SOLAR DRYER CONSTRUCTED IN COMPOSITE USING LUMINAIRE MOLD

Luiz Guilherme Meira Souza, lguilheme@dem.ufrn
Maria kalionara de Freitas Mota, kalionarafreitas@yahoo.com.br
Luiz Guilherme Vieira Meira de Souza, lguilherme_souza@hotmail.com
Elen Fonseca Barboza, Elenf@hotmail.com
Leandro Barboza Inagaki, leandrobi@hotmail.com
Renata Motoki, reantamotoki@yahoo.com.br

Universidade Federal do Rio Grande do Norte

Abstract.
It presents a solar dryer exposure for the production of dried fruit or flour mold constructed from scrap lamp. A lamp was covered on the bottom and sides with the composite gypsum, cement, EPS ground and tire. After curing the composite was removed from the metal mold will examine aspects of construction and assembly of the proposed solar dryer, which has as its main feature low cost and is intended for low-income population, for processing of fruits widely available in our region (mango, banana, guava, cashew, pineapple, tomato and others) in dried fruits and / or flour, increasing the expiration time (consuming) of such foods. Such procedure will contribute significantly to alleviating the problems of hunger and misery of the poor population of our region, dried fruits and flour can be used for marketing, generating employment and income. This paper presents results of tests that diagnose the viability of using solar dryer for various kinds of tropical fruits. Are compared the times of drying fruit in the dryer proposed with those obtained for other literature produced by the solar dryers.

Keywords*:* solar energy, solar dryer, tropical fruits, low-cost composite material.

1. INTRODUCTION

The great challenge of the globalized world is currently producing food for a population that continues to grow and reach six and a half billion inhabitants. Since farmlands are shrinking, the supply of irrigation water is scarce and production technologies are no longer able to give more leaps in productivity, it is believed that in the next decades the food supply in the world will grow unless the population.

Brazil is an exception in this panorama and stands as one of the forces producing the third millennium. Currently, Brazil is the third largest fruit producer in the world, behind China (157 million tons) and India (54 million). Of the 39 million tons of fruit produced, approximately 45% is orange. Secondly, there is the banana, with 6.5 million tons (Neto, 2008).

The Brazilian fruit market moves now over 10 billion dollars a year (only with fresh fruit) and generates products of medium and high added-value, considering the fruit exploitation for exportation and noble fruit. Brazil's climate permits the production of all kinds of tropical fruit and some provide more than a crop per year.

Despite the undeniable need to increase fruit production and expand exports, it is necessary to reduce the losses that occur throughout the production chain. In developing countries the losses are estimated at 50% for some products. Our reality is no different from the producer to the consumer, the losses are considerable. This highlights the need for simple and inexpensive procedures that offer ways to maintain these highly perishable foods (Souza, 2004).

In recent years the solar drying has been growing progressively through process optimization and cost reduction, causing an increase in the dynamic market of dried fruit. The emergence of other dried fruits like apple, papaya, pineapple and mango, even in small quantities, confirm that the market is growing (Costa, 2008).

To combat this serious problem of food waste that could be used to minimize the serious social problems associated with hunger and poverty, the use of solar energy is indispensable. Mainly because it is clean, has great potential, it is widely available throughout Brazil, mainly in the Northeast region that has the highest levels of social inequality, and the facility to build prototypes that transform solar energy into heat.

This work presents a drying system consisting of a direct exposure solar dryer working in a natural convection regime. The dryer was constructed from a mold made of luminary scrap, using a composite material consisting of plaster, cement, crushed EPS and shredded tire. The processes of manufacture and assembly of the proposed dryer are focused. The results of tests for mango drying are presented. The use of this type of dryer can contribute to a progressive increase in solar drying as a way of generating employment and income.

2. REVIEW

Dehydration is the process of combined heat and mass transfer which reduces the availability of water in a food, increasing its lifetime, reducing its perishability and wastage. The main reasons for the dehydration of fruits are: seasonality reduction, increasing the value of the product market, reducing spoilage, improving transport and storage (Meloni, 2002). The methods of dehydration can be divided into four types: contact with hot air, by contact with hot surface, by lyophilization, the addition of osmotic agents. (Fioreze, 2003).

In the drying process are identified two distinctive periods: the period of drying rate constant or almost constant, with a period of decreasing drying rate. The most important factors to consider in the process of drying fruits are: water vapor pressure, air temperature, air speed, rate of diffusion of water in the product, thickness and surface area available (Lee, 2008).

The solar drying can be obtained through two processes, the direct and indirect exposure drying. In the first type the dry food is exposed to solar radiation and energy-absorption and in contact with a circulating air the moisture is vaporized and carried to the atmosphere. In this case the air circulation can be natural or forced. In the second case, drying is achieved through the use of a solar air heater that provides hot air to a drying chamber separately. In the latter case another heat source can be used together in the same solar drying unit.

The solar drying systems can be classified in several ways. Figure 1 presents a classification of solar dryers and drying methods.

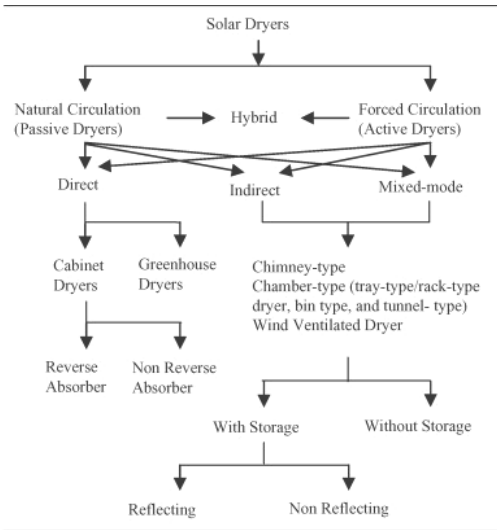

Figure 1. Classification of solar dryers and drying methods.

The dryers can be of three types: natural convection dryer, forced convection and hybrid convection.

Another classification by Khalil in 2007, is the direct exposure dryer in which the radiation is directed at the product to be dried and the indirect exposure dryer which has trays that are added in a drying chamber where the product is being dried.

There are natural convection dryers with direct or indirect exposure and forced convection dryers with direct or indirect exposure. What will determine its use are the resources available for the construction of the dryer.

The solar drying is one of the most promising uses and most far-reaching social primary source that makes life possible on Earth. In Brazil for several decades researchers have been studying many types of dryers to promote the dehydration of numerous types of food.

In UFRN several studies have been developed for various types of products. In LMHES - Laboratory of Hydraulic Machines and Solar Energy, three Master's theses were performed by the Pos-Graduate Program in Mechanical Engineering.

Duarte, in 1996, developed and simulated numerically a modified diffusion model. This study was applied for modeling the drying of cashew.

Santos in 1997, made a comparative study between two dryers, a direct exposure and a convective, to promote the drying of tropical fruits.

Seine in 1997, studied a drying system to seed cotton, using a silo attached to a direct exposure dryer. The system worked in forced circulation achieved by an exhaust fan.

Ramos, in 1997, studied the drying of tropical fruits in spouted bed in their Final Course work, along the course of Chemical Engineering UFRN.

Fioreze in 2003 published book on the principles of drying of biological products by Editora Universidade Federal da Paraíba.

Costa, in 2003, studied the osmotic process, followed by drying to obtain partially dried tomatoes, mixed using a dryer.

Souza, in 2004, studied a dryer built in direct exposure made of composite materials using gypsum and EPS, for drying of tropical fruits.

Davoodi, et al in 2007 studied the effects of different methods of pre-treatment and dehydration on the quality and storage of tomatoes. They used a tunnel type solar dryer to promote convective dehydration.

Costa, in 2008, presented in the Doctoral Dissertation PPGEQ (Graduate Program in Chemical Engineering), a study in a solar drying system for drying fruits and in a static dryer column and the modeling of the drying process for the banana.

Souza, in 2009, presented a paper at the VI Conem on the use of an alternative solar dryer for drying fruits and vegetables, which was characterized by simple manufacturing processes and assembly, significant low-cost efficiency in the drying process. From the dry foods were produced eggplant, guava, banana, beets and cashews flour.

Costa, in 2010, presented in her master's thesis, a study on the production of cashew flour after the fruit passing through a drying process in a natural convection drying system of direct exposure. It was proved possible to obtain flour and when chemically characterized, it was proved its high iron content.

3. MATERIALS AND METHODS

The direct exposure dryer of the proposed drying system was constructed from a scrap lamp shown in Figure 2.

Figure 2. Scrap lamp used as a template to construct the proposed solar dryer.

The internal and external dimensions of the dryer are: external - L - 1.38 m, W - 0.31 m, H - 0.11 m, Internal - L - 1.38 m, W - 0.225 m, H - 0.06 m. The area inside the dryer where the products will be left to dry corresponds to 0.3 m² and the internal volume corresponds to 18.6 liters.

The steps of the manufacturing processes and assembly of the offered low-cost alternative dryer are described below.

1. Withdrawal of electrical wiring and component of the scrap;
2. Withdrawal of two portions of the mold for the inlet and outlet of the dryer;
3. Mold fabrication using wood and pieces of EPS;
4. Placing scrap lamp mold;
5. Preparation of the composite with plaster, cement, EPS and tire and water;
6. Withdrawal of the wooden sides of the mold;
7. Curing of the composite;
8. Withdrawal of scrap molding fixture;
9. Drying the composite dryer in the sun;
10. Painting the dryer;
11. Cut the glass to be used in the dryer through diamond tool;
12. Placing the glass inside the dryer where the fruits will be left to dry;
13. Placing the glass cover of the dryer;
14. Putting the dryer on a pedestal with an inclination of 15.5 ° S.

Figure 3 shows the various operations of manufacturing processes and assembly of the natural convection direct exposure solar dryer built.

Figure 3. Stages of manufacturing processes and assembly of the proposed composite solar dryer.

The dryer was tested by direct exposure to dry of some fruits under natural convection, with data collected from solar radiation, relative humidity, temperature and initial and final mass of three samples, located near the entrance, middle and near the exit of the dryer, every hour. Measures were also the initial and end of each load of product left to dry and the drying time of each product. The drying time for each type of product dried was determined (Fioreze, 2003, Souza, 2004, Costa, 2008, Neto, 2008, Souza et al., 2007).

The temperature of the external surfaces of the dryer to diagnose the level of heat loss was also assessed, since the dryer is not insulated, focusing on the simplicity of manufacturing and technology transfer for poor communities. This initiative facilitates the use of the dryer in order to increase the shelf life of perishable foods and to generate employment and income. The necessary data for the study of thermal efficiency of the dryer was collected from a meteorological center installed in LMHES UFRN. Figure 4 shows the sample test on the dryer in the drying process of tomatoes.

Figure 4. Dryer under test in the drying process of tomatoes.

4. ANALYSIS OF RESULTS

After drying some fruits with the direct exposure natural convection drying system, banana, pineapple, mango and tomatoes, a more accurate test was made to analyze further behavior of the dryer in the drying process. The tomato, was chosen, being assessed its weight loss within every hour. Table 1 presents the results of drying tomatoes test.

The percentage of moisture from the tomato corresponds to 90%, according to the literature for food. The total mass of the dry product was 1128 g. The start of the test was at 9:30 pm and ended at 15:30, started on day 2 at 8:30 and ended at 15:30 hours. After drying the first day the tomatoes were placed in a dissector to maintain moisture.

For this test were used three samples that were in the beginning, middle and end of the dryer. Their masses were measured at every hour.

Table 1. Variation of the mass of tomato samples in direct drying with natural convection.

TIME (hour)	**m_{S1} (g)**	**$loss_{S1}$ (%)**	**m_{S2} (g)**	**$loss_{S2}$ (%)**	**m_{S3} (g)**	**$loss_{S3}$ (%)**	**Relative humidity (%)**	***I*** ***(W/m^2)***
09:30	**24**	**0**	**26**	**0**	**28**	**0**	**63**	**800**
10:30	**18**	**25**	**23**	**11.5**	**26**	**7.1**	**64**	**850**
11:30	**16**	**33.3**	**21**	**19.2**	**23**	**17.9**	**62**	**1051**
12:30	**14**	**41.7**	**18**	**30.8**	**20**	**28.6**	**60**	**905**
13:30	**12**	**50.0**	**16**	**38.5**	**18**	**35.7**	**62**	**837**
14:30	**11**	**54,2**	**14**	**46.2**	**15**	**46.4**	**61**	**697**
15:30	**9**	**62.5**	**13**	**50.0**	**14**	**50.0**	**63**	**492**
08:30	**9**	**62.5**	**13**	**50.0**	**14**	**50.0**	**65**	**565**
09:30	**8**	**66.7**	**11**	**57.7**	**11**	**60.7**	**69**	**648**
10:30	**7**	**70.8**	**9**	**65.4**	**10**	**64.3**	**65**	**873**
11:30	**6**	**75.0**	**8**	**69.2**	**8**	**71.4**	**63**	**950**
12:30	**4**	**83.3**	**6**	**76.9**	**7**	**75.0**	**62**	**918**
13:30	**3**	**87.5**	**5**	**80.8**	**5**	**82.1**	**62**	**840**
14:30	**3**	**87.5**	**4**	**84.6**	**4**	**85.7**	**61**	**678**
15:50	**3**	**87.5**	**3**	**88.5**	**3**	**89.3**	**64**	**472**
Average							**63.1**	**771.7**

The total mass loss for the three samples was close to 90.0%%, with loss of wet mass of 87.5% for sample 1, 88.5% for the sample 2 and 89.3% for sample 3. It can be perceived, therefore, that most of the wet mass of the samples was removed in the drying process as intended to increase the time consumption of this fruit. It can be seen that the sample 3, located near the entrance of the dryer is the one with a higher percentage of lost mass.

Regarding the total load of tomatoes, corresponding to 1128 g, the mass loss of the total load corresponded to 88.6%, with a dry mass of 129 g. The wet mass remaining after the drying process amounted to 16.2 g, equivalent to 12.6% of the final dry load. The dry weight of the cargo amounted to 87.4%.

The surface temperature of the dryer, which was not isolated to accentuate the simplicity of the dryer manufacture process, had maximum temperature around 40° C, at 12:30 pm, to an ambient temperature of 32° C and a wind chill of 36° C. The heat loss was not so significant.

It was demonstrated the efficiency of the drying process obtained with the proposed alternative direct exposure natural convection solar dryer, emphasizing that these results were obtained with a drying system produced at low cost by recycling scrap materials.

The total drying time for tomatoes was around 13 hours, a little above the time appointed by the literature, about 10 hours (Neto, 2008, Costa, 2010). This increased time was due to the cutting of tomato in thicker slices (10mm) than the conventionally used, about 5.0 mm. The relative humidity average was around 63.1% and solar radiation, about 771.7 W/m², significantly favorable levels for a solar drying process.

Figures 5, 6, 7 and 8 shows the behavior assumed by sample mass, loss mass, relative humidity and solar radiation measured during the test for drying tomatoes.

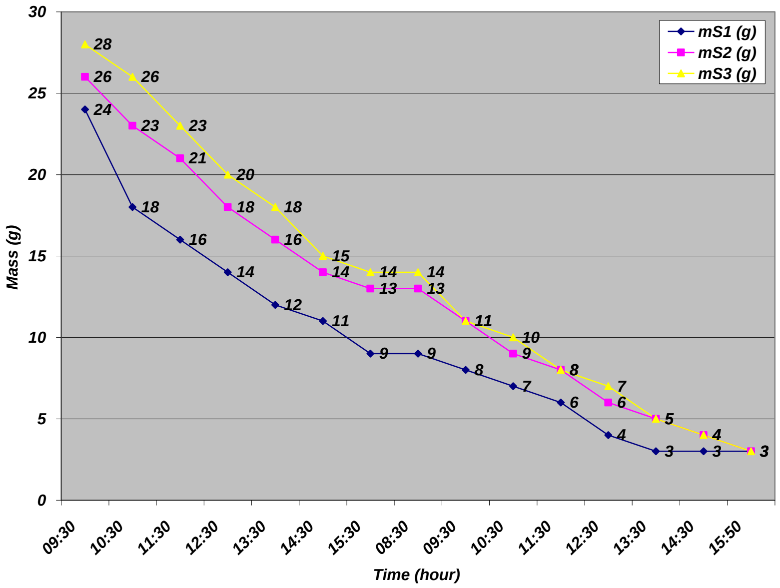

Figure 5. Sample mass of tomatoes in process of dry in solar dryer studied.

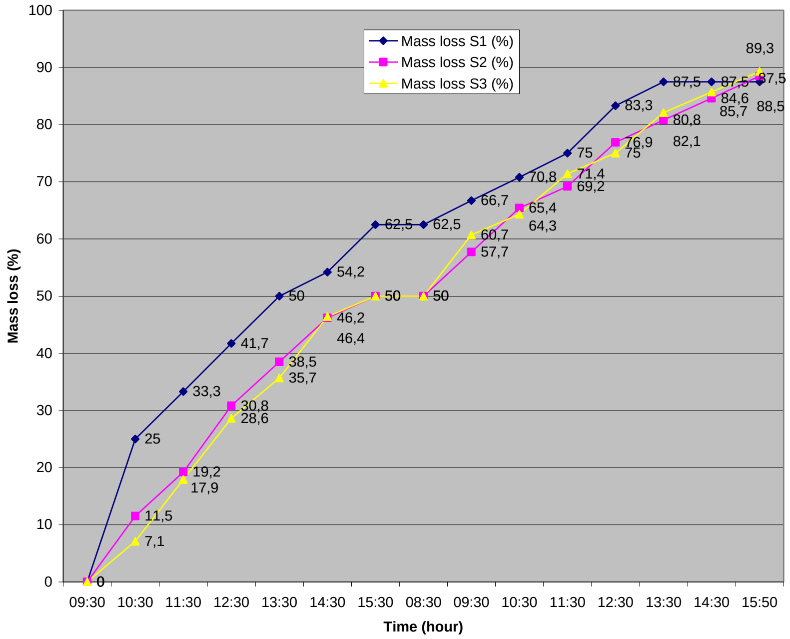

Figure 6. Mass loss of samples of tomatoes drying in direct natural convection.

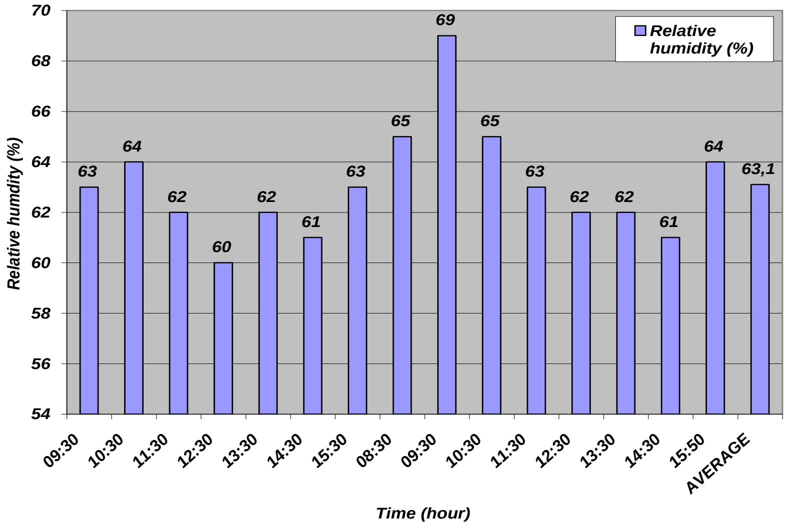

Figure 7. Relative humidity during the test.

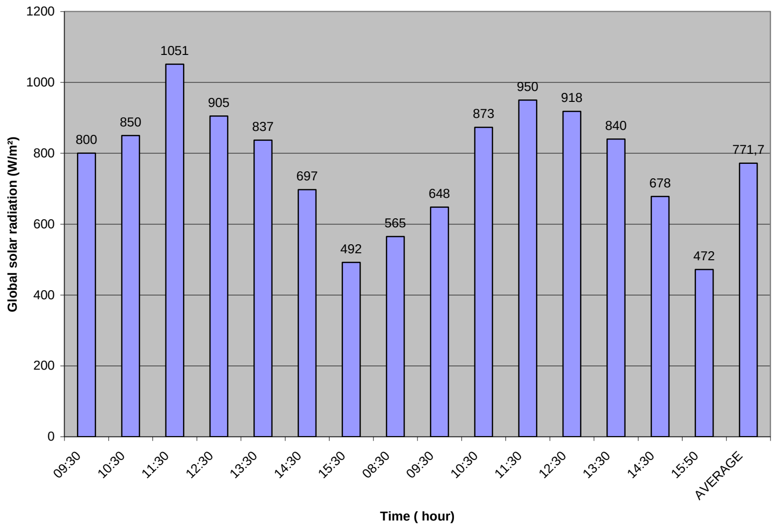

Figure 8. Global solar radiation during the air testing.

The dried tomatoes are shown in Figure 9 and were used for the production of a preserved base of olive oil, oregano, crushed pepper, balsamic vinegar and other ingredients. Pickling produced is shown in Figure 10. Another procedure performed was grinding the dried tomatoes, obtaining the product shown in Figure 11.

Figure 9. Dried tomatoes after the drying process with the proposed solar dryer.

Figure 10. Saves produced from the dried tomatoes.

Figure 11. Tomatoes crushed after drying processes.

The process of drying with the proposed dryer was efficient to demonstrate the viability of tomato drying. Other tests were conducted with other fruits and larger loads. The drying times obtained, final moisture content and mass loss of the final product were compatible and competitive with the indicated by specialized in food dehydration literature. Another extremely positive factor in the drying system presented is its low cost and that it may contribute to the socialization of solar drying as a mean to generate employment and income.

5. **CONCLUSIONS AND SUGESTIONS**

1. The dryer proposed was feasible to produce the drying of all fruits tested at low cost;
2. The drying process by direct exposure proved to be efficient and can produce a loss of mass consistent with what the specialized in food drying literature indicates;
3. The manufacturing cost of this dryer is very low, being competitive with conventional dryers available;
4. The methods of fabrication and assembly of the drying system proposed are quite simple;
5. The proposed dryer is extremely feasible for rural and urban areas for fighting waste and spoilage, many modules can be used for dryers.
6. The proposed system can be an alternative to generate employment and income for poor communities
7. The drying times obtained for the tested products were competitive with those shown in works done on drying and presented in papers and journals.
9. It is important to conduct tests with other fruits and greater drying load to evaluate the efficiency of the dryer and the process.

6. REFERENCES

Costa, A.R.S., 2003, Utilização de Processo Osmótico, seguido de secagem para a obtenção de tomate parcialmente desidratado, Tese de Doutorado do Curso de Pós-Graduação em Engenharia mecânica da UFPB, João Pessoa, PB.

Costa, A.R.S., 2008, ***Sistema de secagem solar para frutos e modelagem da secagem de banana em um secador de coluna estática,*** Tese de Doutorado do Curso de Pós-Graduação em Engenharia Química da UFRN, Natal, RN.

Costa, J.B.S., 2010, ***Obtenção e caracterização de farinha de caju através do uso de um sistema de secagem solar de baixo custo,*** Dissertação de Mestrado Programa de Pós-Graduação em Engenharia Mecânica da UFRN, Natal, RN.

Duffie, J.A., Beckman, W.A., 1991, Solar Engineering of Thermal processes, second edition, New York, John&Sons, & Beckman.

Embrapa - Empresa Brasileira de Pesquisa Agropecuária., 2000, ***Tomate para processamento industrial***, Brasília, DF.

Fioreze, R., 2003, ***Princípios da Secagem de Produtos Biológicos***. João Pessoa, Editora da Universidade Federal da Paraíba - UFPB.

Meloni, P.L.S., 2002, Manual de produção de Frutas Desidratadas, Instituto de Desenvolvimento da Fruticultura e Agroindústria – Frutal/ Sindicato dos Produtores de frutas do Estado do Ceará – Sindifruta.

Neto, H. J. L., 2008, Obtenção de tomate seco através do uso de um sistema solar alternativo de baixo custo, Dissertação de Mestrado do Programa de Pós-Graduação em Engenharia Mecânica da UFRN, Natal.

Souza *et al*., 2007, ***Obtenção de tomate seco utilizando um sistema de secagem solar construído com materiais alternativos***, 8º Congresso Iberoamericano de Engenharia Mecânica, Cusco, Peru.

Souza, L.G. M, 2004, Secador Solar a Baixo Custo para Frutas Tropicais, CONEM-2004, Belém/PA.