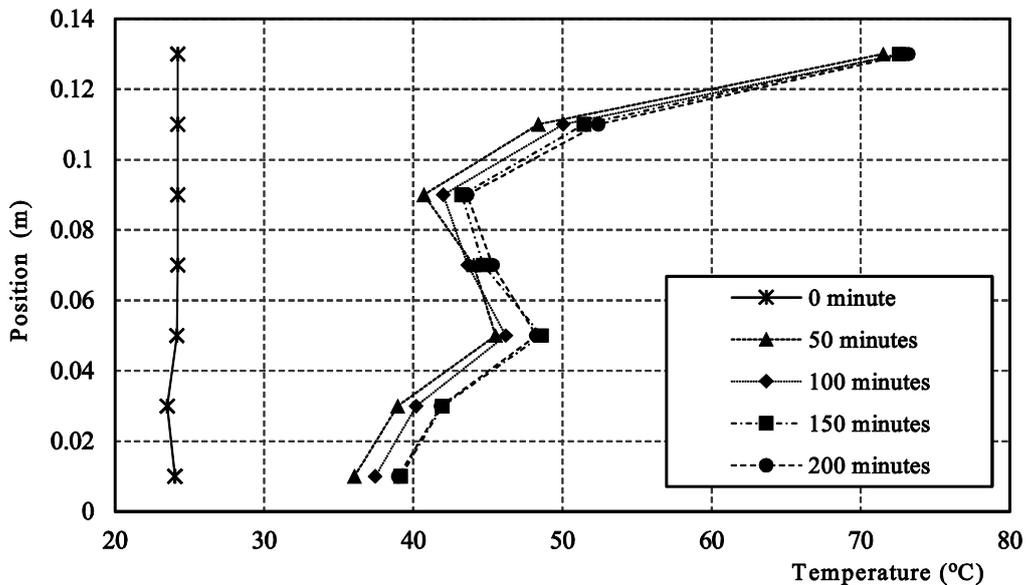

Figure 7. Variation of temperatures outside the dryer during drying period.

Using the average temperature obtained from measurements shown in Fig. 7, it was possible to estimate the average heat transfer coefficient by using the relationship of Eq. (2) and (3) and the heat rate lost to environment by Eq. (4). Table 1 shows the determined values and total heat transferred to the surface of dryer.

Table 1. Average temperature ($\bar{T}_w$) on the dryer surface, average coefficient of heat ($\bar{h}$) and heat lost through the surface ($\dot{Q}_{loss}$).

$\bar{T}_w$ [°C]	$\bar{h}$ [W/m²K]	$\dot{Q}_{loss}$ [W]
72.51	22.25	344.10
50.58	18.41	155.40
42.39	16.40	95.43
44.43	16.95	109.70
47.14	17.62	129.40
40.74	15.92	84.25
37.91	15.02	65.93
Total		**984.21**

4.4 Air flow in the dryer

The flow in the dryer was measured at different points of its cross section, with and without the Fan 2, and an average was calculated. Without the Fan 2, the mean flow rate was 0.64 m/s at 12 measuring points. According to Celestino (2010), in most of the artificial drying processes, hot air with a velocity of 0.5 to 3.0 m/s is used to transfer heat by convection to the food, thereby the dryer used approaches the lower limit, which can be changed by using a more powerful ventilation system. However, further testing should be conducted to evaluate the performance of a new fan configuration.

With the Fan 2, an average rises to 3.18 m/s at 5 measuring points. Whereas the output diameter in position after the Fan 2 (d = 20 cm), the air mass flow in the dryer was estimated at 0.112 kg/s, and remained practically constant throughout the drying period.

4.5 LPG consumption and thermal efficiency of the dryer

The LPG mass consumed during the 200 minutes that the dryer remained working was 7.2 g, which gives a mass flow of m = 0.6 g/s. Considering the Lower Heating Value (LHV) of LPG as 48.150 kJ/kg, the heat transfer rate of combustion gas was 28.9 kW. Applying the energy balance in the air inlet region in the dryer by Eq. (6), i.e., from the position before burner and first temperature sensor, it was possible to determine an average heat transfer rate of 5.07 kW, providing an energy efficiency of the dryer, through Eq. (7), of 17.56%. This low efficiency can be caused by incomplete burning of LPG, which allows us to affirm that the physical configuration of the burner should be reviewed in project.

When comparing heat rate transferred to the air, 5.07 kW, with a heat rate lost by convection from the surface of the dryer, of 0.984 kW (Table 1), it can be observed a loss of about 19.4% to the environment. Thus, should improve dryer insulation system to ensure a higher temperature in the oven, increasing efficiency and reducing the drying time.

5. CONCLUSION

The results allowed concluding that the equipment carried out the drying of fruits in the right way, because it was possible to observe the drying curve. However, the dryer had a low energy efficiency (17.56%) due to some initial settings of the project. Therefore, simple modifications such as replacing the exhaust system (Fans 1 and 2), LPG burner tuning and proper insulation can improve equipment efficiency, making it more suitable for family farmers.

6. REFERENCES

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