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Full Length Research Paper

Development and performance of a laboratory-scale passive solar grain dryer in a tropical environment

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A laboratory-scale passive solar grain dryer was developed and its performance evaluated in Makurdi metropolis, Benue State, Nigeria. The dryer consist of a solar collector panel, a thermal storage unit and a drying chamber. The top of the collector is made of one layer of 4 mm thickness of colourless glass sheet as glazing. The absorber material used was corrugated 0.5 mm thick zinc roofing sheet painted black. The thermal storage unit and the drying chamber were built of wood because of its good insulation properties. The dryer was evaluated using 10 kg of freshly harvested maize at 32.8%wb. The performance evaluation results obtained showed that the mean drying rate of the dryer was 0.7 kg/day per every 10 kg of corn whereas sun-drying rate was 0.3125 kg/day comparatively. The solar dryer has considerable advantages over the traditional sun drying method in terms of faster drying rate, less fear of spoilage by micro-organisms when crop is harvested at high moisture content and handling convenience. Savings in time was achieved by using the solar grain dryer as against the traditional sun drying. It took 4-days to dry the corn to moisture content of 13.1%wb using the passive solar dryer while it took 8-days to dry to 13.4%wb under sun drying. Commercial sizes of the solar dryer can be amplified and produced for community level cooperative use and for prospective investors to fast track agricultural development in the rural areas.

Key words: Passive, solar, grain dryer, development, performance, laboratory-scale

INTRODUCTION

The domestic demand for energy now substantially exceeds supply and the trend is ominous. While the gap is not new, its increasing magnitude is alarming. In recent years, the public has become more concerned about the rapid depletion and escalating cost of fossil fuels, which of course are finite in supplies. These concerns have focused worldwide attention to the potential of harnessing the sun's power in new and varied form to meet society's growing energy needs. The importance of solar drying is increasing worldwide, especially in areas where the use of the abundant, renewable and clean solar energy is essentially advantageous. The supply of solar energy is abundant in most locations in Nigeria where solar heat is intense virtually all the year round (Irtwange, 1991). This is because Nigeria lies between latitude 4° to 14° North of equator geographically, which is in the solar belt. On the average, the yearly total solar energy falling on a horizontal surface in Nigeria is about 2,300 kwh/m^2 (Fagbenle, 1991). This energy could be converted into mechanical, electrical or chemical to be used in various fields, such as the production of electricity, irrigation, drying of crops and fishery products, space heating, water heating and air conditioning (Arinze, 1983). Drying crops by solar energy is of great economic importance the world over, especially in Nigeria where most of the crops and grain harvests are lost to fungal and microbial attacks (Itodo et al., 2002). In realisation of these, research and development programmes in solar energy have been carried out in Nigeria. Some methods of utilizing solar energy have reached a stage of development where they can compete economically with methods of using conventional energy source (Arinze, 1983). The methods used are simple and often crude but reasonably effective. Basically, crops are sprayed on the ground or platforms often with no pretreatment and are

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are turned regularly until sufficiently dried.

In most advanced segments of the society, artificial drying has in many cases supplemented traditional sun drying in order to achieve better quality control, reduce spoilage and in general cut down on losses. The development of artificial, large scale drying processes has resulted in high cost of labour and fossil fuels (Paul, 2001). Preservation of agricultural products by open air-drying in the sun was presumably one of the first conscious and purposeful technological activities undertaken by humanity (Imre, 1995). Traditionally, open-air solar drying methods are based on long-term experience and continue to be used all over the world to dry agricultural products in order to preserve them. Over the last two decades, open air drying has gradually become more and more limited because of the requirement for a large area, limitation of time, the possibilities of quality degradation, high level of dust and atmospheric pollution from the air, cloudiness and rain, intrusion from animals and man, infestation caused by birds and insects and inherent difficulties in controlling the drying process (Imre, 1995).

Global requirements can be and should be considered from an economic view-point, with the main influencing factors being savings and costs (Sadiku et al., 2001). Solar drying is not simply a method for substituting fossil fuels by solar energy, but is a technology based process for producing dried materials of the required quality (Imre, 1995). It influences the marketing capacity and income generating potential, since a higher price can be obtained for products of improved quality and for these reasons, technologically and scientifically based efforts have been made over the last three decades to development, design, construction and operation of solar dryers. The advent of higher charges for fossil fuels has stimulated the renewed interest in solar agricultural dryers.

Over the past three decades, increasing interest has been paid to the development of solar agricultural dryers which make use of known principles of heliotechnology in order to combat some of the principal disadvantages of classical sun drying. Sato and Irie (1981) conducted experiments on the solar drying of paddy and grasses in vinyl plastic hot houses which are in wide use among farmers in Japan, indicating that the farmer should be the focus of all on-farm research efforts. Sharma et al. (1993) described the design and performance of a solar fruit and vegetable dryer comprising plastic covered flat plate collectors, drying chamber and thermally and acoustically insulated pipes joining the two. The experimental results suggest that, even under unfavorable fall weather conditions, the unit is able to produce good quality products. Moreover, due to the low investment required, the solar dryer is predestined for applications on small farms. Soponronnarit (1995) reviewed the research and development work in solar drying conducted in Thailand during the past 15 years (since 1980s). He found that, in term of techniques and economy, solar drying for some crops such as paddy, multiple crops and fruit is feasible. However, the method has not been widely accepted by farmers. Bala et al. (1995) presented a technique for optimization of natural-convection solar dryers. The optimal design was specified for the condition of Bangladesh. The optimum design was a relatively long collector, a thin grain bed and a negligible chimney height. Mumba (1995) developed a photovoltaic-powered forced-circulation grain dryer for use in the tropics. From performance testing results, it was indicated that the dryer has a capacity of 90 kg (maize) for drying from an initial moisture content 33.3% to under 20% during one day. Faborode et al. (1995) carried out experiments to investigate the effects of forced air drying and intermittent resting on the fundamental drying mechanism of fermented cocoa beans and the quality characteristics of the resulting raw cocoa. The results indicate that after an initial warm-up and surface drying period of very short duration, forced air drying of cocoa beans involves a succession of falling rate periods, the number of which appears to depend on drying temperature and post-rest moisture content if the beans are subjected to intermittent resting. Karathanos and Belessiotis (1997) reported the sun and solar air drying kinetics of some agricultural products that is, sultana grapes, currants, figs, plums and apricots. The drying rates were found for both solar and industrial drying operations. The industrial drying operation resulted in a product of superior quality compared to products dried by solar dehydration. Soponronnarit et al. (1997) states that solar natural convection drying using a block-shape dryer made of plywood coated with black colour and transparent plastic cover took 6-7days for completing one batch of fresh bananas weighing 25kg. Ekechukwu and Norton (1999) presented a comprehensive review of the various designs, details of construction and operational principles for a variety of practical solar-energy drying systems. The appropriateness of each design type for applications used by rural farmers in developing countries was discussed.

Gallali et al. (2000) compared products dried by solar dryers and natural sun drying. The study indicated that using solar dryers gives more advantages than natural sun drying, especially in terms of drying time. Aboul-Enein et al. (2000) reported a parametric study of a solar air heater with and without thermal storage for solar drying applications. An optimization process for a flat-plate solar air heater with and without thermal storage was carried out. Roosevelt et al. (2000) developed a forced type of solar dryer set-up with an electrical back-up in order to achieve faster drying rates for higher productivity and economy in drying. They conclude that by controlling the drying temperature and relative humidity in solar drying, it is possible to achieve physical characteristics closer to open drying for higher productivity and cost-effective results. Hodali and Bougard (2001) designed an adsorption unit of silica gel and integrated it in a crops solar drying installation. The integration of the adsorption unit allowed improving the quality of the dried product and permitted a cyclic operation of drying over two days by reducing the drying period from 52 to 44 h. Leon et al. (2002) presented a review of existing evaluation methods and the parameters generally considered for evaluation of solar food dryers. These parameters were classified as physical features of the dryers; thermal performance; quality of dried product; cost of dryer and payback period. Pangavhane et al. (2002) proposed a design, development and performance testing of a new convection solar dryer. The drying time of grapes was reduced by 43% compared to the open sun drying. El-Sebaii et al. (2002) reported a study of an indirect type natural convection solar which investigated experimentally and theoretically for drying grapes, figs, onions, apples, tomatoes and green peas. The drying constants for the selected crops were obtained from the experimental results and were correlated with the drying product temperature. Bena and Fuller (2002) developed a direct-type natural convection solar dryer with simple biomass burner. It was expected to be suitable for small-scale processors of dried fruits and vegetables in non-electrified areas of developing countries. Bennamoun and Azeddine (2003) studied a simple, efficient and inexpensive solar batch dryer for agricultural products through simulations. It was suggested that the study could be developed for other agricultural products and for the behaviour of solar dryer in different seasons. Bahnasawy and Shenana (2004) developed a mathematical model of direct sun and solar drying of some fermented dairy products. The model was able to predict the drying temperatures at a wide range of relative humidity values. Chen et al. (2005) developed an experimental closed-type dryer associated with a photovoltaic system. Lemon slices were dried using the closed-type solar dryer and results were compared with hot air drying at 60°C. The results indicate that the dried lemon slices using a closed-type solar dryer has better general levels of quality in terms of sensory parameters. Tunde-Akintunde et al. (2005) carried out drying of bell-pepper using sun, solar and artificial air drying methods. The drying curves and rates obtained indicated that drying of bell-pepper was done in two drying rate periods, the constant drying rate period (mainly) and the falling drying rate period. The existence of the constant drying rate period was more pronounced in the artificial air-drying method than in the other two drying methods and the drying process was also faster.

Ezekoye and Enebe (2006) successfully developed and characterized a modified passive grain solar dryer using locally available material in Nigeria. The dryer can be enlarged for large-scale drying and commercial purposes by increasing the collector size and adding more number of trays. There is no need of carrying the crops inside during the nights in order to avoid re-wetting since the dryer is sealed with glass and wood to protect the samples from dew and rain. Zhang et al. (2006) states that increasing concerns over product quality and production costs have motivated researchers to investigate and the industry to adopt combination drying technologies but current applications are limited to small categories of fruits and vegetables due to high start-up costs and relatively complicated technology as compared to conventional convection drying. Zomorodian et al. (2007) used a new approach for employing solar radiation as the main source of energy for paddy drying. The rough rice solar dryer was a cross flow and an active mixed-mode type with a new and an efficient timer assisted semi-continuous discharging system. The maximum capacity of the dryer was about 132 kg of rough rice with initially 27%db down to 13%db final moisture content in 3 h of drying period (11 - 14 with 865 W/m^2 average incident solar radiation and average ambient temperature of 25°C). Ferreiraa et al. (2007) determined the performance of a hybrid dryer in which banana slices were dried in the device and the results were compared with natural sun drying and artificial drying. Results showed that the time required by the samples to reach the desired final moisture content was lower in the hybrid dryer when compared with natural sun drying and with the artificial dryer, to similar outlet air temperatures. Tasirin et al. (2007) carried out drying kinetics of bird's eye chilli in fluidized bed dryer and to investigate the performance of the fluidized bed dryer in reducing the moisture content of dried chilli up to 16% as comparable to the dried chilli in the market. Futhermore, dried bird's eye chillies tested in order to determine the suitability of using a fluidized bed dryer compared to sun drying. Comparing the dried products, it was observed that the bird's eye chillies dried using fluidized bed dryer were better in quality compared to those dried under the sun. Tembo et al., 2008 carried out a study to evaluate the effect of different stages of ripening on the quality of *Ziziphus mauritiana* fruits during drying. The fruits were graded into green, yellowish-brown and brown categories and these formed the treatments. Some of these fruits were blanched before drying for 1, 2 and 3 weeks under the solar dryer and the open sun drying methods. Sreekumar et al. (2008) developed and tested a new type of efficient solar dryer, particularly meant for drying vegetables and fruit. The dryer was loaded with 4 kg of bitter gourd having an initial moisture content of 95% and the final desired moisture content of 5% was achieved within 6 h without losing the product colour, while it was 11 h for open sun drying. Sopian et al. (2009) has identified numerous types of solar dryers that have been designed and developed in various parts of the world, yielding varying degrees of technical performance. Basically, there are four types of solar dryers; (a) direct solar dryers, (b) indirect solar dryers, (c) mixed-mode dryers and (d) hybrid solar dryers. The paper is a review of these types of solar dryers with aspect to the product

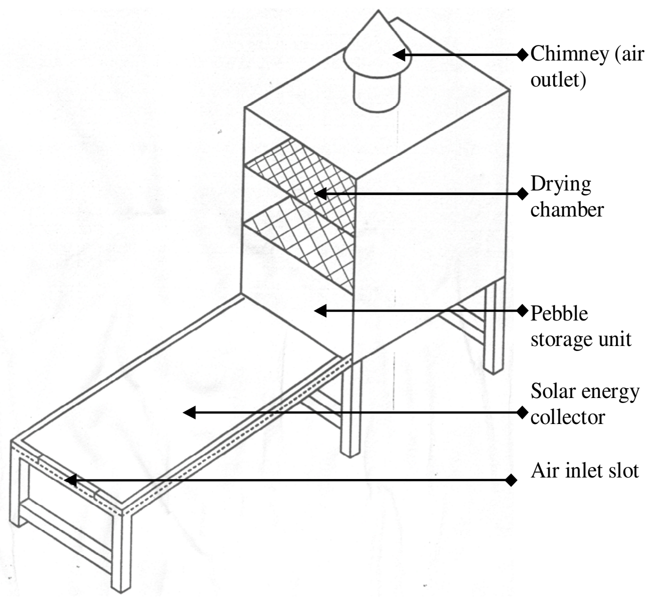

Figure 1. Laboratory-scale passive solar grain dryer.

being dried, technical and economical aspects. Giner (2009) states that food drying kinetics is usually studied by measuring the product average moisture content as a function of time, known as the drying curve, for constant air conditions. The slope of this curve is the drying rate.

In the developing countries and in rural areas the traditional open-air drying methods should be substituted by the more effective and more economic solar drying technologies (Imre and Palaniappan, 1996). This study is therefore devoted to the development, design, construction and performance of a passive solar grain dryer for small scale farmers in a tropical environment. Kisten and van Zyl (1998) defines a small scale farmer as one whose scale of operation is too small to attract the provision of the services he/she needs to be able to significantly increase his/her productivity.

MATERIALS AND METHODS

Description of passive solar grain dryer

The design concept of the solar grain dryer is to collect the solar energy through a solar collector and use it to heat up a mass of air and then pass it through a drying chamber by natural convection. Hence the heat supply to the grain is by indirect absorption of solar radiation. The solar grain dryer was developed, constructed and assembled as shown in Figure 1. The dryer consist of the following components: solar energy collector, drying chamber, storage unit, air vents and dryer stands.

The collector consists of the solar absorbing plate, which is made of corrugated 0.5 mm thick zinc roofing sheet of 1200 mm long and 600 mm wide. The collector casing is made of wood to prevent escape of heat. The top of the collector is made of one layer of 4mm thickness of colourless glass sheet 1200 mm long and 600 mm wide, which is more efficient than other materials (Sadiku et al., 2001). A gap of 0.55 mm between the glass cover and the absorber plate forms the air passage. According to Sayigh (1979), the optimum air gap between the absorber and the glass covers is over 4 cm and owing to the side shading effect caused by the collector box, less than 8 cm. The drying chamber is the place where the drying function takes place. It is fabricated from wood of 25 mm thickness to minimize heat loss. The drying chamber houses a batch tray, which would hold up to 20 kg of shelled maize or sorghum. The batch tray measuring 680 x 680 x 200 mm high is made of stainless steel wire mesh to avoid rusting. The access door for loading and off loading of the grains is pos-itioned at the side of the drying chamber to reduce shadow during handling. The storage unit is matched with the drying chamber and consist of gravel occupying a volume of 800 x 620 x 300 mm or 0.15 m^3, which is the lower limit of volume of 0.15 to 0.35 m^3 recommended by Goswani (1986). The rock pebbles for storage are painted black for better heat absorption. The function of the storage unit is to store heat during the day and release the same during off sunshine hours. There are two air-vents generally referred to as inlet air vent and outlet air vent. The air intake into the collector is through a 300 x 50 mm slot made through the col-lector wooden casing between the absorber plate and the bottom of the collector, which forms the airflow duct. The opening into the bottom of the pebble bed is 180 mm in diameter, supported by a perforated screen at the bottom to support the pebbles and allow for air circulation through the pebbles. The outlet air vent is the chimney which is situated on the top of the drying chamber. It is made of metal tube and co-rrugated roofing sheet painted black which serve the same pu-rpose as the solar collector absorber. It is circular in shape me-asuring 170 mm high and of cross sectional area of 254.4 mm^2. The chimney height is in accordance with a technique for optimization of natural-convection solar dryers presented by Bala et al. (1995). The drying chamber and solar collector stands constitute the dryer stands. The dryer stand is a set of four with 350mm height from the ground. The material selected for the stand is 40 x 40 mm hard wood because of its availability and durability. Makurdi, the Benue State Capital, lies at latitude 07°41' N, longitude 008°37' E and has an elevation of 97m, 318'. The collector slope of 7° which is an approximation of the latitude was used in the design. The solar collector was therefore mounted on a stand fabricated from a hard wood inclined at 7° to the horizontal south facing. Since the entire load is expected to come from the collector during sunshine on daytime operations and since the design is for all-year applications, this slope agrees with the recommendations given by Hsieh (1986).

Experimental procedure

The dryer was evaluated using ten kilogram (10 kg) of freshly harvested shelled maize with initial content of 32.8%wb which is slightly above the optimum moisture content range of 24 - 30%wb recommended during harvest for minimum loss (Brooker et al., 1957). The same quantity of maize at same moisture content was sun dried to allow comparison of the two drying modes. The experiment was replicated three times with the moisture content of the maize being measured daily in morning (9.00am) and in the evening (5.00pm) during the drying process to determine the number of days to attain the moisture content of 13% which is the approximate maximum for safe storage of corn for one year (Brooker et al., 1957). The ambient air, collector outlet, storage unit and drying chamber temperatures were all manually measured hourly between 9.00am to 5.00pm, which is the time sun-drying is done in Makurdi, Nigeria. The moisture content of the corn was determined using ASAE Standards, 1998. Drying rates were determined according to methods presented by Giner (2009). Temperatures were measured using mercury in bulb thermometers. Ambient air temperature was measured from a wet and dry bulb thermometer.

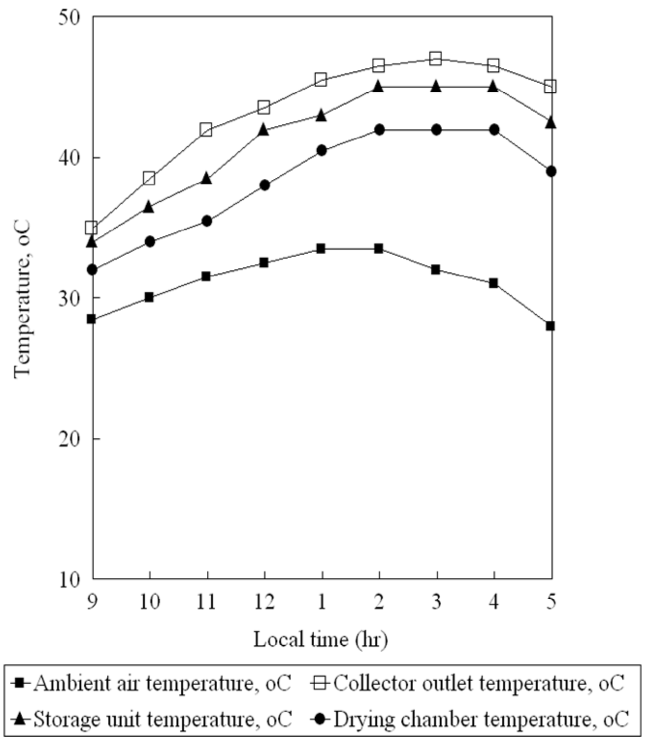

Figure 2. Typical plot of daily dryer system temperatures during the drying period.

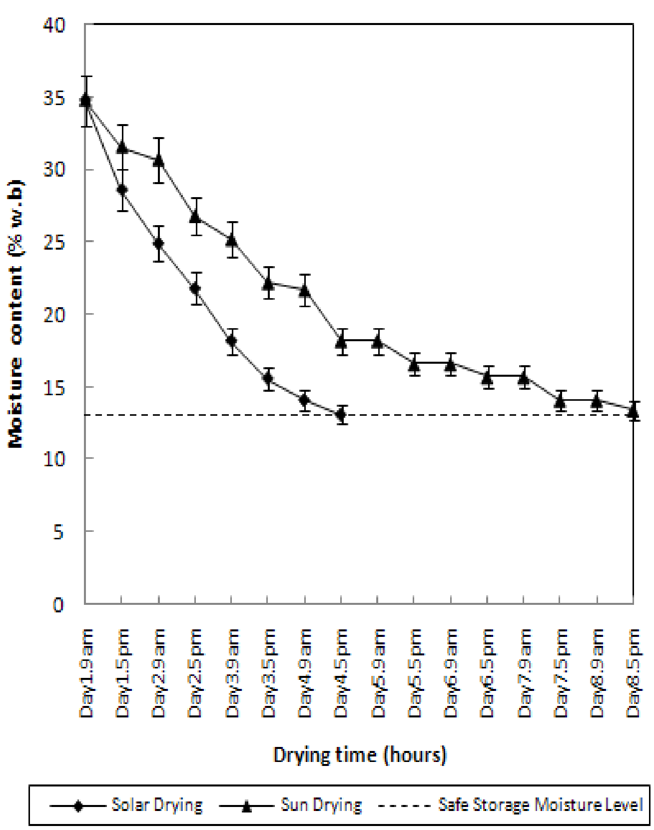

Figure 3. Variation of mean moisture content with drying time.

RESULTS AND DISCUSSION

Figure 2 is the typical plot of variation of the dryer mean system temperatures. The result shows that the average ambient temperature ranged between 28 - 33.5℃, collector outlet temperature ranged from 35 - 47℃, storage unit from 34 - 45℃ and drying chamber from 32 - 42℃.

The result also shows that the air heater (collector) has the capacity to heat air by 6 - 11.5℃ depending on the value of intensity of average daily solar radiation which for the period of the drying test for the month of September 2005 ranged from 37,163 - 37,837 KJ/m^2/day (Fagbenle, 1991). The storage unit has a maximum temperature of 45℃, which shows that the heat transfer coefficient between the air and the rock pebbles was very high.

The collector outlet air temperature was higher than the dryer and ambient air temperature, indicating prospects for higher drying rates over sun drying. For this research work, the purpose was to determine the number of days it will take to dry the corn to the moisture content approximating 13%. Figure 3 shows the variation of moisture content with drying time. The results show that at the end of 4-day drying period at prevailing drying chamber temperatures of 32 - 42℃, the mean moisture content of the corn was determined to be 13.1%wb giving the mean drying rate to be 0.7 kg/day per every 10 kg of corn. Comparatively, it took 8-days to sun-dry the corn to a mean moisture content of 13.4%wb under average ambient air temperatures in the range of 28 - 33.5℃, giving a mean drying rate of 0.3125 kg/day per every 10 kg of corn. This can be explained by the fact that in the case of the dryer, the heat stored in the pebble storage unit continues to effect drying in the night time while the sun-dried which is taken into the processing and storage laboratory and spread on the floor did not lose appreciable moisture to the atmosphere. This is depicted in Figure 4 where for solar drying; there is a marked difference in moisture content between the end of previous drying day (5.00pm) and start of drying on the following day (9.00am) with the difference decreasing with increase in drying days. In the case of sun drying, the difference was noticeable in the first two nights or off-sunshine hours (5.00pm - 9.00am) but subsequently no difference was observed in moisture content between end of drying on the previous day and start of drying on the following day. Ezekoye and Enebe (2006) indicate that with passive grain solar dryers, there is no need of carrying the crops inside during the nights in order to avoid re-wetting. This drying rate compares favourably to values reported in the literature. Falade et al. (1985) reported similar results on a fairly clear day with an indirect passive dryer that was used for deep-bed drying of corn.

In comparison, Mumba (1995) achieved drying of maize from 33.3%w.b to under 20% in one day using photovoltaic-powered forced-circulation dryer whereas for

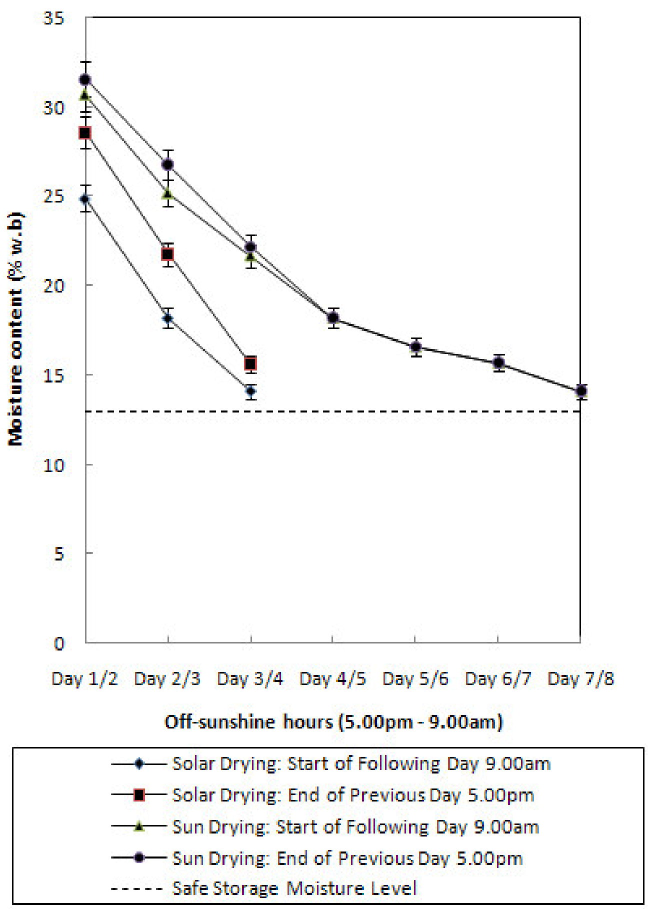

Figure 4. Effect of pebble bed storage on solar drying of corn.

this passive solar dryer, drying was achieved from 34.8 to 24.9%w.b in one day. Zomorodian et al. (2007) achieved 3 h of drying period for 132 kg of rough rice from 27 to 13%db with a cross flow and active mixed-mode type dryer equipped with a timer whereas sun drying was achieved within 11 - 14 h with 865 w/m^2 average incident solar radiation and average ambient temperature of 25℃. Soponronnarit et al. (1997) achieved 6 - 7 days drying of a batch of 25 kg of banana using solar natural convection drying whereas Sreekumar et al. (2008) dried 4 kg of bitter gourd from 95% moisture content to the desired level of 5% in 6 h while it was 11 h for open sun drying.

The potential of solar energy as a source of energy in drying agricultural produce cannot be over emphasized. The result of the study indicates that the natural convection solar grain dryer performed satisfactorily in drying freshly harvested maize from 32.8% initial moisture content, wet basis, to 13.1% in four consecutive days during harvest season. It took eight days to dry the same crop from 32.8 to 13.4%wb by the traditional sun-drying method. Thus the solar grain dryer has considerable advantages over the traditional sun-drying method in terms of faster drying rate and handling.

Savings in time was achieved by using the solar grain dryer as against traditional sun drying method. Gallali et al. (2000) reported savings in drying time for various agricultural products. Pangavhane et al. (2002) reported reduction in drying time of 43% for grapes. Similar results have been reported by Falade et al. (1985) for corn, Soponronnarit et al. (1997) and Ferreiraa et al. (2007) for banana, Zomorodian et al. (2007) for rough rice and Sreekumar et al. (2008) for bitter gourd. In terms of quality of solar dried products, Roosevelt et al. (2000) states that it is possible to achieve product physical characteristics closer to sun drying. Sharma et al. (1993) reported good quality products over sun drying for fruits and vegetables, Karathanos and Belessiotis (1997) achieved superior quality products for sultana grapes, currants, figs, plums and apricots, Chen et al. (2005) reported better general levels of quality in terms of sensory parameters, Tasirin et al. (2007) achieved same quality for bird's eye chillies with solar drying and Sreekumar et al. (2008) achieved no colour loss for bitter gourd using a new type of efficient solar dryer he developed.

Furthermore, the total estimated cost of production (materials + labour cost less profit) of the solar grain dryer was put at $79.00 (1$ = N150.00) based on Makurdi 2005 market prices, with the benefits in terms of market value of achieving higher quality products far outweighing the operational costs and initial investment with anticipated favourable discount pay-back period and benefit to cost ratio. This is desirable as Sharma et al. (1993) indicated that solar dryers are predestined for applications on small farms due to the low investment required. Soponronnarit (1995) states that in terms of economy, solar drying for some crops is feasible. With reference to combination drying technologies, Zhang et al. (2006) reported high start-up costs and relatively complicated technology as compared to conventional convection drying.

Conclusion

From the study, the following conclusions may be drawn:

1. A laboratory-scale passive solar grain dryer was developed and its performance evaluated in Makurdi metropolis, Benue State, Nigeria. With the data available, any convenient size can be produced at community level cooperative use and for any prospective investor.
2. The mean drying rate of the dryer was 0.7 kg/day per every 10 kg of corn whereas sun-drying rate was 0.3125 kg/day comparatively.
3. Savings in time was achieved by using the solar grain dryer as against traditional sun-drying method. It took 4-days to dry the corn to moisture content of 13.1%wb using the passive solar dryer while it took 8-days to dry

to 13.4%wb under sun drying.
4. For further improvement of the dryer, there is need to increase the volumetric airflow rate across the drying chamber.

REFERENCES

Aboul-Enein S, El-Sebaii AA, Ramadan MRI, El-Gohary HG (2000). Parametric study of a solar air heater with and without thermal storage for solar drying application. Renewable Energy 21: 502-522.

Arinze EA (1983). Design and performance evaluation of a commercial size natural convection solar crop dryer. Nigerian J. Solar Energy 4: 120-122.

ASAE Standards, 45th Ed. 1998. ASAE S352.2 DEC 97. Moisture measurement: unground grain and seeds, 551. St. Joseph, Mich.: ASAE. . Pp. 551.

Bahnasawy AH, Shenana ME (2004). A mathematical model of direct sun and solar drying of some fermented dairy products. J. Food Engr., 61(3):309-319.

Bala J, De-Jong K, Huang J, Vafaie H, Wechsler H (1995). Hybrid learning using genetic algorithms and decision trees for pattern classification. Proceedings of the International Joint Conference on Artificial Intelligence, Montreal, August. Pp. 719-724.

Bena B, Fuller RJ (2002). Natural convection solar dryer with biomass back-up heater. Solar Energy. 72 (1): 75-83.

Bennamoun L, Azeddine B (2003). Design and simulation of a solar dryer for agriculture products. J. Food Engr., 59 (2/3):259-266.

Brooker DB, Arkema B, Hall CW (1957). Drying and storage of grains and oil seeds. AVI Book, New York, NY 10003. . Pp. 654.

Chen H, Hernandeza CE, Huang T (2005). A study of the drying effect on lemon slices using a closed-type solar dryer. J. Food Engr., 68 (4): 439-442.

Ekechukwu OV, Norton B (1999). Review of solar-energy drying systems II: an overview of solar drying technology. Energy Conversion and Management. 40: 615-655.

El-Sebaii AA, Aboul-Enein S, Ramadan MRI, El-Gohary HG (2002). Experimental investigation of an indirect type natural convection solar dryer. Energy Conversion and Management. 43: 2251-2266.

Ezekoye BA, Enebe OM (2006). Development and performance evaluation of modified integrated passive solar grain dryer. The Pacific J. Sci. Techn., 7(2): 185 -190.

Faborode MO, Favier JF, Ajayi OA (1995). The effects of forced air drying on cocoa quality. J. Food Engr., 25(4): 455-472.

Fagbenle R (1991). On monthly average daily extraterrestrial solar radiation for Nigeria. Nig. J. Renewable Energy. 22: 1-8.

Falade A, Talabi SO, Akinsete A, Danso FK, Adejuwon AA (1985). A solar grain dryer for rural areas of Nigeria. Nig. J. Solar Energy. 14:121-130.

Ferreiraa AG, Charbelb ALT, Piresb RL, Silvab JG, Maiac CB (2007). Experimental analysis of a hybrid dryer. Engenharia Térmica (Thermal Engineering). 6 (2): 3-7.

Gallali YM, Abujnah YK, Bannani FK (2000). Preservation of fruits and vegetables using solar drier, a comparative study of natural and solar drying III; chemical analysis and sensory evaluation of the dried samples (grapes, figs, tomatoes and onions). Renewable Energy. 19: 203-212.

Giner SA (2009). Influence of internal and external resistances to mass transfer on the constant drying rate period in high-moisture foods. Biosystems Engineering 102 (1): 90-94.

Goswani Y (1986). Alternative energy in agriculture. CRC Press Inc., Florida. 2: Pp. 83-102.

Hodali R, Bougard J (2001). Integration of a desiccant unit in crops solar drying installation: optimization by numerical simulation. Energy Conversion and Management. 42(13): 1543-1558.

Hsieh JS (1986). Solar energy engineering. Prentice-Hall Inc., Englewood Cliffs, New Jersey. Pp. 303.

Imre EE (1995). A handbook of industrial drying. 1st Edition. New York. Pp. 550.

Irtwange SV (1991). Design and development of a passive solar air heated poultry egg incubator. Unpublished M. Eng Project. Department of Agricultural Engineering, University of Nigeria, Nsukka. Pp. 258.

Itodo IN, Adewole AM, Edemeka SK (2002). Development of active solar crop dryer: design analysis and performance evaluation. Nigeria J. Renewable Energy. 10 :1-2.

Karathanos VT, Belessiotis VG (1997). Sun and artificial air drying kinetics of some agricultural products. Journal of Food Engr.,31(1): 35-46.

Kisten JF, van J (1998). Defining small scale farmers in the South African context. Agrekon. 37(4): 560-571.

Leon MA, Kumar S, Bhattacharya SC (2002). A comprehensive procedure for performance evaluation of solar food dryers. Renewable and Sustainable Energy Reviews. 6: 367-393.

Lmre L, Palaniappan C (1996). Development of solar drying. Drying Technology. 14 (6): 1381-1388.

Mumba J (1995). Development of a photovoltaic powered forced circulation grain dryer for use in the tropics. Renewable Energy 6(7): 855-862.

Pangavhane DR, Sawhney RL, Sarsavadia PN (2002). Design, development and performance testing of a new natural convection solar dryer. Energy. (27): 579-590.

Paul VN (2001). Development of an indirect solar crop dryer for rural small scale farms. Unpublished B. Eng. Project. Department of Agricultural Engineering, University of Agriculture, Makurdi. Pp. 54.

Roosevelt DS, Sadulla S, Ramasami T (2000). Solar dryer for leather and a comparative study on the characteristics of open-, solar- and electrical-dried leathers. Renewable Energy. 19 (1-2):123-134.

Sadiku S, Oyero IO, Osunde ZD (2001). Design and evaluation of locally made solar dryers in Niger State. Technical Report. Federal University of Technology, Minna. Pp. 127.

Sato J, Irie M (1981). Solar energy utilization for grain and grass drying. Taiyo Enerugi. 7(4): 28-40.

Sayigh AAM (1979). The technology of flat-plate collector in solar energy conversion. An introductory course. Editors: AE Dixon and JD Leslie. Pergamon Press. Pp. 1324.

Sharma VK, Colangelo A, Spagna G (1993). Experimental performance of an indirect type solar fruit and vegetable dryer. Energy Conversion and Management. 34(4): 293-308.

Sopian K, Fudholi A, Ruslan MH, Alghoul MA, Sulaiman MY (2009). Review of solar dryers for agricultural and marine products. Renewable and Sustainable Energy Reviews, In Press. Uncorrected Proof, Available online 5 August. http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VMY-4WXPXW5-1&_user=10&_rdoc=1&_fmt=&_orig=search&_sort=d&_docanchor=&view=c&_searchStrId=1028996409&_rerunOrigin=google&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=4676b676657567df9174b79c55c1564c

Soponronnarit S (1995). Aeration and drying strategies for managing wet paddy. Proc. 17th ASEAN Technical Seminar on Grain Postharvest Technology, July 25-27 1995, Lumut, Perak, Malaysia. Also in Proc. Farm Machinery Conference on Technology for Agricultural Production, Pattaya (in Thai). Pp. 183-196.

Soponronnarit S, Nathakaranakule A, Limtrakool W, Rungjiwaruk W, Nathakaranakule S, Rakwichien W (1997). Banana fruit drying. RERIC Inter. Energy J., 19 (2):55-62.

Sreekumar A, Manikantan PE, Vijayakumar KP (2008). Performance of indirect solar cabinet dryer. Energy Conversion and Management. 49 (6): 1388-1395.

Tasirin SM, Kamarudin SK, Jaafar K, Lee KF (2007). The drying kinetics of bird's chillies in a fluidized bed dryer. J. Food Engr., 79 (20): 695-705.

Tembo L, Chiteka ZA, Kadzere I, Akinnifesi FK, Tagwira F (2008). Ripening stage and drying method affecting colour and quality attributes of *Ziziphus mauritiana* fruits in Zimbabwe. Afr. J. Biotech. 7 (9): 2509-2513.

Tunde-Akintunde TY, Afolabi TJ, Akintunde BO (2005). Influence of drying methods on drying of bell-pepper (*Capsicum annuum*). J. Food Engineering 68 (4): 439-442.

Zhang M, Tang J, Mujumdar AS, Wang S (2006). Trends in microwave-related drying of fruits and vegetables. Trends in Food Science

and Technology. 17 (10): 524-534.
Zomorodian A, Zare D, Ghasemkhani H (2007). Optimization and evaluation of a semi-continuous solar dryer for cereals (rice, etc). Desalination 209: 129-135.