Performance Evaluation of a Simple Solar Dryer for Food Preservation

B. O. BOLAJI

Department of Mechanical Engineering

Federal University of Technology

P.M.B. 704, Akure, Nigeria

e-mail: bobbolaji2007@yahoo.com

ABSTRACT: This paper presents the design, construction and testing of a simple solar dryer for food preservation. Its construction was accomplished using mainly inexpensive locally available materials to make it relatively affordable to the average poor farmer dwelling in the rural area. The dryer temperature was found to be above the ambient temperature by an average of 51 % throughout the day-light time and the temperature rise was up to 75 % for about three hours immediately after 12.00 h (noon). The drying rate and the system efficiency were 0.46 kg/h and 59 % respectively. The rapid rate of drying in the dryer reveals its ability to dry food items reasonably rapidly to a safe moisture level and simultaneously it ensures a superior quality of the dried product. The results obtained indicate that solar dryers have a future especially in food preservation.

Keywords: solar energy; dryer, food preservation; performance evaluation.

I. INTRODUCTION

The continuous rise in the cost of non-renewable energy sources, the fast rate at which they are being depleted and the growing concern about their availability in both the short and long terms, has resulted in growing interest in the use of renewable resources. Solar energy is the driving force behind several of the renewable forms of energy. Solar energy is an ideal alternative source of energy because it is abundant and inexhaustible (Bather and Caruthers, 1981).

Solar energy has been used for centuries by man for drying animal skins and clothes, preserving meat and fish, drying agriculture crops and evaporating sea water in order to extract salt (Adaramola *et al*., 2004). Due to unexpected high prices of agricultural products, their preservation is becoming more and more important nowadays. Also food preservation should be given priority in developing countries where agriculture plays crucial role in providing employment for the majority of the population.

Food and energy are the essential factors of the human survival, so the efforts for greater food production and smaller energy dissipation can undoubtedly provide more peaceful and secure future for mankind (Kilkis, 1981). The farmers in developing countries are confronted with the problem of preserving their harvested crops to prevent spoilage during storage. Farmers suffer heavy losses of food in the post-harvest period during which the harvested crops pass through series of well-defined steps, like threshing (or shelling), drying and final processing. Therefore, there must be a great interest in any device or process, which can contribute to economic and industrial growth of developing countries.

Drying is a process by which water is removed from a substance. According to Ikejiofor (1985), two types of water are present in food items; the chemically bond water and the physically held water. In drying, it is only the physically held water that is removed. The main reason for drying food items is to reduce its water content to a level where it can be safely stored for future use.

The efficiency of solar dryers is not very high because of the diffuse nature of solar radiation, which put a limit to their use (Othieno, 1985). Any attempt to increase efficiency by using concentrators or reflectors increases construction cost astronomically. However, it has been discovered that most agricultural products dry efficiently at temperatures attainable using simple solar dryer (Fath, 1995).

Traditionally many cereal crops, vegetables and fruits are dried by thinly spreading them on a prepared ground or platforms in open sunlight. Large losses are generally incurred when this method is used. The losses are attributed to birds, rodents and domestic animals and wind blowing the product beyond recovery. Further disadvantage of this technique is due to lack of control over the drying rate, which usually results in under-drying or over-drying. Under-drying leads to deterioration of product due to fungi or bacteria whereas the over-drying may leads to case-hardening, followed by bursting resulting in the spoilage of the product.

Due to increasing demand for food items, practical ways of cheaply and sanitarily preserving foods are needed. Solar dryers will dry the products reasonably rapidly to a safe moisture level, and simultaneously it ensures a superior quality of the dried product. Therefore, the aim of this study is to develop a simple solar dryer in which the problems exhibited by the open-air (traditional) drying can be overcome and agricultural products will be dried under controlled conditions of temperature and humidity.

II. MATERIALS AND METHODS

A. Theoretical Consideration

The heat gained by the dryer per unit time, Q_g is given by the Hottel-Whiller-Bliss equation (Duffie and Beckman, 1991):

$$Q_g = A[I\tau\alpha - U_L(T_i - T_a)] \quad (1)$$

Where: A = area of transparent cover (m^2)

I = incident insolation (W/m^2)

U_L = overall heat loss for the collector (W/K)

α = solar absorptance

τ = transmittance

T_i = temperature of incoming air (K)

T_a = temperature of ambient air (K)

Since the dryer draws the ambient air directly, the last term on the right-hand side vanishes and the rate of energy collection is simply:

$$Q_g = AI\tau\alpha \quad (2)$$

If the mass of air leaving the dryer per unit time is M_a, the heat gained by the air Q_a is (Pratota *et al.*, 1997):

$$Q_a = M_aC(T_o - T_i) \quad (3)$$

Where: C = specific heat capacity of air (kJ/kg.K)

T_o = temperature of out-going air (K)

A simplified energy equation for the dryer is $Q_g = Q_a$, that is,

$$AI\tau\alpha = M_aC(T_o - T_i) \quad (4)$$

Therefore, the required surface area of the transparent cover, which determines the size and dimensions of the dryer, is obtained from:

$$A = \frac{M_aC(T_o - T_i)}{I\tau\alpha} \quad (5)$$

The total energy required for drying a given quantity of food items can be estimated using the basic energy balance equation for the evaporation of water (Howe, 1980):

$$M_w L_v = M_a C(T_o - T_i) \quad (6)$$

Where: L_v = specific latent heat of vaporization of water from the food surface (kJ/kg)

M_w = mass of water from the food item (kg)

The mass of water M_w is estimated from the initial moisture content M_i and the final desired moisture content M_f as follows:

$$M_w = M_{wc}\left[\frac{M_i - M_f}{100 - M_f}\right] \quad (7)$$

M_{wc} = mass of the wet crop or food item (kg)

During drying water at the surface of the substance evaporates and water in the inner part migrates to the surface to get evaporated. The ease of this migration depends on the porosity of the substance and the surface area available. Other factors that may enhance quick drying of food items are: high temperature, high wind speed and relative humidity. In drying grains for future planting, care must be taken not to kill the embryo. In drying items like fish, meat, yam chips, plantain chips etc., excessive heating must also be avoided; it spoils the texture and quality of the item.

B. Construction of the Solar Dryer

The materials for making simple solar dryer are cheap and easily obtainable in the local market. The solar dryer is shown in Fig. 1. The transparent top cover is a clear polyvinyl chloride (PVC) plastic sheet with a total surface area of 1.22 m by 0.90 m. The dryer cabinet is made of 25 mm plywood. The front is higher than the rear giving the top cover an inclination of about 17.5^o. This is approximately 10^o more than the local geographical latitude (Ado-Ekiti Nigeria, 7.5^0N), which according to Adegoke and Bolaji (2000), is the best recommended orientation for stationary absorber. This inclination is also to allow easy run off of water and to enhance air circulation. Vents were made at the low end of the front of the cabinet and at the upper end of the back of the cabinet to facilitate and control the convectional flow of air through the dryer. A drying tray was constructed with wire mesh, which fitted snugly and covered the entire floor of the dryer. Access door was also provided at the back of the cabinet to allow the loading of the drying tray with food items.

C. Operation of the Dryer

Fig. 1 shows the essential features of a simple solar dryer. The dryer is a passive system in the sense that it has no moving parts. It is energized by the sun's rays entering through the transparent top. The trapping of the rays is enhanced by the inside surfaces that were painted black and the trapped energy heats the air inside the dryer. The greenhouse effect achieved within the dryer drives the air current necessary for faster drying. If the vents are opened, the hot air rises and escapes through the upper vent while cooler air at ambient temperature enters through the lower vent. Therefore, an air current is maintained, as cooler air at a temperature T_i enters through the lower vent and hot air at a temperature T_o leaves through the upper vent.

When the dryer contains no item to be dried, the incoming air at a temperature "T_i" has a relative humidity "H_i", and the out-going air at a temperature "T_o" has a relative humidity "H_o". Because $T_o > T_i$ and the dryer contains no item, $H_i > H_o$. Thus there is tendency for the out-going hot air to pick more moisture within the dryer as a result of the difference between H_i and H_o. Therefore, insolation received is principally used in increasing the affinity of the air in the dryer to pick moisture.

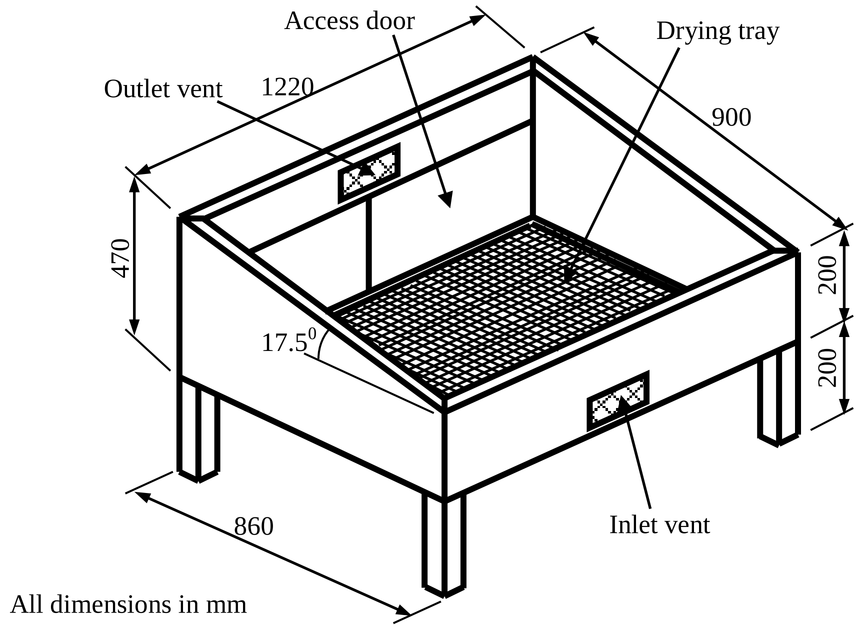

Fig. 1: Simple solar dryer

D. Dryer Performance Evaluation

The solar dryer was tested to evaluate its performance. During the testing period, the temperatures profile of the dryer was determined by measuring the hourly temperatures inside the drying cabinet and the ambient air between the hours of 08.00 and 18.00. The results obtained are shown in Fig. 2.

The dryer was loaded with yam chips (4 mm average thickness) and its weight was measured at the start and at one-hour intervals thereafter. Knowing the initial weight and the final weight at the point when no further weight loss of yam chips was attained, the weight loss was used to calculate the moisture removed in kg water/kg dry matter at intervals as the yam dried. The results obtained are also shown in Fig. 3. The dryer performance was evaluated using the drying rate and the system drying efficiency. The drying rate, which is the quantity of moisture removed from the food item in a given time, was computed from, Eq. 8, (Itodo et al., 2002):

$$\frac{dM}{dt} = \left(\frac{M_i - M_f}{t}\right) \times 100\% \qquad (8)$$

The system drying efficiency is the ratio of the energy required to evaporate the moisture to the energy supplied to the dryer, and is computed from, Eq. 9, (Itodo et al., 2002):

$$\eta_d = \left(\frac{M_w L_v}{AI\tau\alpha}\right) \times 100\% \qquad (9)$$

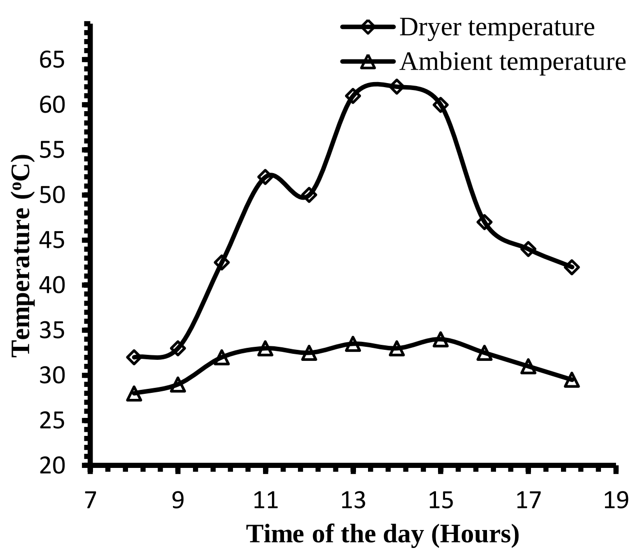

Fig. 2: Hourly variation of the dryer and the ambient temperatures

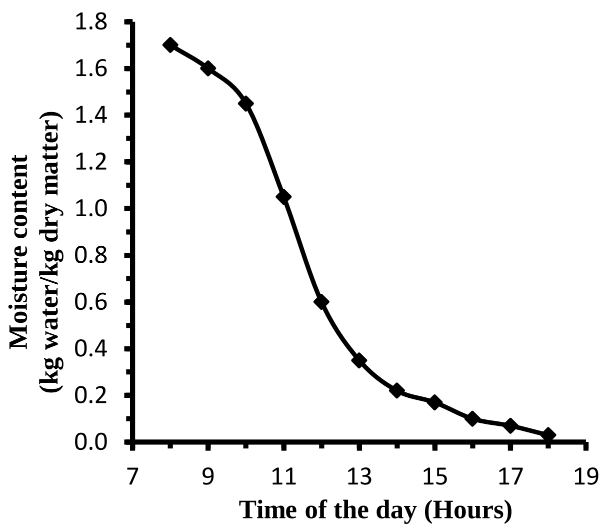

Fig. 3: Drying curve for yam chips in the solar dryer

III. RESULTS AND DISCUSSION

Fig. 2 shows the hourly variation of the temperature inside the dryer compared to the ambient temperature. The average temperatures in the dryer and ambient air were 47.3 ^oC and 31.3 ^oC during the daylight respectively, therefore, the heating temperature inside the dryer was higher than the ambient temperature by an average of 16 ^oC (51 %) throughout the daylight and up to 25 ^oC (75 %) between 13.00 hour and 15.00 hour, which indicates prospect for better performance than open-air sun drying.

Fig. 3 shows the drying curve for yam chips in the simple solar dryer. It was observed that the drying rate increased due to increase in temperature between 10.00 h and 14.00 h but decreased thereafter, which shows the earlier and faster removal of moisture from the dried item. The dryer was able to remove 72.8 % of moisture, dry basis, from 4.6 kg of yam chips in one day of 10.00 hours drying time, which is about 0.46 kg/hr drying rate. This rate compare well with the rate obtained from other dryers. Itodo *et al*. (2002) obtained a drying rate of 0.03 kg/hr for shelled corn using forced convection solar crop dryer for rural application in Nigeria. The system drying efficiency of the simple solar dryer during the test period was found to be 59 %.

IV. Conclusion

A simple and inexpensive solar dryer was design and constructed using locally sourced materials. The hourly variation of the temperatures inside the dryer compare to the ambient temperature shows that the temperature in the dryer is always above the ambient temperature by average of 16 ^oC (51 %) throughout the daylight hours. The temperature rise was up to 25 ^oC (75 %) for about three hours immediately after noon time (between 13.00 h and 15.00 h). The drying rate and system efficiency were 0.46 kg/h and 59 % respectively. The dryer exhibited sufficient ability to dry food items reasonably rapidly to a safe moisture level and simultaneously it ensures a superior quality of the dried product.

The results achieved are possible indications that solar dryers have a future especially in food preservation. However, a lot still has to be done to improve the performance of passive solar dryers. A possible area of improvement is on the use of solar storage systems in the dryer to store heat for use when insolation is insufficient due to adverse weather conditions and in the night when insolaton is totally absent.

REFERENCES

Adaramola M.S., Amaduobigha J., Allen K.O. and Siyanbola W.O., “Design, construction and testing of box-type solar oven”, Nigeria Journal of Engineering Management, Vol. 5, No. 2, 2004, pp. 38 – 46.

Adegoke C.O. and Bolaji B.O., “Performance evaluation of solar-operated thermosyphon hot water system in Akure”, International Journal of Engineering and Engineering Technology, FUTAJEET, Vol. 2, No. 1, 2000, pp. 35-40.

Bather D.M. and Caruthers S.P., “Energy from agriculture; catch crops as a potential fuel source in the UK”, Proceedings of the International Seminar on Energy Conservation and the use of Solar and other Renewable Energies in Agriculture; Polytechnic of Central London, Pergamon Press Ltd., England: 1981, pp. 9-22.

Duffie J.A. and Beckman W.A., “Solar Engineering of Thermal processes”, 2nd edition, Wiley Interscience. New York, 1991.

Fath H.E.S., "Thermal performance of simple design solar air heater with built-in thermal energy storage system", Energy Conversion and Management, Vol. 36, No. 10, 1995, pp. 989-997.

Howe E.D., "Principles of drying and evaporating", Sun World, Vol. 4, No. 1, 1980, pp. 182-185.

Ikejiofor I.D., "Passive solar cabinet dryer for drying agricultural products", In: O. Awe (Editor). Proceedings of the Workshop on the Physics and Technology of Solar Energy Conversion. African Union of Physics, University of Ibadan, Nigeria, 1985, pp. 157-165.

Itodo I.N., Obetta S.E. and Satimehin A.A., "Evaluation of a solar crop dryer for rural applications in Nigeria". Botswana Journal of Technology, Vol. 11, No. 2, 2002, pp. 58-62.

Kilkis B., "Solar energy assisted crop and fruit drying systems", Proceedings of the International Seminar on Energy Conservation and the Use of Solar and other Renewable Energies in Agriculture, Horticulture, and Fishculture, held at the Polytechnic of Central London, 15-19 September 1980. Oxford, Pergamon Press, 1981.

Othieno H., "Design factors of small scale thermosyphon solar crop dryers", In: O. Awe (Editor). Proceedings of the Workshop on the Physics and Technology of Solar Energy Conversion. African Union of Physics, University of Ibadan, Nigeria, 1985, pp. 135-143.

Pratota A., Daguenet M. and Zeghmati, B., "Sizing solar-assisted natural rubber dryers", Solar Energy, Vol. 61, No. 4, 1997, pp. 287-291.