CONSTRUCTIVE ANALYSIS OF A HYBRID SOLAR ELECTRICAL DRYER

Luiz Felipe Oliveira Andrade, luizfoa@hotmail.com
Davidson Alexandre de Freitas Neves, dafneves@hotmail.com
Pontifícia Universidade Católica de Minas Gerais, Av. Dom José Gaspar, 500. Belo Horizonte, Minas Gerais

André Guimarães Ferreira, agferreira@deii.cefetmg.br
Centro Federal de Educação Tecnológica de Minas Gerais, Av. Amazonas, 5253, Belo Horizonte, Minas Gerais

Cristiana Brasil Maia, cristiana@pucminas.br
Pontifícia Universidade Católica de Minas Gerais, Av. Dom José Gaspar, 500. Belo Horizonte, Minas Gerais

Abstract. *Nowadays there are around 6.6 billion people around the world. The world population is expected to reach nearly 10 billion by the year 2042. It would be necessary to double the world's food production to supply this demand. Nevertheless, the number of farmers has decreased over the last years. Besides, it is estimated that around 25% of the food production is lost between the farmer and the consumer. A considerable part of these losses occurs during the storage and transportation of the production. The drying is the oldest method of food preservation, suitable to reduce the losses of most of the products. In the beginning, the products were dried on the plants or in trays on the ground, exposed directly to the sun. Although the natural sun drying has low costs, it has low efficiencies, because the products are subject to outside treats, like animals and weather. The dryers are divided into solar dryers (the drying airflow is heated by the solar radiation); artificial dryers (the drying airflow is generated by other sources of heating); and hybrid dryers (Other sources of heating are used to complement the solar radiation). The hybrid dryers arise as an interesting choice, because they have a superior quality of drying than the solar dryers (since they allow the control of the thermal airflow parameters) with lower costs than the artificial dryers. This paper presents constructive and design details of the construction of a hybrid solar dryer. An electrical resistance is used to complement the solar heating, when necessary. The resistance will be monitored by a temperature control system. The technical and economic details of the development and construction of the dryer will be shown.*

Keywords*: Hybrid solar electrical dryer, Constructive analysis*

1. INTRODUCTION

An analysis of the worldwide food production and consumption indicates that in the next few years, the production of food will not be enough to supply the world's demand (Mühlbauer et al., 1996). The combination of the increase of the population and the amount of agricultural losses is significantly reducing the food availability in the world.

The agriculture plays a major role on the Brazilian's economy, contributing to its development. In comparison to other countries where the agriculture is important to the economy, Brazil's agriculture has overwhelming conditions to increase its productivity and to upgrade the commerce of agricultural goods (Silva, 2000). Brazil has a great diversity in the climate, regular rain regime, great incidence of solar energy and almost 13% of the fresh water of the world. The country also has 388 million hectares of fertile agricultural land, 90 million hectares of them yet unexplored.

In 2004 the agribusiness was responsible for 33% of the Brazilian Gross Domestic Product (GDP), for 42% of exports and for 37% of Brazilian's employment. Between 1998 and 2003 the agriculture GDP increase rate was around 4,67% a year (Iglécias, 2007).

In the last years, only a few countries were able to reach such a considerable growth in the international agricultural commerce as Brazil did. In ten years, the country doubled the outside commercial profit with agribusiness products and had over a 100% increase on the commercial balance. Based on these results, the United Nations Conference on Trade and Development (Unctad) predicted that Brazil will be the greatest food producer in the next decade (Iglécias, 2007).

Around 25% of the world's food production is lost between the producer and the consumer (Junqueira e Luengo, 1999). Those rates are usually higher in developing countries. Although Brazilian's agricultural potential, Silva (2000) estimates that over 25% of the grain crop is wasted. Vilela et al. (2003) estimate that the losses in the vegetables reach around 35 to 40%. Considerable losses occur mainly because of inadequate storage, damages during transportation and attacks by rodents, birds, insects, and microorganisms (Vilela et al., 2003; Silva et al., 2003; Mühlbauer et al., 1996).

In order to reduce the losses and increase the exports, it is necessary to increase the quality of products storage, adjusting it to the international quality standards. The medium and big producers are already adapting the storage systems to international quality levels. Nevertheless, the small producers do not have technology or financial resources, and they tend to dry the products on the field or storing the products under direct sunlight, slow processes that lead to great losses.

In this context, it's of urgent necessity to develop new low-cost dryers. The hybrid dryers represent the most interesting choice, because they promote superior quality of drying, compared to solar dryers, and lower costs than artificial dryers. The purpose of this paper is to present and constructive and design details a hybrid solar dryer.

2. THE DRYER

The proposed hybrid solar-electrical dryer consists of a solar collector connected to a drying chamber (Fig. 1). The solar collector is placed inside a box, opened in the inlet and in the outlet. The bottom and the inner walls will be made of plates painted in tarnished black, thermally insulated. The cover will be made of glass.

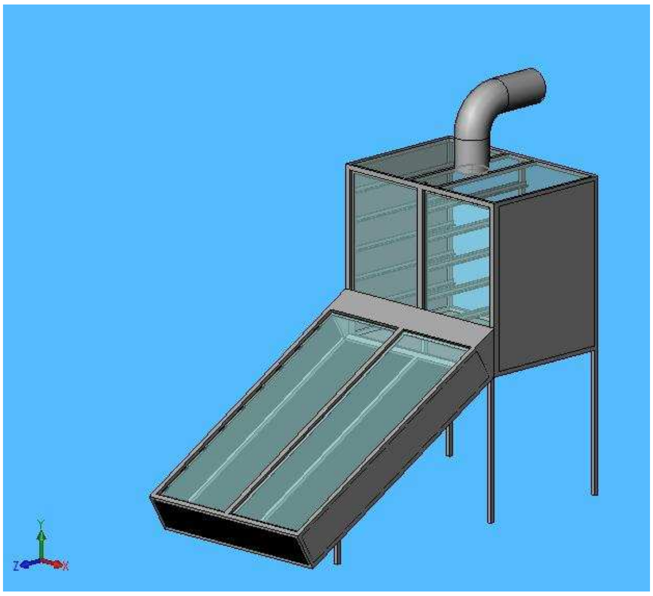


Figure 1 – Hybrid solar-electrical dryer

The drying chamber will be made of thermally insulated metallic plates. In the bottom of the chamber, it will be installed an electrical circuit with a electrical resistance to complement the heating of the drying air. The operation of the electrical resistance will be monitored by a control system, based on the average temperature inside the drying chamber. On the top of the dryer, it will be installed a chimney with an air exhauster, to promote the outlet of the air. Inside the drying chamber, eight trays nets will be placed to support the drying products. Two doors will allow the insertion and remotion of the products. A temperature sensor will be installed in the chimney entrance and it will be connected to a outlet air flow controller.

During the period of sunshine, part of the solar radiation incident on the solar collector is transmitted trough the glass top of the solar collector and reaches the absorber. The temperature in the collector plate rises. Air at ambient temperature inlets the device and is heated. Since the solar collector is tilted from horizontal, the air inside the solar collector moves towards the drying chamber and is heated as it moves. If necessary, the air will receive additional heating from the electrical resistance. The airflow will cross the drying trays, removing moisture from the drying products. After that, the airflow leaves the device by the chimney outlet. The artificial movement of the drying airflow is generated by the air exhauster.

The geometric configuration defined for the dryer is similar to the dryers proposed by El-Sebaii et al. (2002), Pangavhane et al. (2002) and Ekechukwu and Norton (1999). However, in these dryers the airflow temperature depends exclusively on environment conditions. The use of auxiliary heating systems to complement the solar energy increases the quality of the drying process. Bena and Fuller (2002) proposed a biomass burner as the auxiliary heating system. Ivanova et. al. (2004) used geothermal energy and Nandwani (2007) used a water heater coupled to the dryer.

3. Materials and Methods

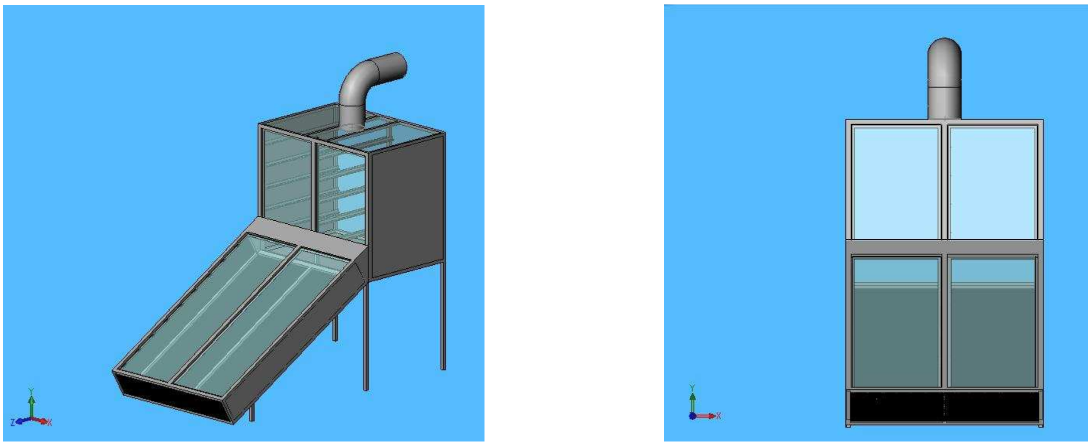
The hybrid solar dryer consists of a solar collector and a drying chamber. An auxiliary heating system with electrical resistances will be used to complement the solar energy. It will be developed a control system to control the electrical power of the dryer, ensuring more uniform drying conditions. A data acquisition system will be used to monitor the airflow temperature and velocity and the incident solar radiation. A control system will be developed so the electric power of the resistance can be regulated, controlling the appropriate airflow for the situation.

Leon et al. (2002) established optimal parameters to the operation of a food dryer. According to them, the drying capacity of a solar dryer must be 4 kg of fresh product per each square meter of drying tray area. In hybrid solar dryers, the solar collector area must be at least 75% of the drying tray area. The optimal volume flow must be $0.0125 m^3/s$ per each square meter of drying tray area.

The configuration of the proposed dryer was based on a similar dryer built in a previous project, shown in Figure 2 (Ferreira et. al., 2007). The earlier dryer showed as main disadvantages low electric power from the electrical resistance and a big tray area.

Figure 2 – Previously built dryer

Figure 3 presents the geometric parameters of the dryer. It will have eight trays, with 0.8 m x 0.6 m, with a total area of 3.8 m^2. However, due to the structure of the dryer, the drying tray area is reduced to 3,75 m^2. According to Leon et al. (2002), the drying capacity of the dryer is estimated in 15 kg of fresh products. Besides, the solar collector area should be of $2.88 m^2$.



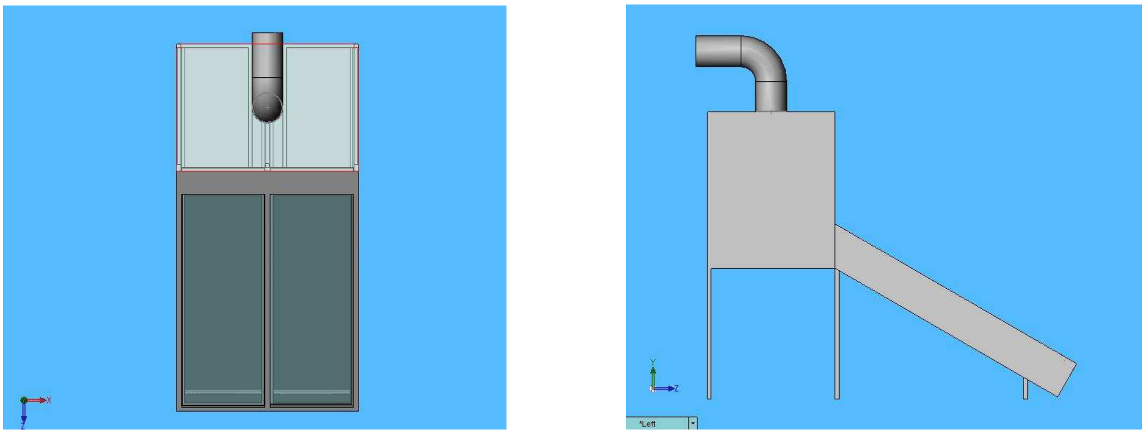


Figure 3 – Geometric parameters of the dryer

The volume flow is an important parameter to be defined. According to Leon et al. (2002), the optimal airflow is estimated in 2.8 m^3/min. With 7.5 cm diameter tubes in the outlet of the dryer, the average outlet velocity should be around 10.6 m/s. Based on the optimal airflow and on the head losses of the usual commercial dryers, the air exhauster can be determined.

The electric power is the last technical parameter to be defined. The electric power can be determined by

$$\dot{W} = \dot{m} c_p \Delta T$$

In order to ensure an increase of temperature of 60°C, it is necessary an electric power of 2.8 kW, if the losses are not considered. To maximum losses of 30%, the electric power should be around 4 kW.

The hybrid dryer has 2.32m in length; 1.20m in width and it height is 1.90m. The solar collector has 1.90m in length and 1.20m in width. The drying chamber has 0.90 in length, 1.20m in width and 1.03m in height.

The dryer will be installed in Belo Horizonte (latitude 19.93°S). In order to absorb the maximum solar radiation in the winter, the solar collector will have a slope of 30° (the angle between the plate and the horizontal). Since the collector area will be smaller than 2.88m^2, the drying chamber front area and top will be made of glass. The glass used has a 6mm thickness. It is tempered, in order to increase the structure's mechanical and thermal resistances.

The metallic plates used in the dryer will be 3 mm thickness galvanized plates. The frame will be made with rectangular bars and iron angles. Glass wool will be used between the plates to minimize the heat losses (Figure 4). The walls will be painted black and covered with a product for protection against oxidation and corrosion. The black color was defined in order to increase the absorptance and reduce the reflectance of the walls.

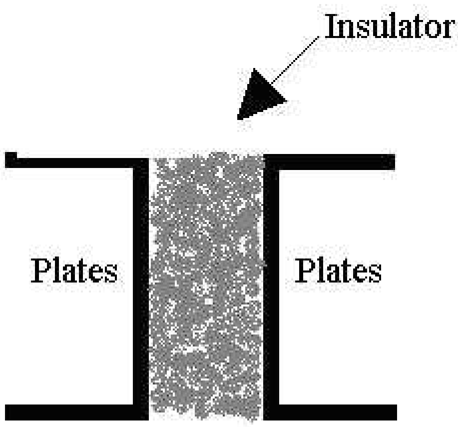


Figure 4 – Schematic representation of the insulation

The operation of the dryer will be evaluated by standard tests. In order to determine its performance, drying tests will be performed. One particular test consists on the evaluation of the drying time and the comparison with the drying time of natural sun drying, in the same meteorological conditions. The drying curve can be plotted by measuring the weight of the products along the drying. A load cell will be used to continuously measure the weight of the products.

The uniformity of the airflow will be ensured by the electrical resistance. Its operation will be controlled by a control system. The average temperature inside the drying chamber will be monitored. When the average value drops below a predefined value, the electrical resistance will be turned on. When the temperature exceeds another predefined value, the resistance will be turned off. It is important to mention that the temperature limits depend on the drying products and they can be set up.

The ambient temperature and humidity, the temperature in several locations inside the dryer, the velocity and the humidity of the airflow leaving the dryer and the incident solar radiation will be measured by appropriate sensors. A data acquisition system will be used to store this information.

The total cost of the dryer material is estimated in approximately R$ 4.000,00, according to Table 1. It will be built by the university staff.

Table 1 – Description of the material

Material	Quantity	Unit cost	Total cost
Galvanized Plates	16	R$ 97,00	R$ 1552,00
1”x1” Rectangular tubes	15	R$ 21,50	R$ 322,50
1”x1” Angle iron	15	R$ 22,00	R$ 330,00
1cmx1cm Angle iron	2	R$ 15,00	R$ 30,00
Paint		R$ 170,00	R$ 170,00
Enamel	4	R$ 39,50	R$ 158,00
Glass plates	5		R$ 413,50
Electrical Resistance	1	R$ 320,00	R$ 320,00
Glass Wool	30	R$ 9,80	R$ 294,00
Silicone and others		R$ 410,00	R$ 410,00
TOTAL			≈ R$ 4000,00

4. CONCLUSIONS

The experience gained during the previous hybrid solar dryer built lead to a reformulated project, with lower costs and an improved design. The automatic control of the operation of the electrical resistance will reduce the operation costs of the system and promote more uniform conditions of drying, increasing the efficiency of the dryer. It is expected that the dryer promote a good quality of drying with low costs, contributing to improve the final products and reducing the losses.

5. ACKNOWLEDGMENTS

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6. REFERENCES

Bena, B. and Fuller, R. J., 2002, “Natural Convection Solar Dryer With Biomass Back-up Heater”, Solar Energy, Vol. 72, No.1, pp. 75-83.

Ekechukwu, O. V. and Norton, B., 1999, “Review of Solar-energy Drying Systems II: an Overview of Solar Drying Technology”, Energy Conversion and Management, Vol. 40, pp. 615-655.

El-Sebaii, A.A., Aboul-Enein, S., Ramadan, M. R. I. and El-Gohary, H. G, 2002, “Experimental Investigation of an Indirect Type Natural Convection Solar Dryer”, Energy Conversion and Management, Vol. 43, pp. 2251-2266.

Ferreira, A.G., Charbel, A.L.T., Pires, R.L., Silva, J.G. and Maia, C.B., 2007, “Analysis of a Hybrid Solar-Electrical Dryer”, Proceedings of the 19th Brazilian Congress of Mechanical Engineering, Vol.1, Brasília, Brazil.

Iglécias, W., 2007, “O empresariado do agronegócio no Brasil: ação coletiva e formas de atuação política”, Revista de Sociologia e Polítiva, Vol. 28.

Ivanova, D., Enimanev, K. and Andonov, K., 2003, “Energy and Economic Effectiveness of a Fruit and Vegetable Dryer”, Energy Conversion and Management, Vol. 44, pp. 763-769.

Junqueira, A. H. and Luengo, R. F. A., 1999 “Mercados Diferenciados”, Embrapa Hortaliças, Circular Técnica, No 16, pp 1-7.

Leon, M. A., Kumar, S. and Bhattacharya, S. C., 2002, “A Comprehensive Procedure for Performance Evaluation of Solar Food Dryers”, Renewable and Sustainable Energy Reviews, Vol. 6, pp 367-393.

Mühlbauer, W.; Müller, J.; Esper, A. and Bux, M., 1996, “Secagem Solar e ao Sol para Produtos Agrícolas e Florestais” (Translation to Portuguese), Universidade de Hohenheim/Instituto para Engenharia Agrícola nos Países Tropicais e Subtropicais, Stuttgart/Alemanha.

Nandwani, S. S.; 2007. “Design, construction and study of a hybrid solar food processor in the climate of Costa Rica”. Renewable Energy, Vol. 32, pp. 427/441.

Pangavhane, D. R., Sawhney, R. L. and Sarsavadia, P. N., 2002, “Design, Development and Performance Testing of a New Natural Convection Solar Dryer”, Energy, Vol. 27, pp. 579-590.

Silva, C. S.; Pedrosa, J. M. Y.; Rua, P. S.; Abreu, C. L. M.; Pântano, S. C.; Vieira C. R. Y. I. and Brizola, R. M.O., 2003, “Avaliação Econômica das Perdas de Banana no Mercado Varejista: Um Estudo de Caso”, Ver. Brás. Frutic., Jaboticabal-SP, Vol. 25, No 2, pp. 229-234.

Silva, J. S., 2000, “Secagem e Armazenagem de Produtos Agrícolas”, Editora Aprenda Fácil, Viçosa, Brazil.

Vilela, N. J.; Lana, M. M. and Makishima, N. O., 2003, “O Peso da Perda de Alimentos para a Sociedade: O Caso das Hortaliças”, Horticultura Brasileira, Brasília, Vol. 21, No 2, pp. 141-143.

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