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Solar Drying in Africa

Proceedings of a Workshop held in Dakar, Senegal, 21-24 July 1986

Editors: Michael W. Bassey and O.G. Schmidt

Postal Address: P.O. Box 8500, Ottawa, Ont., Canada K1G 3H9

Bassey, M.W.
Schmidt, O.G.

IDRC, Ottawa CA

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ABSTRACT / RÉSUMÉ / RESUMEN

Abstract -- This book presents the proceedings of a workshop on solar drying in Africa attended by 24 participants involved with solar drying research relevant to the continent. Of the papers, 17 describe research activities on socioeconomic aspects, design and testing of solar dryers, and future research needs. In addition, a summary of the discussions held during the workshop to assess the state of the art of solar drying research in Africa are outlined, focusing on progress made and on possible research and collaborative activities that are needed to overcome the technical and socioeconomic problems that limit the development and introduction of improved solar dryers.

Résumé -- Voici le compte rendu d'un colloque sur le séchage solaire en Afrique auquel participaient 24 personnes effectuant des travaux de recherche propres à ce continent. Au nombre des communications, 17 décrivent les activités de recherche sur les aspects socio-économiques, la conception et l'essai des séchoirs solaires, ainsi que les besoins futurs de recherche. En outre,le lecteur trouvera un résumé des discussions sur l'état de la recherche sur le séchage solaire en Afrique, notamment les progrès réalisés et les activités de recherche coopératives nécessaires pour surmonter les problèmes techniques et socio-économiques qui entravent la mise au point et la diffusion de séchoirs solaires améliorés.

Resumen -- Este libro contiene los trabajos presentados en un seminario sobre secamiento solar en Africa, al cual asistieron 24 participantes del área de investigación en secamiento solar referida a este continente. Diez y siete de los trabajos versan sobre actividades de investigación en aspectos socioeconómicos, diseño y prueba de secadores solares y necesidades futuras de investigación. Se describe además la discusión sostenida durante el seminario para sopesar el estado de la investigación en secamiento solar en Africa, discusión que se centró en los progresos realizados y en las posibilidades de investigación y acciones colaborativas necesarias para superar los problemas técnicos y socioeconómicos que obstaculizan el desarrollo y la introducción de secadores solares mejorados.

CONTENTS

EVALUATION OF THREE TYPES OF SOLAR DRYERS FOR NIGERIAN CROPS

J.C. Igbeka[1]

Abstract -- *Three types of solar dryers were compared -- a solar concentrator with a drying chamber, a flat-plate collector with an in-bin storage/dryer, and a flat-plate collector-cum-dryer. In the last two, the crops themselves absorb solar heat. Although the concentrator produced the greatest temperature difference, its drying efficiency was the lowest. The third type of dryer was found to give the best drying result; but the modified version of the second design was recommended for adoption for the rural farmers. Recommendations that can help designers of solar dryers are given. Factors that affect the drying efficiency of solar dryers in the humid tropics were also investigated. The performance of solar dryers during the dry hot season was found to be better than during the wet humid season. The seasons also affected the moisture content of the crops at harvest. The sociocultural standard of the farmers was found not to inhibit the adoption of solar dryers. The need for the use of locally available materials for the construction of solar dryers is emphasized.*

Introduction

Nigeria's oil reserves have been estimated to last for another 20 years, thus, advantage must be taken of the sunshine that is available all year round as a result of the country's location in the tropics. The humid southern part of the country, represented by the city of Ibadan, records its lowest mean monthly sunshine (88 hours) in August (wet cloudy season) but can receive as much as 235 hours/month between November and January (dry hot season) (Igbeka 1980). The equivalent values are higher in the northern, savannah, part of the country.

Solar energy is fast becoming an alternative source of energy because of the high rate of depletion of the conventional energy sources. It is preferred to other alternative sources of energy, such as wind and shale, because it is abundant, inexhaustible, and non-polluting. Equally, it can be tapped at a relatively low cost and has no associated dangers of fire or other hazards. Therefore, the use and application of solar energy for rural development cannot be over-emphasized.

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[1] Department of Agricultural Engineering, University of Ibadan, Ibadan, Nigeria.

One of the applications of solar energy is in the drying of agricultural and food materials. However, many different types of crops are available in Nigeria, depending on the ecological location, and the successful application of solar energy in drying these crops or foods will depend on several factors: average temperature, relative humidity, and insolation or sunshine of the location; initial moisture content of the crop; and socioeconomic status of the people. The basic problem of using solar dryers in Nigeria are high air relative humidity, especially in the southern part of the country; high initial moisture content of crops during harvest; and, sometimes, low insolation during harvest period.

The objectives of this paper are fourfold: first, to review the work done in applying solar energy, especially in drying food, in Nigeria; second, to analyze and compare three types of solar dryers; third, to identify the socioeconomic factors that influence the implementation of solar energy application (drying) in rural areas; and, fourth, to recommend areas for future research and development work. It must be noted that only passive solar systems, as the systems most adaptable to rural areas, are considered.

Review of Past Work in Nigeria

Most of the research on solar-energy application in Nigeria has been done in the departments of physics, mechanical engineering, and agricultural engineering of Nigerian universities and in some research institutions. Unfortunately, most of this research has not been published but only documented as project or research reports in the various institutions. Thus, it has been very difficult to review all the efforts made in solar-energy application. The only forum where the work on this topic can be coordinated and discussed is the annual conference of the Solar Energy Society of Nigeria. Most of the papers presented at this conference are published in The Nigerian Journal of Solar Energy.

One element of solar energy research is the determination of the input parameters, particularly the solar radiation available for collection either directly (Ezeilo 1979; Bamiro and Ideriah 1982; Doyle 1982; Ideriah and Bamiro 1982) or through mathematical models (Ezekwe and Ezeilo 1981; Ideriah 1981; Arinze 1982; Bamiro 1983). These researchers, because of their backgrounds, were much more interested in the collector performance than in the application of the collected energy.

Some of the work done in applying solar energy was in water heating and photovoltaic storage for water pumping and refrigeration. Tani (1979), working in the International Institute of Tropical Agriculture (IITA) at Ibadan, collected and stored solar energy in photovoltaic cells and later used it for lighting, pumping water, and operating a refrigerator for rural conditions. At the same time, a great deal of meteorological data were collected from this station: they included sunshine hours, insolation, relative humidity, and average daily temperature (Fig. 1).

A third element of solar energy research is the design of appliances. Chendo and Schmitter (1982) investigated the performance of a Perspex-covered solar still. They found that, for rural areas,

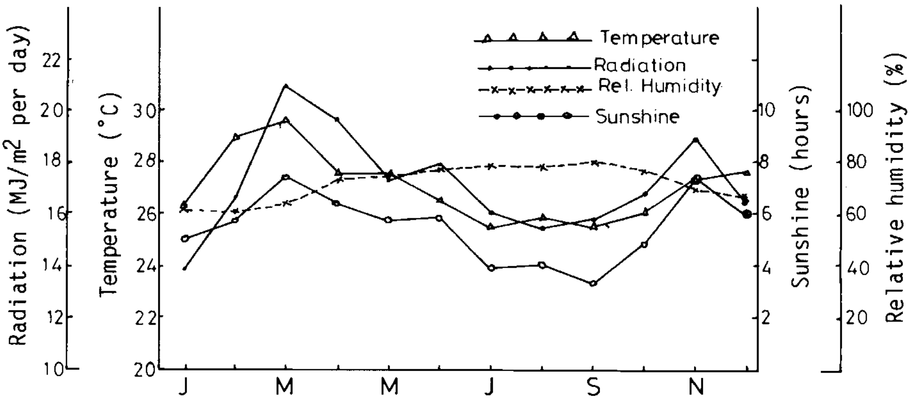

Fig. 1. Monthly average of daily total radiation, temperature, relative humidity, and sunshine duration in Ibadan, Nigeria.

Perspex was preferable to glass because it was less likely than glass to be broken by stray stones and animals. This view was confirmed by Araoye (1984) when he evaluated the performance of a solar dryer/storage system.

Adebiyi (1982) designed, constructed, and evaluated a solar steam unit made from locally available materials. He found the overall efficiency of the solar heater to be 69%, which is quite high. His design has been quite widely applied in the rural areas of the northern part of Nigeria.

Solar Dryers

Solar drying research has been going on in Nigeria for 10 years mostly in universities and polytechnic colleges in the departments of agricultural and mechanical engineering. Some of the work has been published in journals or conference proceedings but other work remains unpublished although it has been documented as project reports.

Ofi (1982) constructed and evaluated a solar dryer using a flat-plate collector. Although he did not dry any crops with it, he obtained a plenum chamber temperature that was about 50°C above the ambient under maximum sunshine conditions. He calculated an overall efficiency of 30%.

Awachie (1982) used a solar hot box to dry fish, coconut, and maize. He obtained air temperatures of 40-50°C in the chamber during the wet seasons and above 50°C during the dry seasons. He reported that 0.74 kg of coconut lost 0.143 kg of moisture within 24 hours and that uncut fresh fish were fully dried in less than 72 hours, with about 50% of the moisture lost within the first 24 hours.

Arinze (1985) has successfully designed a commercial solar dryer for maize and other cereals that will be suitable for the northern part of Nigeria. Some states in the north are already using this dryer and others have placed orders for more.

Before 1980, some experimental solar dryers were tested at the universities of Nigeria, Nsukka, and Ife. In 1980, the design and evaluation was reported for a solar dryer with a reflector/concentrator type of collector in which shelled maize and sliced plantain were dried (Igbeka 1980). This dryer was also used to dry some other crops. Later, a flat-plate collector was used to heat air for drying maize on cob and sliced okra (Igbeka 1982) and this dryer was modified as a solar dryer/storage system by Araoye (1984) with very satisfactory results. In 1985, a solar dryer in which the crop being dried was also used as a heat absorber was designed and evaluated. The data and results of these three designs are reported here.

Evaluation of Three Types of Solar Dryers

Solar dryers available in Nigeria can be categorized into three types: concentrator/dryer, flat plate/dryer, and flat plate/dryer/storage unit. These may be passive or active systems but the work reported here was concerned with passive systems because they are more adaptable to rural areas. This study was conducted between the months of May and November.

Solar Concentrator/Dryer

The solar concentrator collector is not normally used for crop drying. However, it is evaluated here along with the other two dryers because it was the first collector built at Ibadan. The solar dryer is made up of a collector and a drying chamber (Fig. 2). The collector, which uses a stationary nontracking concentrator, was constructed from four reflective sheets of tin plate mounted on a parabolic frame structure with 3 cm of coconut fibre insulation between the plates and the frame. The frame structure was made from plywood (Igbeka 1980) and forms a parabola with a focal length of 25 cm. Other components of the collector include a black-painted aluminum pipe (145 cm long and 5 cm external diameter) fixed along the focal point of the parabolic mirror. The pipe is held concentrically within a glass tube (129 cm long and 8.8 cm diameter) with two wooden bungs. A transparent polyvinyl fluoride (PVF) film (0.15 cm thick) was used as the cover plate. With this arrangement, all rays normal to the surface of the mirror are reflected and concentrated on the black aluminum pipe. The parabola is tilted at 10° to the horizontal.

The drying section was constructed from 1.27-cm plywood and the sides are insulated with fibreglass. It is 48 x 48 x 123 cm including a plenum chamber 25 cm high where the aluminum pipe from the collector enters through a 5.3-cm hole. Above the plenum chamber is a false floor made of wire mesh. The drying chamber is constructed so that the dryer can be used both for tray drying and deep-bed drying and maize can be dried on-cob or shelled. The dryer was evaluated using shelled maize and sliced plantain. During field tests, chopped okra, sorghum, rice paddy, and maize on-cob were also used. This dryer was designated Dryer 1.

Flat-plate Collector/Dryer

The flat-plate collector/dryer is made up of a flat-plate collector (3.66 x 0.95 m) with glass cover and a drying chamber (1.06 x 0.54 x 0.76 m) made from plywood (Fig. 3). The absorber of the collector

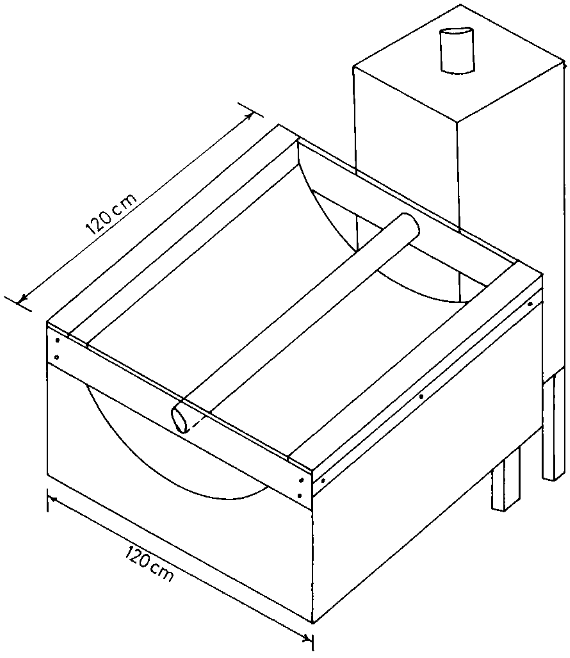

Fig. 2. Dimensions of the concentrator/dryer.

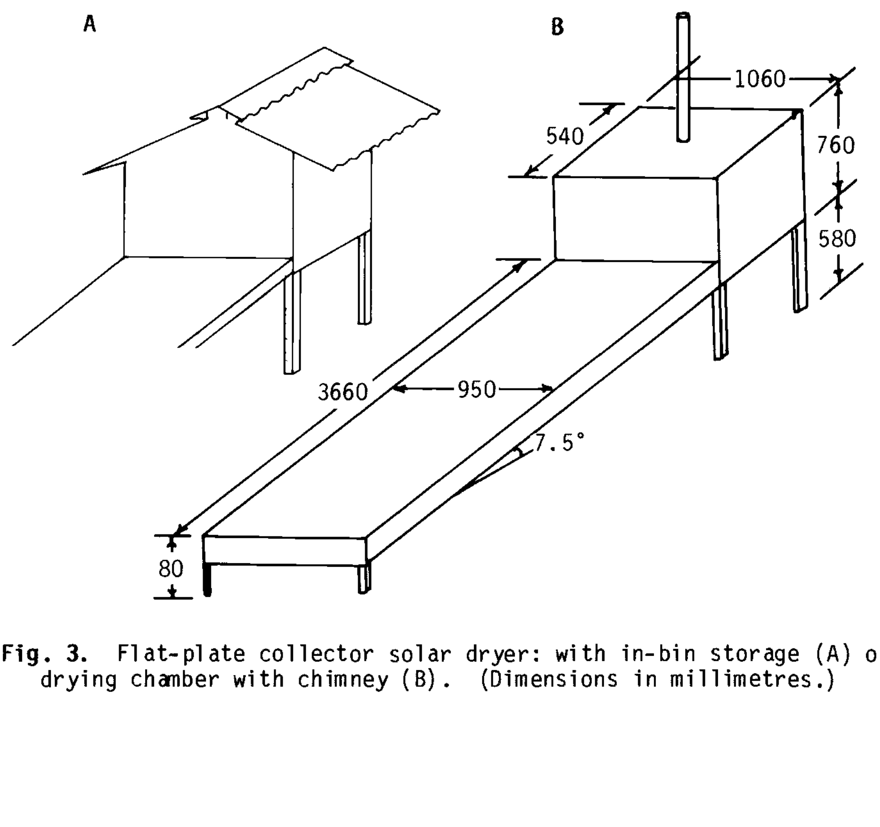

Fig. 3. Flat-plate collector solar dryer: with in-bin storage (A) or drying chamber with chimney (B). (Dimensions in millimetres.)

is made of corrugated galvanized sheet that is painted black. The base and sides of the metal casing holding the plate are insulated with fibreglass of density 200 kg/m^3 and K of 0.038 W/m per °K. The sides of the drying chamber are also insulated with fibreglass.

The effective area of the collector is 3.22 m^2 and the cross-sectional area of the air passage is 0.0285 m^2. The dryer has a plenum chamber and a false floor made of wire mesh. The top of the dryer is covered with transparent corrugated sheet and has a chimney (50 cm long). This was designated Dryer 3. The dryer was evaluated with maize, either shelled or on-cob, sliced plantain, chopped okra, sorghum, and rice paddy.

Flat-plate Collector Dryer/Storage Unit

The collector for the dryer/storage unit is exactly the same as that for Dryer 3 and the drying bin is also of the same size and material. However, the roof is made of transparent corrugated plastic sheets fitted in a triangular cross section so that the apex has a sort of chimney effect (Fig. 3A). With this arrangement, the roof acts as a solar heat transmitter and the crop in the upper part of the bin also acts as a solar absorber. All other features are as in Dryer 3. This dryer was designated Dryer 2.

The dryer was evaluated with shelled maize, maize cobs, sliced plantain and yam, chopped okra, sorghum, and rice paddy.

Results and Discussion

Dryer Performance

The performance of the dryers was evaluated in two ways: drying rate, which is defined as the amount of water evaporated per unit absorbing area per day [$kg(H_2O)/m^2$ per day] and solar drying efficiency. The results of drying tests for three types of grains are presented in Figs 4 and 5. Also the drying curves for sliced plantain and shelled maize are given in Figs 6 and 7.

The solar drying efficiency, η, was defined as the ratio between the energy used for evaporating moisture out of the grain and the solar radiation against the absorbing area:

$$\eta = 100 \left[\int_0^t (M_w r / I) dt \right] \quad [1]$$

where

M_w = drying rate [$kg(H_2O)/m^2$ per hour],

r = heat of vaporization of water out of the grain [W/hour per $kg(H_2O)$], and

I = solar radiation (W/hour per m^2)

The results are averages over a period of 6 months during which the minimum daily average radiation was 15.1 MJ/m^2 and maximum was

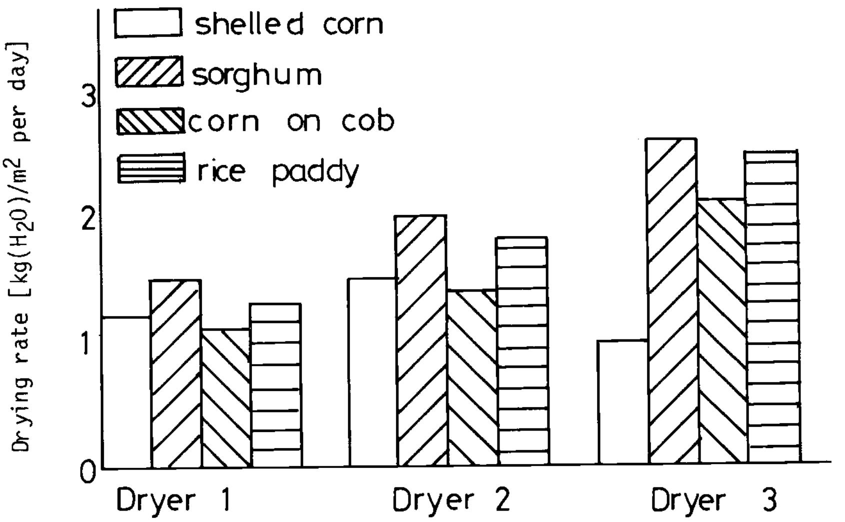

Fig. 4. Drying rates using the three dryers.

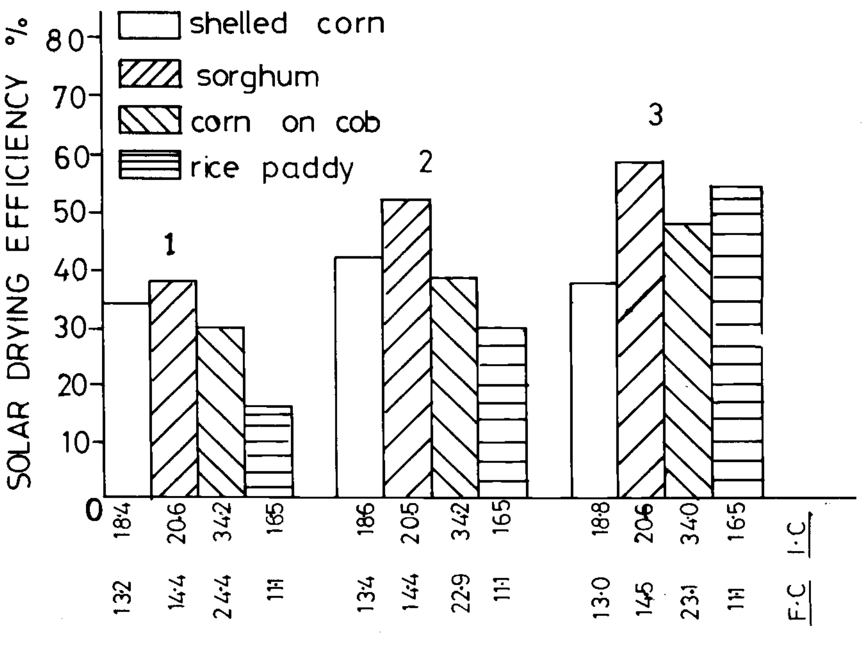

Fig. 5. Solar drying efficiency for three solar dryers: initial (IC) and final (FC) moisture content (% wet-basis).

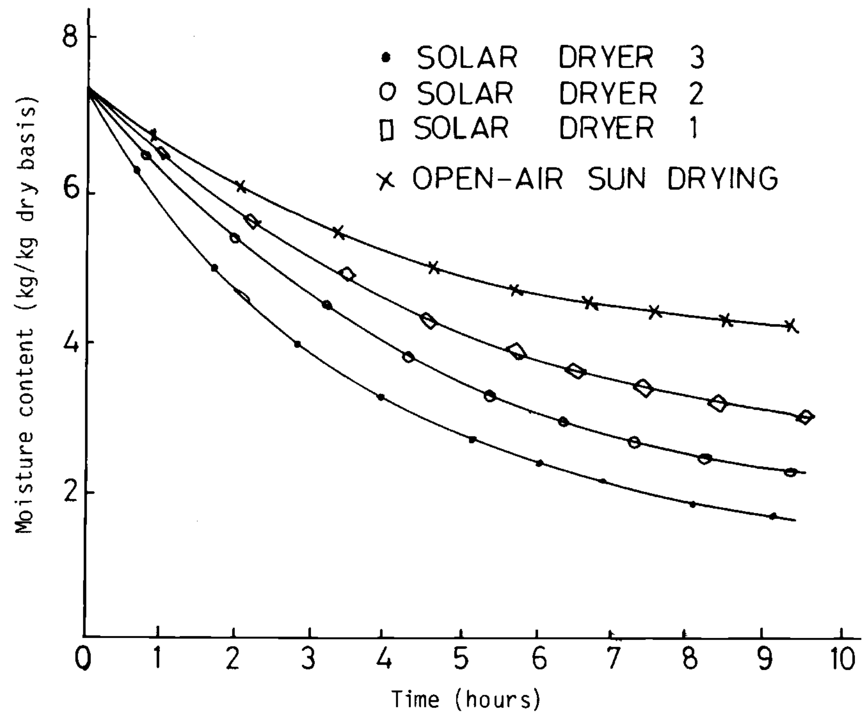

Fig. 6. Drying curves for plantain.

21.6 MJ/m^2. Dryers 2 and 3 were found to be more effective than Dryer 1. Although the air temperature difference recorded from collector 1 was the highest, the volume of air passing through it was far smaller than those of collectors 2 and 3. Therefore, the efficiency of collector 1 may be higher than the other two but its drying efficiency is lower.

The other results can be summarized as follows:

° For all three dryers, sorghum dried faster than the other grains (Fig. 4).

° There was not much difference between Dryers 2 and 3 especially for shelled corn but, for corn-on-cob and rice paddy, Dryer 3 is better (Fig. 4).

° Dryer 3 also gave the most rapid drying of plantain (Fig. 6), yam, and okra.

The better performance of Dryer 3 could be attributed to the better flow of heated air due to the chimney effect. It has been found that, in the absence of a fan, it is possible to obtain a substantial air movement through grain by creating a small pressure difference by the chimney effect. The pressure difference caused by the chimney effect can be described by:

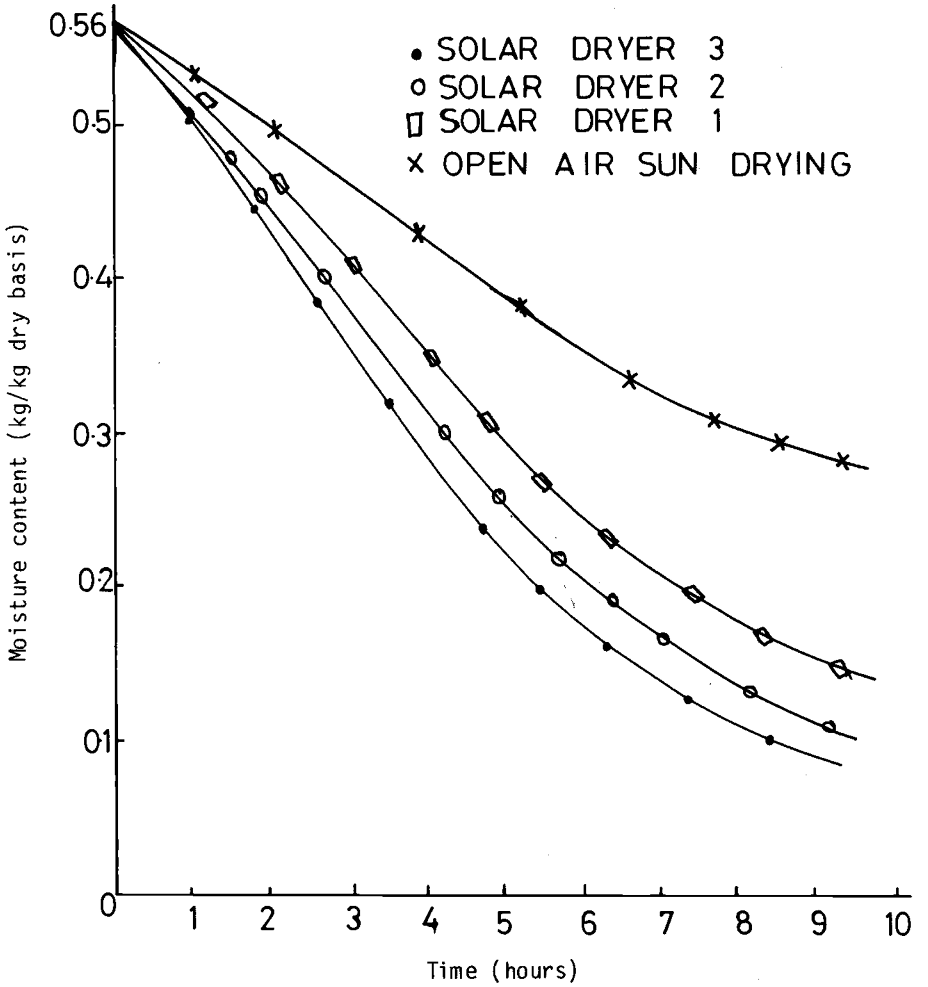

Fig. 7. Drying curves for maize.

$$\Delta P = \Delta\rho_{air}(gH) \qquad [2]$$

where

$\Delta\rho$ air = difference in density of the air inside and outside the drying chamber (kg/m^3),

g = gravity constant (m/s^2), and

H = vertical distance between the air inlet and outlet of the dryer (m).

The performance of Dryer 2 could, therefore, be improved by installing a chimney. This has already been suggested by the users and is being done in the modified version. The concentrator (Dryer 1) is not the best solar collector for drying but could perform very well for water heating. Because of the small volume of heated air coming in through the pipe, its effect is drastically reduced when it enters the much bigger plenum chamber of the dryer.

From the tests, it was observed and proved that, for passive solar grain dryers, which are most adaptable to rural farmers, the following parameters affect the drying capacity:

- Solar radiation;
- Type of grain, which will affect the airflow resistance, absorption of solar radiation, and moisture movement;
- Moisture content of the grain because moisture content at harvest affects the amount of moisture to be removed;
- Wind velocity;
- Height difference between the air inlet and outlet of the dryer (chimney effect); and
- Relative humidity of air, which depends on the climate or season. During the rainy season, the air is very humid and, even when it has been heated, the evaporative power of the air stream is still low. In fact, the air may be adding moisture instead of removing it. During this period, the use of dessicant is recommended.

Field Tests and Customers' Reaction

These three types of solar dryers have been demonstrated in agricultural shows and Technology Week exhibitions to farmers and the public. During these demonstrations, grains and food products such as plantain, yam, and okra were dried. The people were asked to give their opinion of choice among the dryers and to make critical analysis. A total of 210 people responded. Some of the questions were:

- What is your level of farming (small, medium, or large) and what types of crops do you produce?
- What type of drying and storage systems do you use now? If none, do you want to adopt one? If you have one, do you want to change for a solar type?
- If you were to adopt a solar dryer, which of the three would you choose? Give reasons.
- If you do not want to adopt a solar dryer, give your reasons.

From the reactions of the farmers and other people, three main conclusions could be drawn.

First, most of the small-scale farmers did not have any artificial drying system and their drying was done in the open sun. Some of the medium-scale and all of the large-scale farmers had some sort of artificial drying and storage systems.

Second, the medium-scale farmers preferred either Dryer 2 or 3 whereas the small-scale farmers preferred Dryer 3, which is a batch dryer and could be used for different crops instead of the dryer-storage system (Dryer 2), which would be tied to one type of crop.

Third, most of the rural farmers noted that their reservations in adopting a solar-drying system were due to lack of skill for maintenance and the initial cost, a miminum of USD 500. They believed that the equipment needed much skill to operate and maintain. Most of them had not seen the solar dryer physically but only in newspapers and televisions. This showed that the testing or extension procedure was not adequate.

Recommendations and Conclusions

A substantial amount of work has been done in the application of solar energy to agriculture in Nigeria, especially for food drying, the results of this work have not been used productively by the rural farmers. This is due to lack of coordination between the workers and researchers and also due to inadequate extension of the results to the farmers.

It has been found that the Nigerian farmer has no sociocultural inhibition to using solar dryers but will readily accept a design that is maintenance-free and inexpensive to buy.

On this basis, the following six recommendations are made to help achieve the objectives of getting solar dryers to the rural farmers in Nigeria.

First, solar dryers designed for the Nigerian rural farmers should be cheap, easy to maintain, and easy to use for drying any of the tropical crops. To achieve this, local materials should be used.

Second, there should be coordination between researchers and workers in the areas of solar drying in the country. A good forum is the Solar Energy Society of Nigeria and some coordination is already being achieved through its annual conference.

Third, because of the differences in the climatic zones in Nigeria, it might be necessary to zone the country for the purposes of solar-drying research. The north is dry almost throughout the year but the humidity in the south is quite high for more than 4 months. Therefore, the use of dessicants in the humid south should be investigated: some local dessicants, for example, granular wood ash, are available.

Fourth, the best design, which is recommended for Nigerian rural farmers, is the flat-plate collector/dryer with transparent roof. The roof, which should be double-pitched, acts as an insolator. Depending on the available funds, the transparent covering of the collector could be made from glass, plastic, or polyethylene. To improve the performance of this dryer, a chimney should be installed.

Fifth, the design of the drying chamber should permit the farmer to use it as a tray dryer or as an in-bin storage dryer.

Sixth, funds should be made available for research into the effect of size on the performance of solar dryers. At present, the designs have been limited to small-capacity collector/dryers. Also, funds should be made available for research into use of local materials to reduce the cost of the solar dryer.

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