IMPROVEMENTS AND ADAPTATIONS IN A FRUIT DEHYDRATOR AT LOW COST

Dioni Carlos Reis Evangelista, dionieva@gmail.com
Antônio João Diniz, diniz@dem.feis.unesp.br
Unesp, São Paulo State University "Júlio de Mesquita Filho".
Brasil-Centro Av., 56. Ilha Solteira-SP, Brazil.

Abstract. *A good alternative of food conservation is dehydration. Microorganism being responsible for deterioration processes in food need for developing a minimum of water for developing. Therefore there number will be restricted. Aside the positive effect of a longer expiration time, this process still stands to maintain the characteristics of the natural product and reduces the weight of the natural product and consequently the transportation costs decrease. However, the high price in investing in a food dehydrator is still an obstacle in Brazil.*
That`s why it was tried to construct a food dehydrator for a cheaper price. The design principle was to transform an industrial oven in a dehydrator. Based on these fact three simple modifications were necessary: (a) creation of a controlled flow of heated air inside the chamber, (b) construction of an appropriate path for hot air to flow through the load and dehydration (c) stabilization of the heat of radiation.
This work includes improvements and adjustments for the above mentioned food dehydrator. The main problem to correct was to get control the temperature. The test product (banana) should be heated up in a temperature interval between 60 and 70 °C, however it was achieving values around 180°C. Thus, the problem with the high temperature is due the air flow tangent to the testing product is so below of the recommended levels (between 1 and 10m / s), then it will change the fan system of the chamber, through the installation of an axial fan in order to increase the flow velocity inside the chamber and therefore, keeping the temperature in the recommended range.

Keywords*: Food dehydrator; ventilation; Tube-axial fan, raisin food, raisin banana*

1. INTRODUCTION

One of the major challenges of the globalized world is to keep the food production in growth, because the world's population continues to grow, exceeding 6 billion in 1999. Experts estimate that by 2020 the supply of food has a growth rate lower than global population growth rate. The landscape in Brazil has a great potential from the point of agriculture- The country could develop to the largest food producer in the world. It has over 150 million hectares of areas being suitable for agriculture and produced 34 million tons of fruits in 2003. (MELONI, 2003a).

Banana is the second most produced fruit in Brazil, approximately 7 million tons in 2008. It is a fast ripening fruit and their post-harvest loss ranges from 22 to 40% of production (ROSSANA, 2010). One solution of minimizing this loss is drying this fruits, from the surpluses, increasing product value, prolonging its *expiration time* and selling the product outside the harvest season (Queiroz and Perez, 1994).

But this process is not much explored in Brazil. Meloni (2003b) outlines some important factors to this market, the natural fruits are available all time long, it not being usual the consumption of dehydrated fruits. Another factor is the low production, focused on artisanal scale. And finally, there is not the standardization of these products, not much marketing, since they do not have reference consumption and the high prices of fruit dryers turn the initial cost so high for opening a business. Some examples of Dehydrators price are showed in the Tab. 1.

Table 1. Typical prices on fruit dehydrators on Brazilian market (MELONI, 2003c)

Model	Capacity [kg of bananas]	Tray	Price
PD-150	150	Aluminum	US$ 3,130.00
PD-150	150	Stainless steel	US$ 3,880.00
PD-25	30	Aluminum	US$ 1,290.00

2. FOOD DRYERS

The development of equipments for food drying should have the target to reach a product with a high level of quality at low costs. This work adopts a dryer in question is a kind cabin with attached trays and it has following features:

- Dehydrate a batch at a time;
- Easy construction;
- Relatively low construction cost;

A schematic of the dryer of the type cabin with attached trays is shown in the Fig. 1:

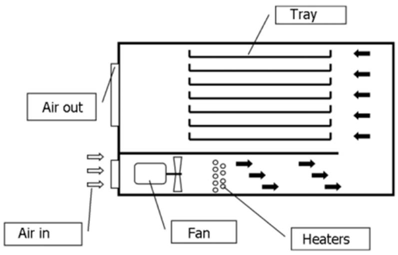


Figure 1. Scheme of dryer type cabin with attached trays

The basic principle of fruit dehydrators using ambient air is to heat up the air and force it to flow over the food via a ventilation system. The high temperature air causes the fall of the relative humidity (considering the absolute humidity constant) and therefore its ability to absorb humidity increases. The transference of kinetic energy to the flow contributes to increasing the coefficient of heat transfer, facilitating the exchange of heat air transport to the food and removal the humidity out. Parameters such as load of food per square foot of tray area of the trays, the distance between the trays, the type of fan (axial or centrifugal) can be adopted by the recommendations of the literature.

2.2. Raisin banana

The banana is obtained from dried or artificial drying of ripe banana. Many varieties are used as “nanica”, “nanicão” or “prata”, because when processed correctly present stage of maturation, are more aromatic and have higher sugar content (MELONI, 2003d).

According to de Lima *et al.* (2000), the product obtained by drying is dark colored and firm, can be stored for several years without food conserve products, because of the high sugar content of around 50%). However, the use of appropriate techniques during drying may make the product more acceptable marketing aspect, i.e., soft consistency, pleasant taste and aroma. According to Villar (1999a), the drying of ripe banana occurs by varying the temperature in an interval between 50 to 80 ° C; air speed between 0.2 to 2.2 m/s.

In order to avoid the problem of browning of dried banana, Yoneya (2010a) reported the technique of dipping the cleaned and peeled bananas in a solution of 1 liter of water and 1 kg of sugar per 6 hours before drying. Due to aggregation of sugar this is dehydration. Immersion, bananas and sugar aggregates loose water on its surface, preventing contact with oxygen and restrict the process of browning. Subsequently, the fruits heated up in a dryer for 2 hours at 60 ° C and in the following 22 hours at 70 ° C.

The flowchart in Fig. 2 represents each stage of processing to obtain the raisin fruit:

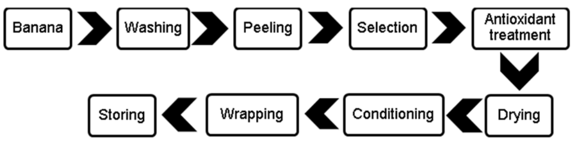


Figure 2. Processing of banana (Folegatti and Matsuura, 2004)

First it is need to wash the banana, next this, peel it and select the ripe and good fruits. Then anantioxidant treatment is conducted (the treatment indicated by Yoneya (2010b), mentioned before) and subsequently the heating in a dryer to realize the dehydration. The next step is to set a condition how to conserve it, wrapping and store it to the future consumes.

2.3. Humidity

Humidity in wet weight (U_w) given by Eq. 1 is the ratio of the humidity mass (M_w) and the total mass of the solid, like this the "dry mass" plus the humidity mass ($M_w + M_d$)

$$U_w = \frac{M_w}{M_d + M_w} \quad (1)$$

Thus, the humidity is a ratio of masses and can be expressed, for example, in g water per g of solid (mass of humidity-free basis if the total mass is dry or wet basis).

2.4. Drying Curve

The results of a study of the rates of water loss from a food during dehydration are given with drying curves. The rate of water loss is not constant throughout the process. In order to set the temperature conditions, air tangent velocity and other conditions to the food, the rate of water removal decreases during the drying. According to Meloni (2003e), this phenomenon occurs because of the principles of heat transfer and mass. The water evaporated at the beginning is near the surface, however, over time, begins to evaporate the water trapped in the center. Thus, the rate of water loss is decreased mainly by two related factors: the dry outer layer begins to act as an insulating barrier against the diffusion of water out of the center and distance to go before the water surface increases the closer the humidity to locate the center. Cano-Chauca *et al.* (2004a) show the variation in the dimensionless humidity content (U / Uo) in bananas as a function of drying time for air temperatures of 50, 60 and 70 ° C (Fig.3).

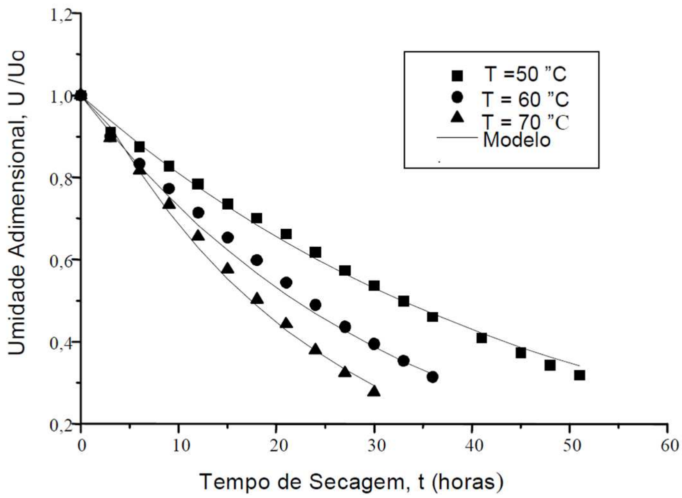


Figure 3. Experimental drying curves (CANO-CHAUCA *et al*., 2004b)

In Fig. 3, it is shown that the rate of water loss decreased every time after of the drying process starts. How amount of humidity is removed in the less time (keeping the raisin banana quality), better will be the drying process.

3. CASE STUDY

3.1. Parameters, variables and hypotheses of the project

In order to obtain the parameters to recalculate the values of the drying chamber, was adopted around the values recommended by the authors Villar (1999b), Bittencourt (2001) and Cano-Chauca *et al.*(2004c):

- Humidity content in wet-end of the banana goes up 20%;
- Internal chamber temperature around 70 ° C (+ / - 5 °);
- Tangent velocity to the top banana at 1.5 m / s;
- Trays with banana 10kg per square meter;
- Drying time 12 hours

Following values were used as well:

- Humidity in wet weight equal to 74%
- Tray area: 0,52 m x 0,71 m

Following assumptions were taken:

- In the calculation of flow, the air velocity has similar speed in the section perpendicular to the airflow;
- Relative humidity around 70%;

3.2. Flow as variable adjustment of the project

In the flow calculations, the tangential velocity on the bananas was below of the recommended range; this was the reason by the high temperature into the chamber. Low flow causes the reduction of the heat transference from the and on the other hand, high flow keeps the temperature near ambient air temperature. The new speed adopted for the calculations is equal to 1.5m/s.

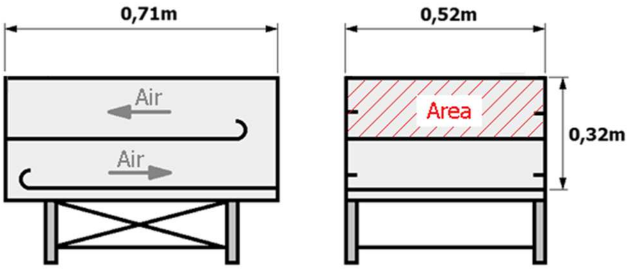


Figure 4. Simplified scheme of the chamber with the geometrical

Figure 4 shows a simple scheme of the dryer chamber, where the left schematic shows the direction airflow and the right shows the perpendicular section area.

The cross-sectional area ($A_{section}$) to the arrows is given by the product of half the height *h* by width *l*, as in Eq. (2).

$$A_{section} = \left(\frac{h}{2}\right) * l = \left(\frac{0{,}32}{2}\right) * 0{,}52 = 0{,}0832 m^2 \quad (2)$$

Flow equation *Q* is given in Eq. (3): The area *A* and the velocity *V* are supposed to be constant in each point of the section *A*:

$$Q = \int V \,.\, dA = V \,.\, A = 1{,}5 \,.\, 0{,}0832 = 0{,}1248\, m^3/s \quad (3)$$

Converting the flow in cubic meters per hour (usual industrial unit in the sale of fans)

$$Q = 0{,}1248 \frac{m^3}{s}\, x \frac{3600s}{h} \cong \frac{500m^3}{h}$$

The use tube-axial fan has a flow speed of 1200m³/h and thus its speed higher than the needed one.

4. CONSTRUCTION

Increasing the flow: In this case would have to put a fan with higher flow, so, to not use a fan as big, it was decreases the flow area by placing a plate (septum) that divides the combustion chamber in two parts (Fig.5).

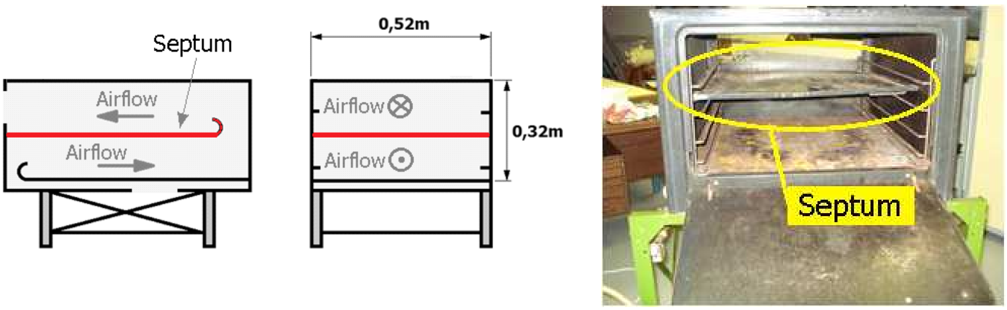
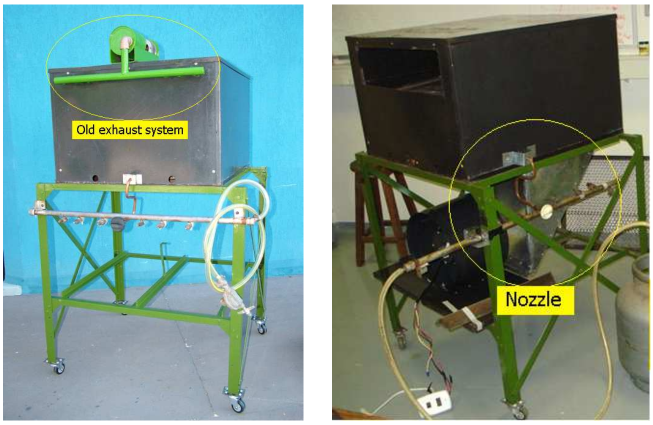


Figure 5. Plate inserted into the chamber to reduce the area perpendicular to flow

About the fan system: In the old fan system, the air was exhausted from the chamber through ducts. It was decided to remove the duct pipe thin (one inch or 25,4 millimeter), since the new flow projected pipelines would cause a great loss of pressure. Under the new system the air is not exhausted most of the camera, but inflated by a nozzle that directs air into the chamber (Fig. 6)



(a) Old (2006) (b) 2011

Figure 6. Ventilation of output to input and preparation of a nozzle

The nozzle showed in the Fig. 7 was constructed by using galvanized sheets. It has the function to guide the air insufflated from the Tube-axial fan to into the chamber.

Figure 7. Construction of the nozzle

About the burner: Due to the new design, the burner stays on of the rectangular area at the bottom of the chamber, where it will opening insufflated air, result in the flame out of the combustion, so this was turned squarely in relation to the former position (Fig. 8).

(a) 2006 (b) 2011

Figure 8. Change in direction of the burners due to new air intake

About the fan system: After conducting some tests sequences, both propeller and tube-axial fan has attended the flow expected. The tube-axial fan was chosen because it generates less noise than the propeller. Figure 9 illustrate the old system (a), the propeller fan (b), with WEG motor, speed 1490 rpm and 5 blades and, still, the tube axial fan (c) purchased for this project, from the manufacturer Tron, 30cm, multi-voltage and flow rate of 1200m³/h. This fan can operate at environment the temperature until to 40 ° C for long periods, therefore, was placed at the entrance, it breathes cold air.

(a) (2006)

(b) fan propeller - the alternative project

(c) tube axial fan

Figure 9. Ventilation Systems – Fans

5. PROCESSING

In order to perform experiments a mass of 4.6 kilograms of "nanica" bananas was used. (Fig. 10).

(a) Banana washed

(b) Banana peeled

Figure 10. Washing and peeling bananas

Thereafter, the bananas were submerged in a solution of 1 kg sugar per one liter water as recommended by Yoneya (2010c). After leaving the bananas in these conditions for 6 hours they were taken directly to the camera dryer. In Fig. 11, the solution used is shown for an antioxidant treatment (a) and the bananas submerge in that solution (b).

(a) Antioxidant solution

(b) Bananas submerges on the solution

Figure 11. Solution Treating water / sugar

In the dryer, the bananas were put on two trays in order to monitor their temperature. distribution and improve the flow in each region of each tray. In the (a) and (b) pictures from the Fig. 12, it can be seen the distribution of bananas on the trays. In the picture (c) the color change of the bananas due to the drying process is shown.

(a) Distribution

(b) Distribution

(c) Result

Figure 12. Distribution of bananas within the chamber

6. RESULTS AND DISCUSSION

6.1. Pre-test (Experiment without bananas)

In order to check the temperature inside the chamber before entering the fruit, was made a measurement of temperature on the septum (see the septum in Fig. 5).Temperature values were collected at 4 points of the septum, according with illustrate showed in the Fig. 13. This values plotted of graphs was performed Arithmetic average between these four points, called "average temperature". The temperature at each point (P1-P4) using the tube-axial fan is shown in Fig. 14.

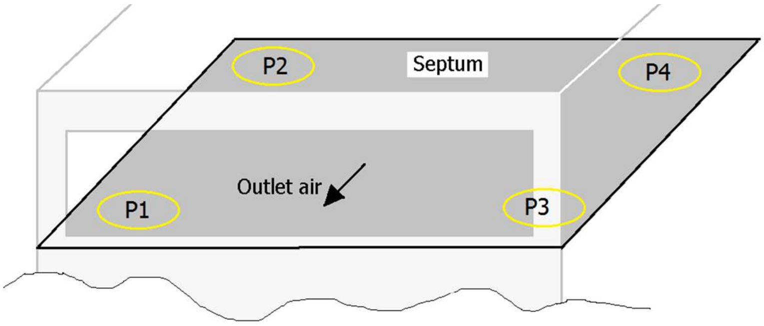


Figure 13. Temperature measurement at 4 points

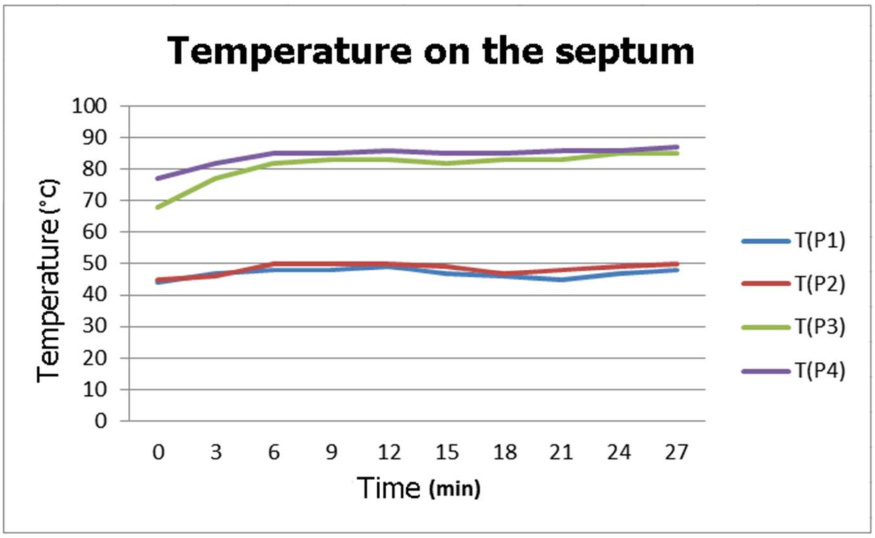


Figure 14. Temperature on the septum during the 30 minutes

Figure 14 shows that there is a gradient of temperature in the chamber having a warmer side (which is located the side of the P3 and P4 points) and cooler side. This gradient of temperature is caused due the high flow blown on the burners avoiding the flame to distribute over all the holes of the burner, causing the non-uniform temperature distribution in the chamber.

Another this test was turn off the tube-axial fan after 30 minutes. It was noted that the average temperature was between 60 and 70 ° C until the first 30 minutes reached a value greater than 140 ° C over the next 10 minutes (fan off). This analysis is illustrated in Fig. 15.

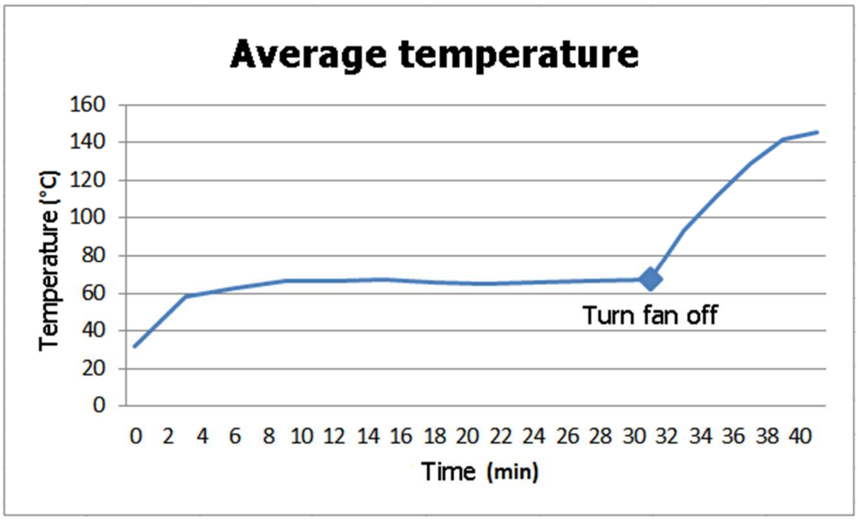


Figure 15. Variation of temperature after turning off the fan

Using TAMAGAWA (2006a) data from the fan system, it was compared the behavior of temperature in the Fig. 16 with the follow three situations: No fan, Tube-axial on and propeller fan on.

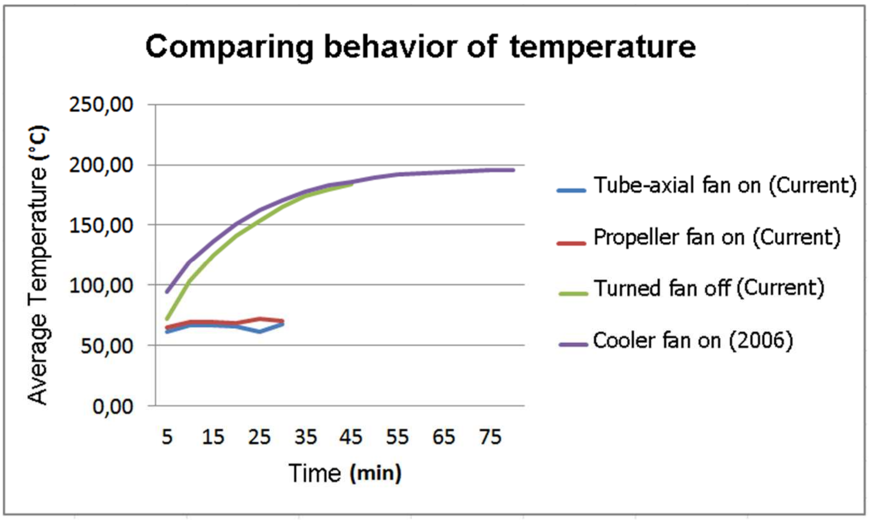


Figure 16. Comparison of behavior temperature due ventilation systems current with the old

Comparing the graphs from the old fan system and the graph "Turned fan off (Current)" it can be seen that they are similar. This behavior can be explained by a low flow in the old system due to a cooler fan and pipes didn't get exhaust the heat out of the chamber.

Thus, during the pre-test, it was noted that the chamber was ready for drying because the temperature is stabilized close 70°C

The temperature profile of the pre-test revealed a problem with the burners. Due to high flow practiced in this work, combustion occurs only in the burners to a certain extent, as illustrated in Fig. 17, causing the temperature gradient (shown in the Fig.14) in one side of the chamber.

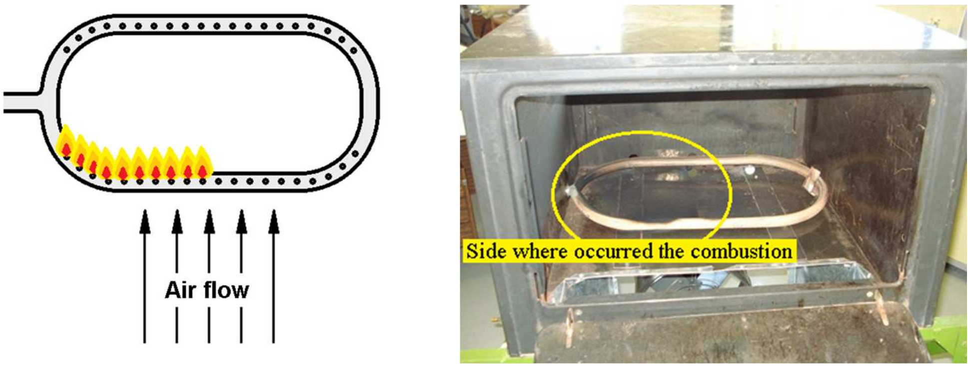


Figure 17. Irregular gas combustion in burners

Basis on Fig. 17, it can be seen that combustion particles (a black material) only accumulated on one side of the chamber proving the irregular gas combustion in burners.

6.2. Experiment (With bananas)

From the conclusions of the pre-test, it was expected the gradient of temperature between the sides of the chamber and consequently the irregular dryer process. Therefore, the temperature measurements were conducted collecting the temperature in three bananas, one located in the most heated, and the other in the middle and the last in the less heated region;

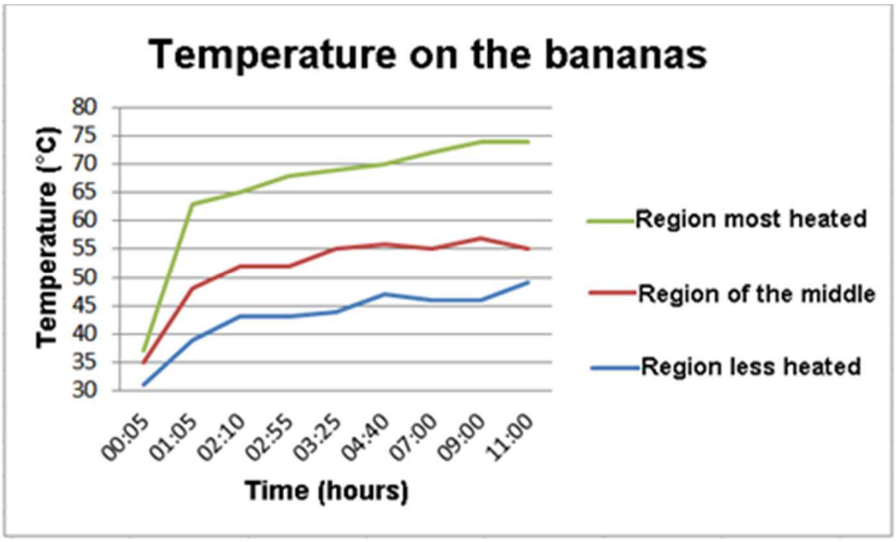


Figure 18. Temperature on the bananas

Figure 18 shows the temperature on the banana increased during the 11 hours, regardless of the side of the chamber, this behavior was expected because the outer dried layer of the banana acts as an insulating barrier against the removed water from the center to out and water located in the middle needs to flow until the surface take more time to do this. How the water activity reduces, the heat that would be used to evaporate the water is converted in thermic energy increasing the temperature of the bananas.

The velocities in the outlet were measured using a monitor and they are shown in Fig. 19. The velocity in the center of outlet air is higher than the sides, result expected, because due the friction force appear on contact of the air movement against the walls chamber. Also, the velocities are higher than design value (V = 1,5m/s) because the outlet air area is smaller than section area (see Fig. 13).

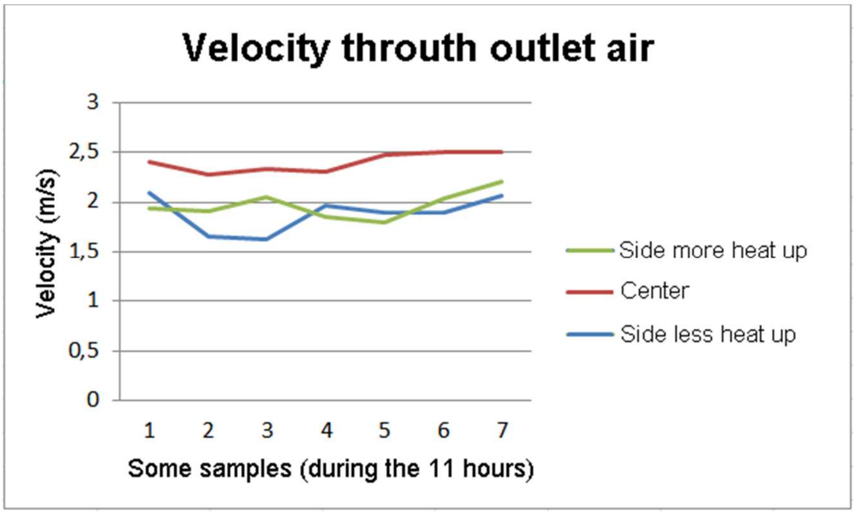


Figure 19. Air velocity at the outlet air chamber

Bananas were weighed during intervals around one hour and the results were plotted in Figure 20.

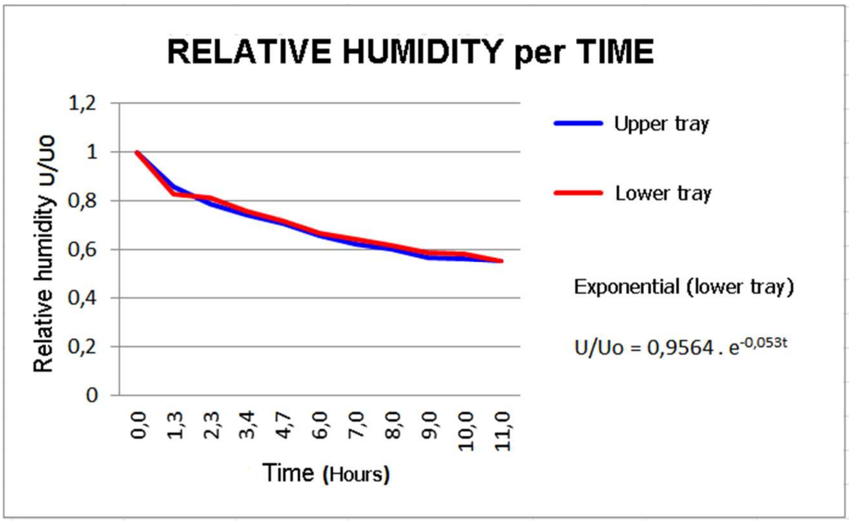


Figure 20. Variation of relative humidity of the banana in function of the time

Comparing this Figure with the Figure 3 (CANO-CHUACA *et al.*, 2004d), it can be saw that the drying process this work over of the expected, achieving retire more humidity to the same time. In order to compare the two figures, the point equal the 10 hours in Figure 20 has relative humidity about 0,55 while the Figure 3 has relative humidity about 0,7. Then, this drying process gets to remove humidity more quickly.

6.3. Goal of a dryer at low cost

Since the beginning this project, the goal was to building a dryer at low cost of production. Table 2 contains the costs of the modifications in the dryer. In this work was spent US$ 250,00 while the cheapest dryer from Table 1 costs almost US$ 1300,00. Then, the goal was achieved, because this work turns possible to start a new business constructing a dryer at low cost.

Table 2. Estimated cost to construct the dehydrator at low cost.

TAMAGAWA (2006b)	COSTS	ADD COSTS OF THIS WORK (2010)	COSTS
Discarded industrial oven, with well-preserved insulation, structure and gas system.	US$ 25.00	Sheet (nozzle)	US$ 15,00
Steel sheets, pipes, connections, metallic frames from junkyard.	US$ 20.00	Tube-axial Fan	US$ 60,00
Rent of 4 hours of machinery	US$ 90.00	Others	US$ 20,00
Five trays of thermal-resistant plastic screen	US$ 20.00	TOTAL COSTS	US$ 95,00
TOTAL COSTS	US$ 155.00		
GENERAL TOTAL COSTS (Tamagawa costs + Costs of this work)			US$ 255,00

7. CONCLUSIONS

In this study, it was possible to obtain dried banana, in spite of some problems arising during the dryer process. The objectives were achieved, because the temperature was stabilized, the value of airflow stayed in the recommended levels on the bananas and therefore it was gotten raisin banana. However, the nozzle constructed to guide the airflow in the chamber had not a good aerodynamic shape and a large portion of the flow was lost. Another problem was detected in the oven burner, the high flow blown on the burners has avoided the flame distribute over all the holes of the burner, causing the non-uniform temperature distribution in the chamber.

8. REFERENCES

BITTENCOURT, J., Assessment of a banana dryer kind cabin with. Dissertation (Master's degree) – Campinas State University, Agricola Engineer College, Campinas, Brazil, 2001

CANO-CHAUCA, M., RAMOS A. M., STRINGHETA, P. C., MARQUES, J. A., SILVA, P. I., Dryer Curve and assessment of activity water of the raisin banana, B.CEPPA, Curitiba, v. 22, n. 1, p. 121-132, jan./jun. 2004.

FOLEGATTI-MATSUURA, M. I. S.; MATSUURA, Fernando Cesar Akira Urbano. Process (banana). In: Ana Lúcia Borges; Luciano da Silva Souza. (Org.). Cultivate of banana tree. 1 ed. Cruz das Almas – Bahia, Brazil: Embrapa Manioc and Fruit culture, 2004, v. 1, p. 232-244.

LABAKI, J., TAMAGAWA, A. H., A low cost technique for manufacturing food dehydrators, UNICAMP, State University of Campinas. Campinas-SP, UNESP, São Paulo State University "Júlio de Mesquita Filho", Brazil, COBEM, 2009.

LIMA, A. G. B., NEBRA, S. A, QUEIROZ, M. R., Scientific and Technologic aspects of banana, Technical communication, Brazilian magazine of agro industrial products , Campina Grande, v.2, n.1, p.87-101, 2000.

MELONI, P. L. S., drying of fruits and vegetable, Dryer food consulting, 10ª International week of fruit culture, Flower culture and agro-industry, September, 01 until 04 2003, Center of Convention, Fortaleza, Ceará, Brazil, FRUTAL, 2003.

QUEIROZ, M. R. de & PEREZ S. A. N. de., Theory-experimental study about the drying kinetic of Bananas, Doctor's degree Thesis, Campinas, SP. 1994.

ROSSANA, C. B. G., Study of process variables in the banana candy of elaborate cut with variety resistant to "sigatoka-black", Paraná Federal University, CURITIBA, 2010.

TAMAGAWA, A. H., Improvements and adaptations in a fruit dehydrator, Ilha Solteira Engineer College, São Paulo State University "Júlio de Mesquita Filho" , UNESP, 2006. (Graduation Work)

VAN WYLEN, G.J.; SONNTAG, R.E.; BORGNAKKE, C.. Fundamentals of classical thermodynamics. São Paulo: Ed. Edgard Blücher, 1995. 594 p.

VILLAR, G. C. Performance study of a consecutive dryer with trays to dry banana: Assessment of operator variable influences. Campina Grande: UFPB/DEQ, 1999. 117p. (Master's degree dissertation).

YONEYA, F., Embrapa get to preventing browning of the raisin bananas, "Emerging bananas in sugar and water mix preventing browning, it may to rise the selling price. Available at: http://www.estadao.com.br/noticias/suplementos,embrapa-consegue-clarear-banana-passa,518748,0.htm. Access: November 05, 2010.

9. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.