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Solar Drying in Africa

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

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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

SOLAR ENERGY FOR CROP DRYING IN DEVELOPING COUNTRIES

E.A. Arinze[1]

Abstract -- *This paper discusses solar energy availability (with data for typical tropical locations) and applications of solar energy in agricultural production. Various methods are discussed for improving the traditional methods of sun-drying crops and commodities in developing countries by developing and introducing appropriate solar-drying techniques. In particular, the construction and performance of some controlled solar energy crop dryers developed in Nigeria are presented. Experimental data on solar energy absorption characteristics of some agricultural products are also presented.*

Introduction

Petroleum energy now supplies most of the energy for production in agriculture and industry. As the conventional petroleum fuels become scarce and expensive, the use of these high energy-content fuels in low-temperature stationary uses, such as environmental temperature and humidity control, crop drying, water heating, and irrigation must be restricted. Energy for all these can be supplied by solar energy. Solar energy technology and research are developing fast and much of the technology needed for these applications in industry and agriculture is already available.

In most developing countries, there is increased emphasis on rural development and this undoubtedly will require a phenomenal increase in the use of energy in some form in rural areas. A distinct departure must be made from the age-old techniques of exclusively using manual and animal labour, animal wastes, and firewood or charcoal as the main sources of energy. Past experience has shown that such methods are highly regressive in human as well as environmental terms. The increased use of renewable energy sources -- solar energy in its various forms -- should, therefore, be encouraged in developing countries, especially for agricultural production.

This paper presents a general outline on solar energy availability with emphasis on a typical developing tropical location (Nigeria) and other relevant climatological parameters in crop drying. Various methods of improving the traditional methods of sun-drying crops in developing countries by the development and

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introduction of appropriate solar crop-drying techniques are discussed. In particular, the paper describes the construction and performance of some controlled natural- and forced-convection solar energy crop dryers fabricated and tested at the Department of Agricultural Engineering of Ahmadu Bello University in Zaria, Nigeria. Useful experimental data on solar energy absorption characteristics of some agricultural products are also presented.

Solar Energy Availability and Other Climatological Parameters

At present, the mean intensity of normal solar radiation (solar constant) outside the earth's atmosphere is 1353 W/m^2. As this radiation passes through the atmosphere, it is partly scattered, reflected, and absorbed by the atmospheric particles so that only a portion reaches the surface of the earth. The total solar radiation reaching the earth's surface has both direct (beam) and diffuse components.

The available total solar radiation on the earth's surface is intermittent and seasonal in nature. Generally, sloping the collecting surface toward the south (in the northern hemisphere) at the latitude angle will reduce the seasonal variation and lead to maximum total annual collection.

The most important factors that determine the amount of solar radiation reaching the earth's surface are:

° Composition of atmosphere;

° Depth of the atmosphere (air mass) that the radiation must pass through before reaching the surface;

° Time of day or solar hour angle -- maximum collection occurs at solar noon;

° Latitude of the location;

° Earth's tilt and rotation that determine the seasonal and daily variation in the amount of solar energy; and

° Tilt angle of the surface to the horizontal.

Figure 1 shows the daily average of total horizontal solar radiation (on a monthly basis) for two typical tropical locations (Zaria and Kano, latitudes 11°N and 12°N, respectively) in northern Nigeria. Seasonal variations in solar energy availability is slight in such tropical locations.

The annual available total horizontal solar radiation in Nigeria determined from mean annual sunshine hours (Arinze and Obi 1984b), varies from 5000 MJ/m^2, or 45% of the maximum possible value outside the earth's atmosphere, in the humid Niger Delta to over 9400 MJ/m^2, or 70%, in the extreme northeast of Nigeria (Fig. 2). Generally, January to April are the months with greatest solar energy availability and July to September have the lowest availability: this period is also the wettest.

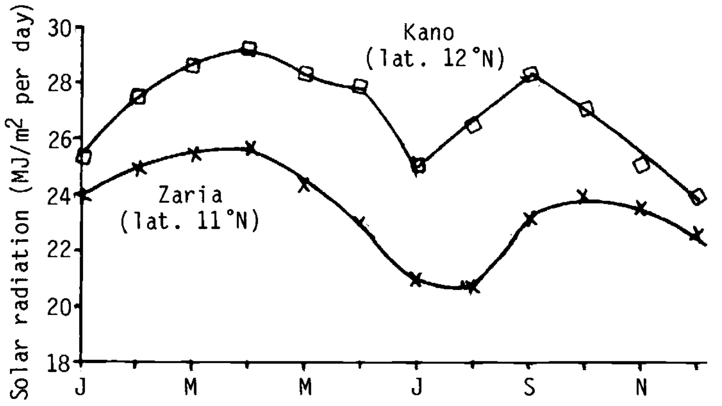

Fig. 1. Total horizontal solar radiation (daily average) for two tropical locations in Nigeria.

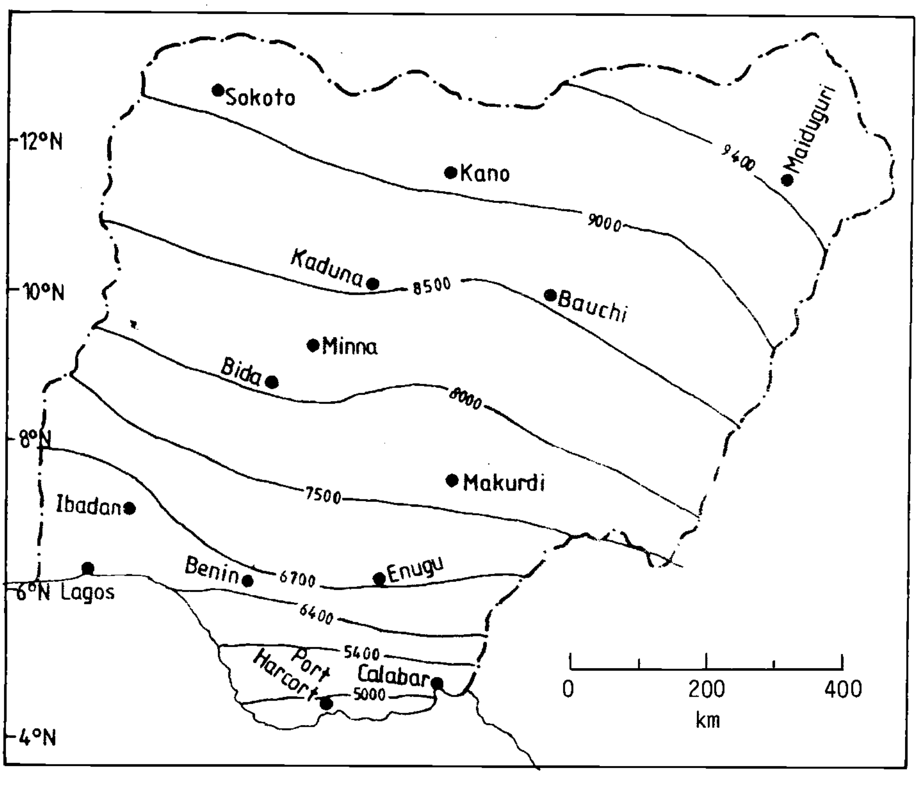

Fig. 2. Mean annual solar map of Nigeria (MJ/m^2).

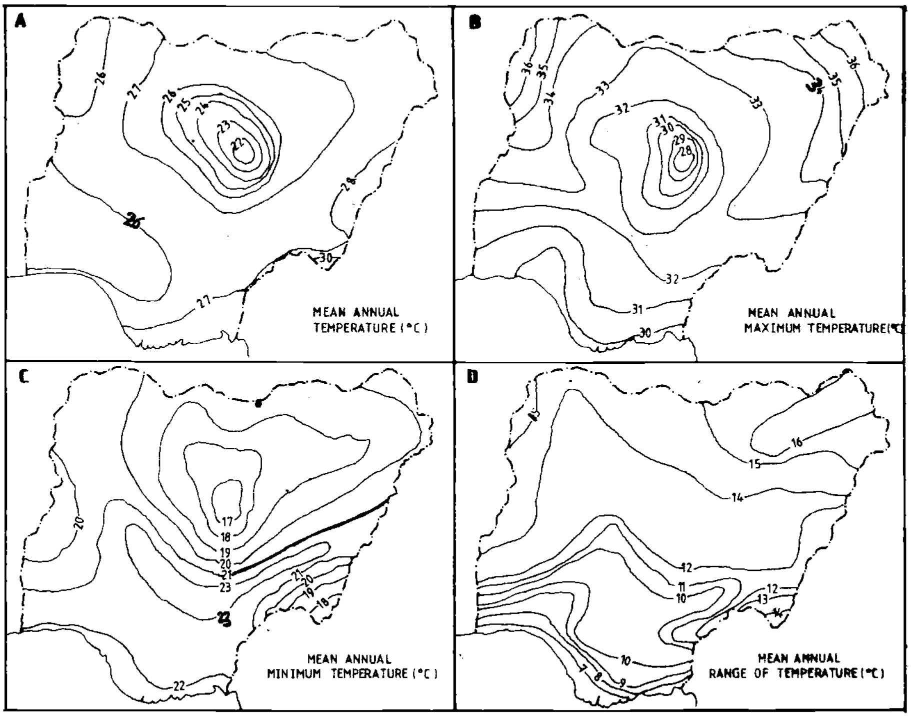

Fig. 3. Outdoor temperatures (°C) for Nigeria: mean annual (A), mean annual maximum (B), minimum (C), and range (D).

Nigeria is within the tropics, and it experiences high temperatures all the year round. The mean for most stations in Nigeria is about 27°C. As with solar radiation, seasonal and latitudinal variations affect the extremes and the diurnal and seasonal ranges of temperature. The highest air temperatures are normally in March and April with minimum temperatures in the north usually in December and January, during harmattan weather, and during the rainy season in July and August in the south. Mean maximum temperatures increase from 32.2°C at the coast in the south to 40.6°C in the extreme north (Fig. 3). Mean minimum temperatures, by contrast, decrease northward with a lowest mean of 21.1°C on the coast to less than 12.8°C in the north due to the effects of continentality.

Relative humidity (RH) varies considerably both in space and between seasons. In the southern, coastal, region, June to October have monthly means over 90% but, in the north during January to April, mean values vary from 30% at dawn to 10% in the afternoon. This is characteristic of harmattan season when the dry and dust-laden northeast trade winds are blowing from the Sahara under cloudless but dusty conditions. Generally, the rainfall decreases both in duration and amount from the south coast to the interior. The coastal areas receive over 4000 mm of rain spread over 8-10 months whereas the extreme north receives less than 250 mm spread over 3-4 months.

The climate of Nigeria represents a microcosm of the climate of West Africa. The climate fluctuations in Nigeria and the rest of West Africa are not local occurrences; rather they form part of global climatic patterns.

Crop Drying Techniques

The land constraints (such as intercropping and two or more crops per year), harvesting losses, early maturing hybrids, timing of harvesting operations with respect to the field conditions (for example, groundnut must be harvested when the soil is sufficiently wet), and other factors have made it necessary to dry most crops mechanically after harvest. Harvested agricultural products must be stored dry (12-14% moisture content, wet basis) to prevent attack and destruction by microorganisms and fungi and self-heating of the products. At some stages of food preparation, drying is also necessary.

Artificial dryers are commonly used in many developed and highly industrialized countries because labour costs are high, climates unfavourable, throughputs are high, and high quality standards must be maintained. The sources of energy for these dryers are mainly electricity, gas, oil, or solid fuels. They are generally capital intensive and are not suitable for the small-scale farmers or for the majority of agroindustries in African or developing countries. Because of their size and complexity, they are incompatible with the requirements of a farmer with relatively small quantities of crops to be dried for short seasons throughout the year.

Drying with the sun's energy is an effective alternative, in whole or in part, to artificial drying although it is not capable of comparable throughput. Comparatively unskilled labour can be used to construct, operate, and maintain solar dryers using materials that are readily and cheaply available in rural areas.

Sun Drying

In several developing countries, sun drying of harvested crops is the general practice and the sun is the source of energy for drying. Generally, sun drying applies to spreading the crop in the sun on a suitable surface (such as roadsides and mats), hanging crops from the eaves of a building, trees, etc., and drying on the stalk by standing in stooks or bundles.

Although sun drying requires little capital or expertise, it has many limitations and problems. Loss of moisture is usually intermittent and irregular, and the rate of drying is generally low, thus increasing the risk of spoilage during the drying process. The final moisture content of the dried product can be high because of low air temperatures and high relative humidities: this can result in crop spoilage during subsequent storage. Contamination by dust; infestation by insects and rodents; theft or damage by birds, animals, or humans; the need for relatively large areas of land or surfaces to spread crops; and the need to move crops under cover in the event of rain are also problems associated with sun drying. However, it is still, by far, the most widely practiced agricultural processing operation: in Nigeria, over 80% of harvested agricultural products are sun dried.

Solar Crop Drying

Solar crop drying also relies on the sun as its major source of energy. However, it differs from sun drying in that a simple structure, such as a flat-plate solar collector, is used to enhance the effect of insolation and minimize loss of the collected sun energy to the surroundings. Solar drying is a good alternative to sun drying, especially for farmers in developing countries. In comparison with sun drying, solar dryers can generate higher air temperatures and consequently lower air relative humidities, both of which are conducive to improved drying rates and lower final moisture contents of the dried product. This advantage reduces the risk of spoilage both during the actual drying process and in storage. The higher temperatures attainable are also a deterrent to insect and microbial infestation, and protection against dust, insects, and animals is enhanced by drying in an enclosed structure.

Solar dryers are generally classified based on whether the product is directly exposed to insolation, the mode of air flow through the dryer, and the temperature of the air circulated to the drying chamber. In direct dryers, the crop is exposed to the sun but, in indirect dryers, the crop is placed in an enclosed drying chamber and thus shielded from insolation.

Airflow in the solar dryer may be natural or forced (by a fan or blower). Because of the higher airflow rates, solar collector efficiencies in forced-convection dryers are relatively higher than in natural-convection dryers.

Four types of dryers are commonly used in solar crop drying:

° Direct dryers with natural convection where the solar collector and drying chamber are combined;

° Direct dryers with natural convection where the solar collector and drying chamber are separate;

° Direct or indirect dryers with forced convection where the solar collector and drying chamber are separate; and

° Hybrid dryers that may be direct or indirect with forced convection where the solar collector and drying chamber are separate and with another form of heating the drying air, which may be electricity, gas, oil, or solid fuel.

Crop-Drying Requirements in Nigeria

Both rain-fed and irrigation agricultural production is practiced in Nigeria, and over 75% of the total crop produced is grown during the rainy season. Irrigated production is practiced mainly in northern Nigeria. Maize, millet, sorghum, cowpeas, soyabeans, groundnut (peanuts), and rice are the most common grains grown in Nigeria. The tubers include yam, cassava, and Irish and sweet potatoes, and the common vegetables are tomatoes, onions, and pepper. Because preservation facilities are inadequate or nonexistent, the prices of these commodities can fluctuate by over 500% during the year. Most of these crops may require drying after harvest for short- or long-term preservation.

The needs for grain-crop drying are more serious in the middle-belt and southern parts of Nigeria where the ambient relative humidity is relatively high during the harvest season. This makes it extremely difficult to dry crops naturally in the field. Maize is the major grain grown in these areas and is harvested between July and September, the wettest months. With the government ban on importation of maize, rice, and wheat for 1987, and attempts to substitute maize flour for wheat flour in bread production, efforts are being made to increase maize production, and thus a means of heating the relatively humid air to permit drying of the grains is needed. Unless this is done, grain losses will increase, and the expected positive net return from increased maize production will not be achieved.

In northern Nigeria, planting for rain-fed grain production normally starts in June. Over 95% of these grains dry down naturally in the field before final harvest, usually under favourable conditions (good sunshine and low relative humidity). However, supplemental heating for drying may be required for early harvested crops, in August and September, especially on the Jos Plateau, where the rain pattern and amounts are similar to those in the south, and in some good years when planting starts as early as April-May.

Tomato is the most widely used and important vegetable in Nigeria, and it is mainly produced in northern Nigeria through supplemental irrigation schemes. During both the dry- and wet-season harvests, tomatoes are abundant and cheap, but because preservation facilities are poor or nonexistent, the prices of this commodity can be five times higher at the end of harvest period. Tomatoes can be adequately preserved by cutting into slices and drying.

Groundnuts are mainly grown in northern Nigeria and the middle-belt and are harvested between August and September. The pods must be dried before shelling to avoid spoilage by microorganisms.

Other crops grown in both northern and southern Nigeria that may be preserved by drying include yam and cassava, in slices, and pepper. Rice is one of the most staple foods in Nigeria and, with the ban on its importation, more fields are being cultivated. At certain stages in the processing of rice, drying is required.

Solar drying can be applied to all these crop-drying needs.

Construction and Performance of Solar Crop Dryers

Two types of commercial-scale natural and forced convection solar-energy crop dryers have been designed, constructed, and tested at the Department of Agricultural Engineering, Institute for Agricultural Research of Ahmadu Bello University.

Description and Construction

One natural-convection solar crop dryer and one forced-convection solar crop dryer were built from readily available materials. Each of the dryers consists primarily of a flat-plate solar collector used to heat the drying air, drying bins or chambers where the crops are dried, and air circulation components such as fans, ducts, manifolds, and chimney.

The forced-convection solar crop dryer is 1.2 m wide and 15 m long. The framework for the solar collector was constructed from 12.5-mm plywood, which is usually available in 1.2 x 2.44 m sheets. The sheets were joined edge to edge with overlapping boards to obtain the 15-m length for the collector. The solar collector was covered with double-layered clear polyethylene sheets 4 μm thick. The collector back and edge insulation consisted of 25-mm fibreglass foam insulation and two sheets of 12.5-mm Celotex fibreboard. This combination gave an insulation thickness of 50 mm and a thermal resistance value of about 1.4 $m^2 \cdot °C/W$. Sheets of 20-gauge galvanized steel welded together and painted with flat-black paint formed the absorber plate. The space between the absorber plate and top of the fibreboard was 25 mm and this formed the air passage or duct (Fig. 4a). Inlet and outlet air manifolds, constructed of plywood, were installed at the ends of the collector. The collector outlet air manifold was insulated with polystyrene board and connected to an insulated metal duct that was connected to the inlet of a cylindrical metal bin (Figs. 4b and 5).

The 1.5-m diameter, 1.8-m high cylindrical drying bin was constructed from 18-gauge galvanized steel. A ladder was provided for loading the bin from the top. The bottom of the bin was conical to aid in off-loading the crop through a gate closed by a sliding metal plate. An air-distribution system inside the drying bin provided uniform distribution of heated air. A centrifugal fan placed at the inlet end of the solar collector forced air through the solar collector and into the drying bin. To compare the effectiveness of forced circulation heated and unheated (natural) air drying, a second cylindrical drying bin similar to the first was constructed and connected through metal ducts to a similar centrifugal fan.

The natural-convection solar crop dryer consisted of a solar collector section for preheating the air and a drying chamber at the end of which was attached a chimney (Figs. 6 and 7). The framework for the solar collector and drying chamber was constructed with 19-mm plywood and both were insulated at the bottom and sides with fibreboard. The top of the solar collector and drying chamber was covered with transparent clear corrugated fibreglass sheets sloped slightly to allow rain water to drain. To minimize sagging effects, the fibreglass covers were supported at intervals by wood stringers nailed to the sides of the solar collector and drying chamber.

The collector-absorber plate was supported 0.08 m above the bottom of the collector. A divergent wooden manifold at the inlet of the collector helped to spread the air draft across the collector and drying chamber. The crop to be dried is kept on an extended-metal or perforated-metal screen supported also 0.08-m above the bottom of the drying chamber. Air chambers, therefore, existed below and above the absorber plate and drying chamber metal screen. The drying chamber consisted of four detachable units, each of which could hold 250 kg of crop in a layer of about 0.15-0.20 m. This is the maximum depth for effective drying because the airflow through the drying chamber, which is brought about by thermal forces, is limited to low levels. In the air circulation through the system, a chimney effect was obtained by mounting vertically at the end of the drying chamber a 3-m long, 0.3-m diameter cylindrical galvanized-metal chimney.

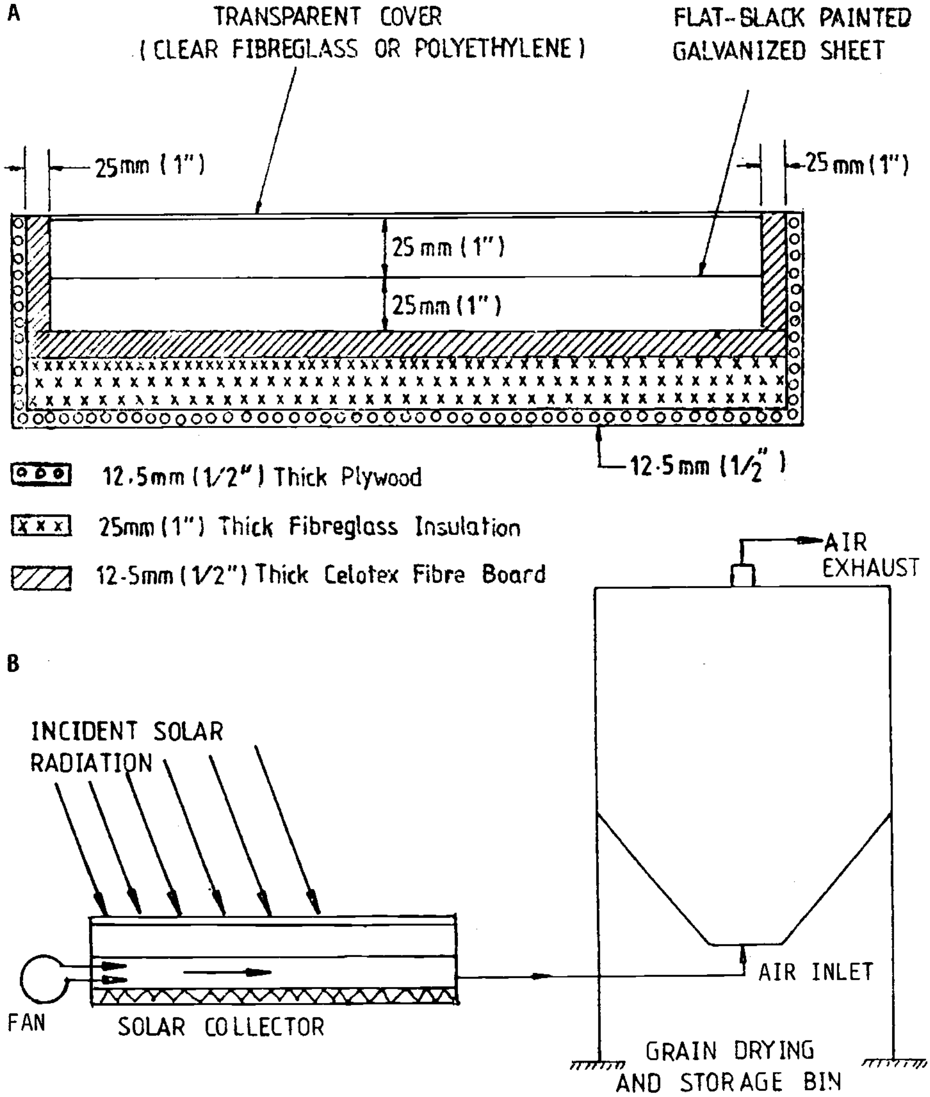

Fig. 4. Solar crop dryer: cross section of the standard-design flat-plate solar collector (a) and schematic for the solar collector and drying bin of the forced-convection dryer.

A hinged wooden window at both sides of each unit of the drying chamber was provided to aid in loading and unloading crops from the drying chamber. The windows had staple locks to seal the chamber tightly during drying.

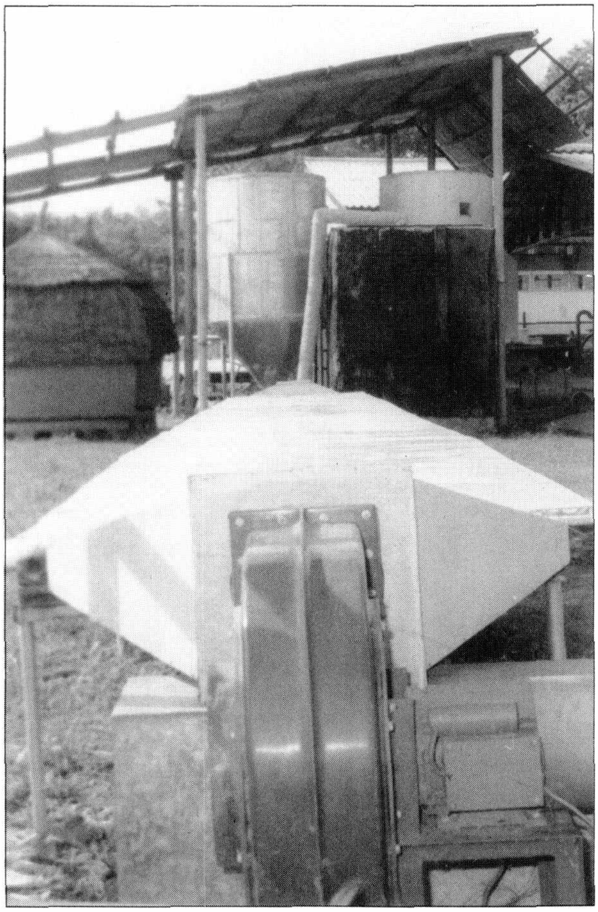

Fig. 5. Forced-convection solar crop dryer.

Theoretical Performance Analysis

As presented in detail in Arinze and Obi (1984a), and in Duffie and Beckman (1980), the collector useful energy gain is:

$$Q_u = M_a C_{pa}(T_o - T_i)$$
$$= A_c[\tau\alpha\ I_T - U_L(T_{pm} - T_i)]$$
$$= A_c\ \tau\alpha I_T - Q_L \qquad [1]$$

where

Q_u = collector useful energy gain (W)
M_a = mass flow rate of working fluid (kg/sec)
C_{pa} = specific heat of working fluid (J/kg per °C)
T_o = collector outlet fluid temperature (°C)

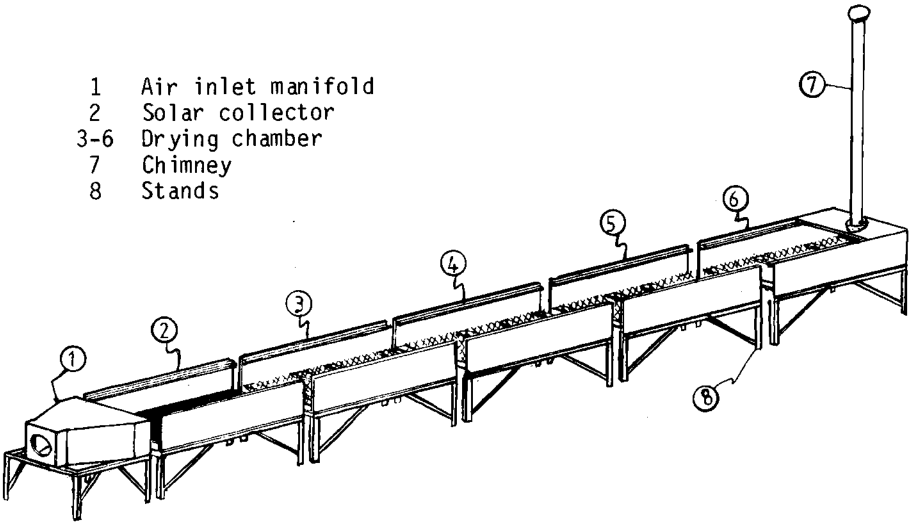

Fig. 6. Natural convection solar crop dryer.

T_i = collector inlet fluid temperature (°C)

A_c = collector area (m^2)

$\tau\alpha$ = effective transmittance-absorbance product for the collector cover and absorber plate

I_T = incident solar radiation on the collector cover (W/m^2)

U_L = overall collector heat loss coefficient (W/m^2 per °C)

T_{pm} = mean temperature of the collector absorber plate (°C)

= $T_i + (T_o - T_i)/2$, approximately

Q_L = rate of energy loss from the collector to the surroundings (W)

= $U_L A_c(T_{pm} - T_i)$.

For a given period, dt, the collector efficiency is (Duffie and Beckman 1980):

$$\eta = \int QUdt / \int A_c I_T dt \qquad [2]$$

Assuming that the exit air from the drying bin is at the ambient temperature, T_i, the overall energy balance of the system for the collector and dryer is:

$$Q_u = A_c\, \tau\alpha\, I_T - Q_L$$

$$= Q_D + Q_S$$

$$= M_a\, C_{pa}(T_{Di} - T_i) + M_a C_{pa}(T_o - T_{Di}) \qquad [3]$$

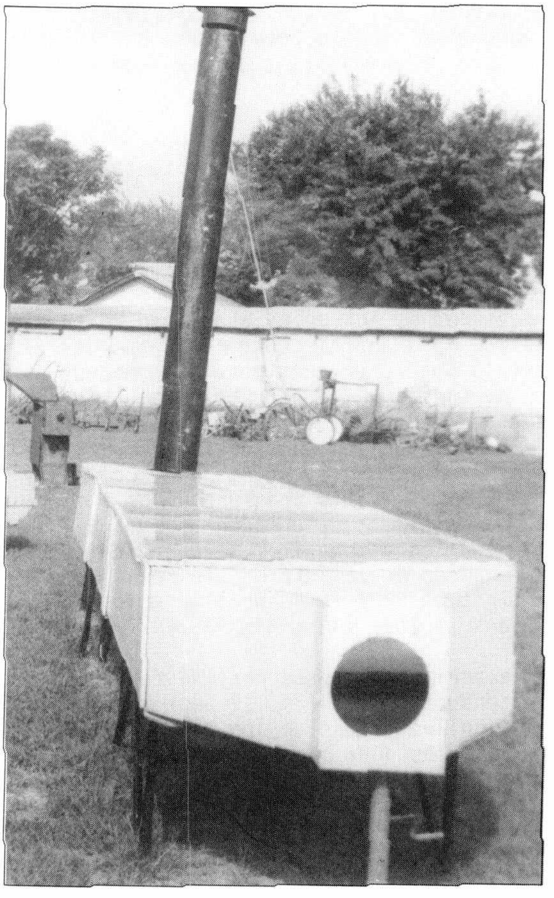

Fig. 7. Natural-convection solar crop dryer.

where

Q_D = rate of energy delivery to the dryer from the collector (W)

= $M_a\ C_{pa}(T_{Di} - T_i)$

Q_S = rate of energy loss in the ducts and manifolds from the collector to the dryer inlet (W)

= $M_a C_{pa}(T_o - T_{Di})$

T_{Di} = inlet air temperature to the dryer (°C)

T_o = outlet air temperature from the dryer or ambient temperature (°C).

The methods of evaluating all the terms in equations 1-3, including natural convection and forced convection mass flow of air through the collector-dryer system, are given in Arinze and Obi

(1984a), Arinze (1985), Duffie and Beckman (1980), and ASHRAE (1977). The equations were also used to predict the performance of the solar crop dryers and were programed in a digital computer.

Experimental Results and Discussion

The performances of the natural- and forced-convection solar crop dryers were investigated in several experiments. During the tests, various parameters, such as the total solar radiation incident on the collector cover, temperatures at different locations in the collector and drying chamber or bin, outdoor temperatures and relative humidity, and moisture content of the crop were measured. The total solar radiation was measured by an Eppley Black and White pyranometer and the output recorded by a chart recorder. Temperatures were measured at 1-hour intervals by copper-constantan thermocouples and the output recorded by a mini-thermocouple potentiometer. Mercury thermometers and bimetallic graduated thermometers were also used for temperature measurements. The moisture content of the crop placed in the dryer was determined by oven method by using an electrically heated laboratory oven set at 100°C. Static pressure drops at various locations along the flow channels were determined using a U-tube manometer or appropriate empirical equations from temperature measurements (ASHRAE 1977), and the measured or calculated pressures were used to determine various system airflows from fan-characteristic curves or appropriate empirical equations (Arinze 1985; ASHRAE 1977).

Continuous experimental tests for the forced-convection solar crop dryer were conducted from 7 to 12 September with air circulation through the solar collector and drying bin. The drying bin was filled with about 3.5 t of groundnut pods of about 39% initial moisture content (wet basis). Figures 8 and 9 show the measured and computer-predicted inlet and outlet air temperatures for the collector (Fig. 8) and useful heat gain, Q_U, for the collector (Fig. 9) for the forced-convection solar crop dryer for 1 day with average weather. The measured total horizontal solar radiation is also indicated in Fig. 8. The experimental collector efficiencies are shown in Fig. 10 for 7-12 September. (Each point in the figure represents the hourly collector efficiency plotted as a function of $(T_O - T_i)/I_T$ and the data for each day are represented by a distinct symbol.)

The drying bin for the unheated air dryer was also filled to the same depth with groundnut pods of the same initial moisture content. The moisture content of the groundnuts from the dryer with supplemental solar heat and without supplemental heat were determined by oven method at the end of each day of drying. The samples were taken from the bottom cone section (up to 0.6 m from the discharge gate), middle section (0.6-1.2 m), and top section (1.2-1.8 m). The moisture contents of the groundnuts in the bottom, middle, and top sections were 10.3, 18.4, and 30.6% (wet basis), respectively, at the end of the drying test for the forced-convection solar crop dryer. The bottom section, therefore, dried to safe moisture content within 5 days with solar supplemental heat. On the other hand, the moisture content of the crop in the bottom section of the forced-convection unheated air dryer was about 18% (wet basis), which was still unsafe for the crop after 5 days of drying, and mould formation was already noticed in the top section.

At the end of the 5th day, the contents of the two forced-

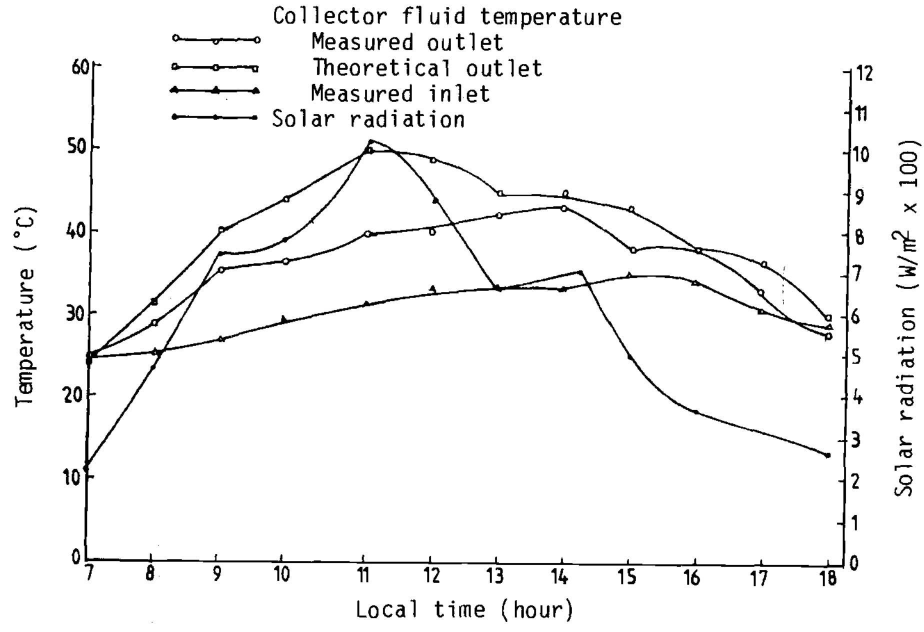

Fig. 8. Measured and theoretical collector fluid outlet and inlet temperatures, 10 September 1983.

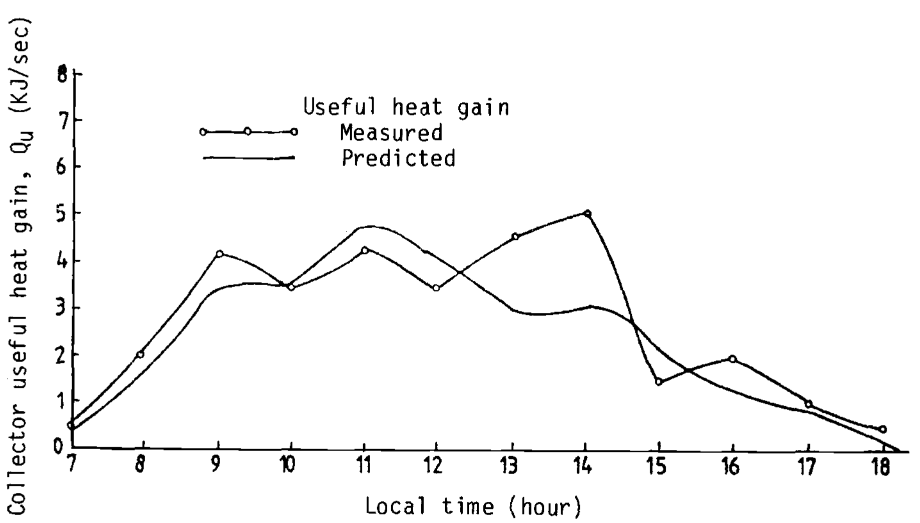

Fig. 9. Measured and theoretical useful heat gain by the collector, 10 September 1983.

convection dryers were partly emptied because the drying rate in the middle and top sections was not fast enough to prevent mould formation

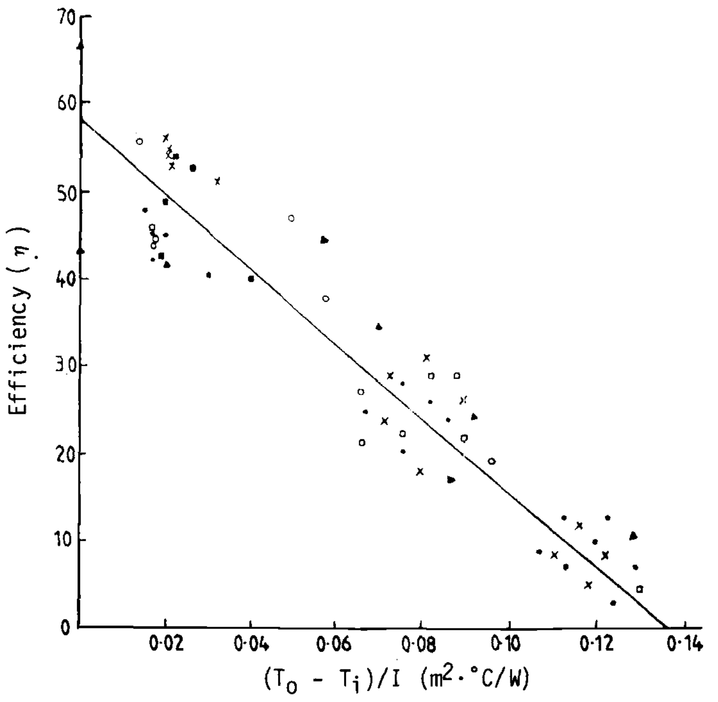

Fig. 10. Experimental thermal efficiency curves. Each symbol represents the data for a single day.

or self-heating. For this deep-bed dryer, a more effective and safer drying procedure would be step-wise filling for batch drying. This will obviously produce a better result and prevent crop spoilage.

One tonne of fresh maize cobs was dried with the natural convection solar crop dryer during harvest season for 5 consecutive days in September 1984. The maize cobs, with an initial kernel moisture content of 34.5% (wet basis), were spread to a depth of 0.15 m in the drying chamber. The kernel moisture contents in the inlet, middle, and outlet sections of the drying chamber were measured daily at 1900 hours.

Ambient, collector, and dryer air temperatures for the solar crop dryer during the test were generally highest between 1200 and 1400 hours (Fig. 11). At the end of the 5 consecutive days drying, the kernel moisture contents were 11.5, 13.3, and 14.5% (wet basis) for the inlet, middle, and outlet sections, respectively, giving a mean value of 13.1% for the entire dryer (Fig. 12): this mean moisture content is considered safe for storage. For the same initial kernel moisture content of 34.5%, it took 12 consecutive days for maize cobs spread outside to dry down to 15.5% kernel moisture content. This uncontrolled sun drying outside was interrupted several times by rain, which is usually very frequent in July, August, and September in Zaria.

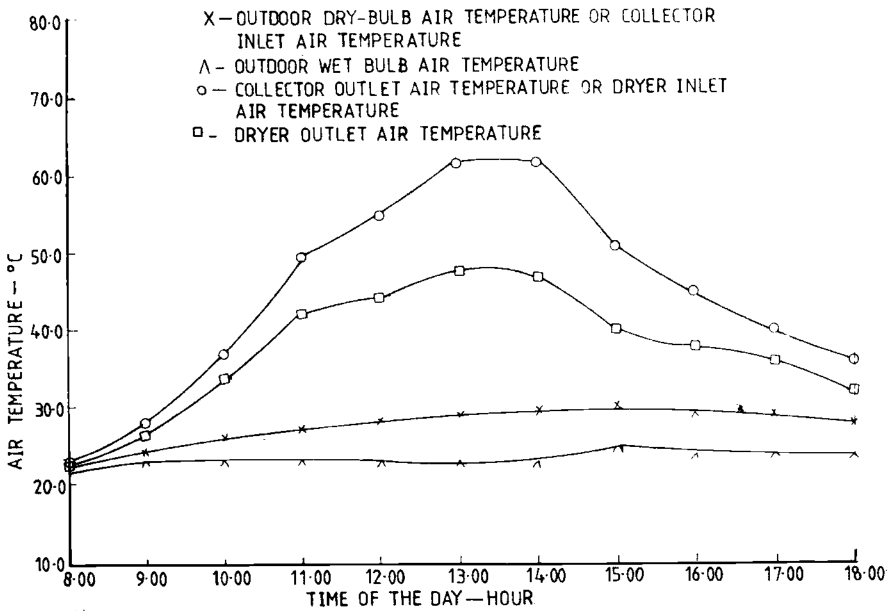

Fig. 11. Typical measured hourly outdoor (ambient), collector, and dryer air temperatures for the solar crop dryer during drying of maize cobs (22 September 1984).

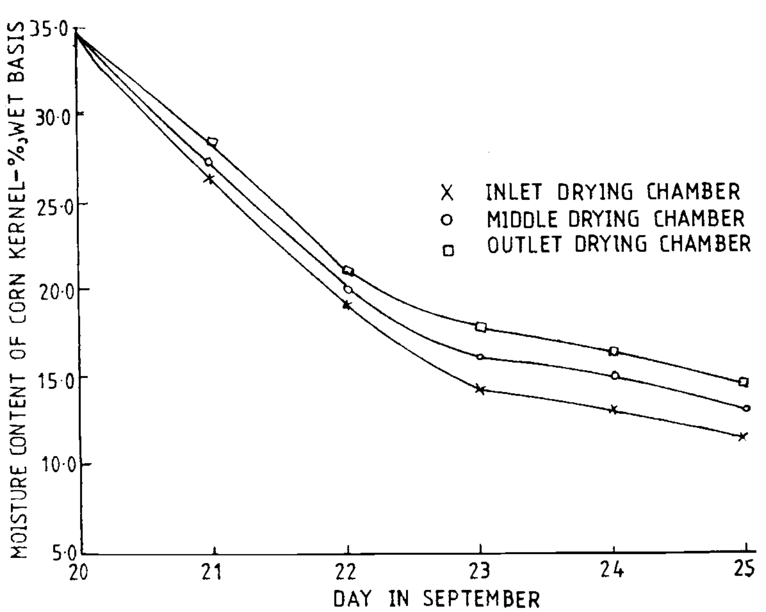

Fig. 12. Measured daily moisture content of maize kernels at three locations in the dryer during continuous drying of maize cobs with the solar crop dryer (20-25 September 1984).

In September 1984, about 50-mm thick layers of sliced yam and fresh tomatoes placed in the drying chamber of the natural-convection solar dryer dried to bone-dry condition in 1 and 2 days, respectively. About 50-mm thick layers of fresh pepper were also successfully dried to almost bone-dry condition in 2 days with the solar dryer. In addition, 520 kg of shelled groundnut (kernels) with initial moisture content of 9.8% (wet basis) and spread uniformly to a depth of 0.08 m in the 9.8-m drying chamber dried down to 6.3% moisture content in 12 hours on 1 May 1984. It took 2 days or 48 hours for about 50 kg of groundnut kernels of the same initial moisture content (9.8%) spread outside to the same depth on tarpaulin to dry naturally down to 6.5% moisture content under the sun. The relative advantage of the natural-convection solar crop dryer over the traditional sun drying is, therefore, evident from these tests.

The performance of direct natural-convection solar crop dryers as described here is influenced by the solar radiation absorption characteristics of the crop exposed to the sun. Earlier studies by Arinze (1978) and Arinze et al. (1979) indicated that the solar absorbances of most agricultural products, determined by calorimetric technique, are comparable to that of flat-black galvanized metal sheet (Fig. 13). By using the agricultural products as solar energy absorbers, as was done in the natural-convection solar crop dryer, the product's temperature would be higher than the drying air temperature. Under these conditions, the vapour pressure of water in the crop would be higher than that of water in the drying air. Thus, moisture will move out of the crop even though the relative humidity of the air is high. This is particularly advantageous in humid tropical areas or drying

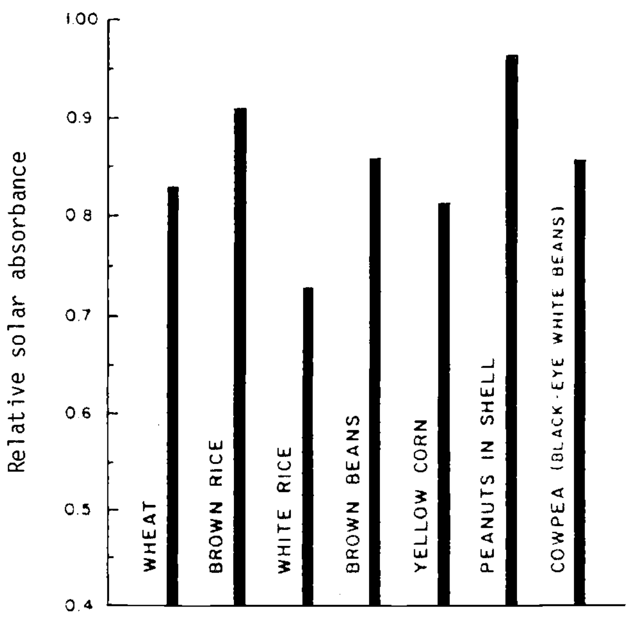

Fig. 13. Relative solar absorbance of various agricultural products compared to flat-black paint on galvanized metal (=1.00).

under cloudy conditions, especially in the southern and middle-belt parts of Nigeria.

Conclusion

Solar energy, which is sufficiently abundant in most developing countries and in Nigeria particularly, can be used to produce heat for various applications in homes, industry, and agriculture. Some low-temperature solar energy systems, such as are applied in crop drying and food processes, hot-water supply, and industrial process heat, are now cost effective and their widespread use in agricultural production and industry is highly recommended to conserve fossil fuels. Crop drying is necessary in Nigeria, and in most developing countries, for both long- and short-term crop preservation.

The results of the experimental tests on solar crop drying indicated that the forced-convection solar crop dryers performed satisfactorily in drying various agricultural products under varied weather conditions. The solar crop dryers have considerable advantages over the traditional uncontrolled sun-drying method in terms of much faster drying rate and handling convenience. Over 50% savings in time can be achieved by using the solar crop dryers as against the traditional sun drying. Further, by using the solar dryers, harvesting at higher moisture content is possible without fear of crop spoilage. The solar crop dryers can be made in various sizes, depending on the farmer's needs and capital availability. An intensive campaign is needed for adoption of solar crop-drying techniques for short- and long-term crop preservation in Nigeria and other tropical developing countries.

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