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NATURAL CONVECTION MUD TYPE SOLAR DRYERS FOR RURAL FARMERS

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ABSTRACT

A prototype direct mode natural convection mud type solar dryer was designed, fabricated and tested. Mud was selected as a major dryer material based on its thermal properties, availability and workability by the rural dwellers who are the end users. Consequent to the laboratory test which dried maize from initial moisture content of 29 % wet basis to final moisture content of 12 % wet basis, three large scale mud type solar dryers of 400 kg capacity of maize grain, were constructed and each located at Jere, New-Wase and Kwaka, in Kaduna and Niger states of Nigeria respectively.150 kg of maize grain available from the farmers, at 30 % initial moisture content wet basis was dried at a batch in three replicates to 12 % moisture content wet basis, with the dryers. The dried crops were used to evaluate the large-scale mud solar dryers. The results showed that the dryers achieved 55 percent saving in drying time, with high quality dried crops, over the open sun drying. Also, the dryers and open sun drying methods attained average system drying efficiencies of 45.6 and 22.7 percent in the same order. Oral interview conducted to randomized sample of farmers in Jere, New-Wase and Kwaka, showed that the farmers were willing to adopt mud solar dryer for drying their crops, because they normally work with mud, and can afford to own mud type solar dryers.

Key words: Solar Energy, Mud, Dryer, Open sun, Farmers, Maize.

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1.0 INTRODUCTION

The need to feed Nigerian's teaming population has induced farmers to increase their food production. But the limiting factor on the extent of crop production has been post harvest handling of the crops. Iwena (2008) stated that agriculture and other agro-based industries, basically in rural areas, provide employment opportunities for 60 to 70 percent of the Nigerian population. Nielsen(2005) and Susan (2011) pointed out that solar energy, which is renewable, commonly available and affordable can be employed to preserve agricultural produce. One of the ways farmers preserve their crops is by drying. This approach mainly includes natural field drying and open sun drying as reported by(Arinze et al, 1990). Traditionally, farmers spread their crops in the sun on mats, top of rocks, roofs, roadsides or by hanging on trees to dry. Though sun drying requires little capital and manpower, it is associated with many problems and shortcomings.

On the other hand, the renewable solar energy can be harnessed for artificial drying of crops. Dixon and Leslie (1978) stated that solar energy can be trapped directly from the sun by heliothermal conversion. Thermal collector is a device that converts the energy in solar radiation into a more usable or storable energy (Wikimedia, 2010). By the principles of heliothermal conversion, solar dryers were developed and tested in the laboratory (Akani, 1990, Eke 1991 and 2003). They went further to apply the principle of natural convection heat flow to develop portable solar dryers as a means of solving the identified problems of traditional open sun crop drying. AMECO (2009) indicated that plastics can be used for low temperature collector top cover, but it deteriorates quick due to ultra violet radiation effect. Michael(2003) stated that the transmissivity of glass tends to be very high at the range of 0.4 μm to 2.5 μm wavelength. Farmers acknowledged that the crops dried with the solar dryer were of better quality than that dried traditionally in the open sun. However the farmers complained that the portable solar dryers could not accommodate the large quantity of crops, they needed to dry in a batch. Besides, if the materials used in fabricating the portable solar dryer are blown up to a large size That Will Contain The Quantity Of Crops Farmers Normally Dry Per Batch, The Cost Would Be Too Exorbitant For Them To Bear. Based On The Results Of The Laboratory Test Of Prototype Solar Dryers, Mud Was Selected As A Solar Dryer Material That Could Be Suitable To Farmers. Hence The Aim Of This Study Was To Construct And Perform Experimental Evaluation Of A Medium-scale Direct Mode Free Convection Mud Type Solar Dryer In the Field.

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2.0 THEORETICAL ANALYSIS

Among the three weather factors, (relative humidity, air velocity and heat energy)that affect the rate of crop drying, only heat energy can be manipulated in a free convection solar dryer. Therefore the design consideration and material selection, in this work are mainly heat energy based. Mud was chosen as the major construction material for the mud type solar dryer. When the surface is painted black, it emits high thermal energy and at the same time serves as an insulator.

2.1 Prediction Equation for Mud Type Solar Dryer Size-configuration

2.1.1 Determination of the dryer wall thickness:

Fourier basic equation for heat flow through a slab and the collector useful heat gain equation given by Duffia and Beckman (1980) were applied to calculate the mud type solar dryer wall thickness.

Thus

where: Q = Collector useful heat energy gain, (W)

A_c = Collector area, (m^2)

$$Q = \frac{A_c K_s dT}{dx} \quad (1)$$

hermal conductivity of mud (W/m°C)

emperature difference (°C)

d_x = Mud wall thickness (m)

$$Q = A_c F_R \left[I T_e - U_L dT \right] \quad (2)$$

where: FR = heat removal factor,(decimal)

I = Solar radiation, (W/m2)

Te = Glass transmissivity (decimal)

UL = Overall heat transfer coefficient (W/m °C)

and others as indicated in Equation(1)

Combining equations(Eqn.) 1 and 2 the required m ud dryer wall thickness becomes:

$$dx = \frac{K_s (T_c - T_a)}{F_R (I T_e - U_L (T_c - T_a))} \quad (3)$$

Where: Tc = Collector air outlet temperature (°C)

Ta = Ambient temperature (°C)

and others as indicated in Eqn(2)

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Eke (2003) worked out the average values of the parameters in (Eqn.) 3 for natural convection direct mode solar dryer in Zaria, from where the values of the variables used in Eqn. 3 were obtained as Tc = 48.5 C for collector air outlet temperature, Ta = 29.5 C for ambient temperature, FR = 0.487 for heat removal factor, 1= 465.9W/m for solar radiation, Te = 0.95 for Transmissivity of transparent glass used as solar dryer top cover and UL = 7.8 W/m C for overall heat transfer coefficient

Frank and David(198) reported by Eke,(2003) gave the value of thermal conductivity of soil, (mud Ks as 0.52W/m°C).

c

2.1.2 Determination of solar collector area

The expression used to predict the collector's useful heat energy gain, Q, required to dry a given quantity of agricultural product, W_p, from the initial moisture content to final moisture content wet basis is given in Eqn.(4 Eke,1991) as;

$$Q=\left[C_p w_p (T_c - T_a) + \frac{L_v (M_{ci} - M_c)}{100}\left(w_p - \frac{w_p M_{cm}}{100}\right)\right] \quad (4)$$

where: C_p = Specific heat capacity of material, (J/kg °C)

W_p = Weight of material before drying (kg)

L_v = Heat of vaporization of the removed water at the drying temperature (J/kg)

MC_i = Initial moisture content of the product, dry basis, (%)

MC =Final moisture content of the product, dry basis, (%)

MC_m = Initial moisture content of the product, wet basis (%)

And others as already defined.

Combining Equations: 2 and 4, the collector area, A_c is obtained as:

$$A_c = \left[\frac{C_p W_p (T_c - T_a)}{F_R (IT_e - U_L (T_c - T_a))} + \frac{L_v (M_{ci} - M_c)(w_p - w_p M_{cm})}{100 F_R (IT_e - U_L (T_c - T_a))}\right] \quad (5)$$

where all symbols remain as previously explained.

The expression for calculating the rectangular solar dryer size-configurations developed by Eke (2003) was employed in the determination of the dimensional relationship between collector and drying chamber sections in this work.

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$$A_c = L_c W \tag{6}$$

where: A_c = Area of collector(m^2)
L_c = Length of solar collector se)ction (m)
W = Collector width (m)

$$A_D = L_D W \tag{7}$$

where: LD = Length of drying chamber section(m)

Equations 6 and 7 expressed a solar dryer size configuration of a rectangular shape.

2.1.3 Performance Evaluation of the Mud Type Solar Dryer

The performance of mud solar dryer was evaluated by considering its' system drying efficiency and the organoleptic quality of the dried product. Brenndorfer et al (1987) as given in Akani (1990) showed that the system drying efficiency, Esd, can be calculated as :

$$E_{sd} = \frac{W_w L_v}{IT_e A_c t} \tag{8}$$

where: Te = Glass transmissivity(decimal)

t= Drying time (sec)

E_{sd} = System drying efficiency,(%)

and others are as earlier expressed.

3.0 MATERIALS AND METHODS

3.1 Fabrication of the Mud Type Solar Dryer

Material for construction of the mud type solar dryer were chosen based on availability and affordability of the dryer materials by the local farmers, who are the end users. Mud was chosen as the major material for construction of this solar dryer. A prototype direct mode natural convection mud type solar dryer was fabricated in the Department of Agricultural Engineering, Ahmadu Bello University, Zaria; following the model expressed in Equations 1 to 8. Mud was prepared in a local method by thoroughly mixing soil, chopped summer-grass and water to paste-Consistency.

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The prepared soil was used to form mud blocks of sizes 300 mm x 250 mm x 100 mm each. The mud blocks were used to construct the mud solar dryer, by laying and sticking mud blocks with the mud paste-consistency. The wall surfaces were as well plastered with the mud paste-consistency. Thin pieces of wood were used to form a structure on which mud was overlaid to form the dryer floor. Then solar collectors and the drying chamber sections of areas 0.5 and 0.7 m^2, respectively, were constructed. Wooden doors were fixed by the sides of the drying chamber for loading and unloading agricultural materials. Water colour glass as one of the suitable optical materials for solar collector as recommended by Gilligan and Brzuskiewict (1978), was used as the dryer top cover. Crop trays were fixed in the drying chamber where materials for drying were spread. Inlet and outlet air plenum were provided for free circulation of air through the dryer. The inner surface of the dryer was painted black. The dryer was inclined towards the South at an angle of 15 ^{0} to the horizontal. Basically fresh maize grain was used to evaluate the dryer. The crop was dried in thin layers at the depth of 0.05 m, and was turned after an interval of two hours for uniform drying. A set of the same maize sample was dried in the open sun along side with the one in the dryer and served as the control.
ddle-belt of Nigeria where crops like grains, cereals, legumes and vegetables are produced in large quantities. The farmers normally encounter drying problems, because they harvest when rains have not completely stopped. Most of the farmers in the middle-belt dry about 100 kg of non-vegetable crops per drying batch. Hence the mud solar dryer was designed for a batch drying capacity of 400 kg of non-vegetable crops in thin layers of 0.05 m thickness.

Pictorial Presentation of Mud Type Solar Dryers In Jere, New-Wuse and Kwaka

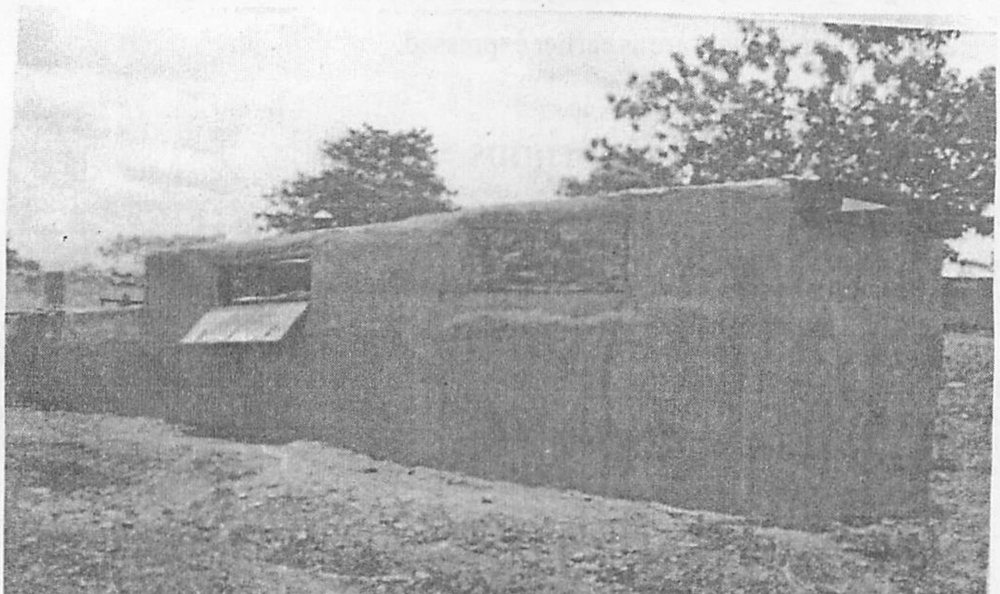

Plate 1

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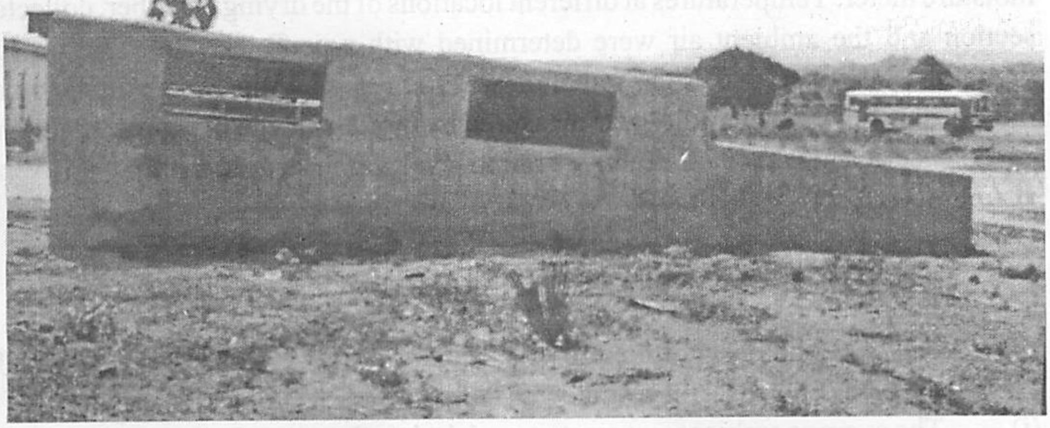

Plate 2: Side View Of Mud Type Solar Crop Dryer At New-wuse Village (Niger State)

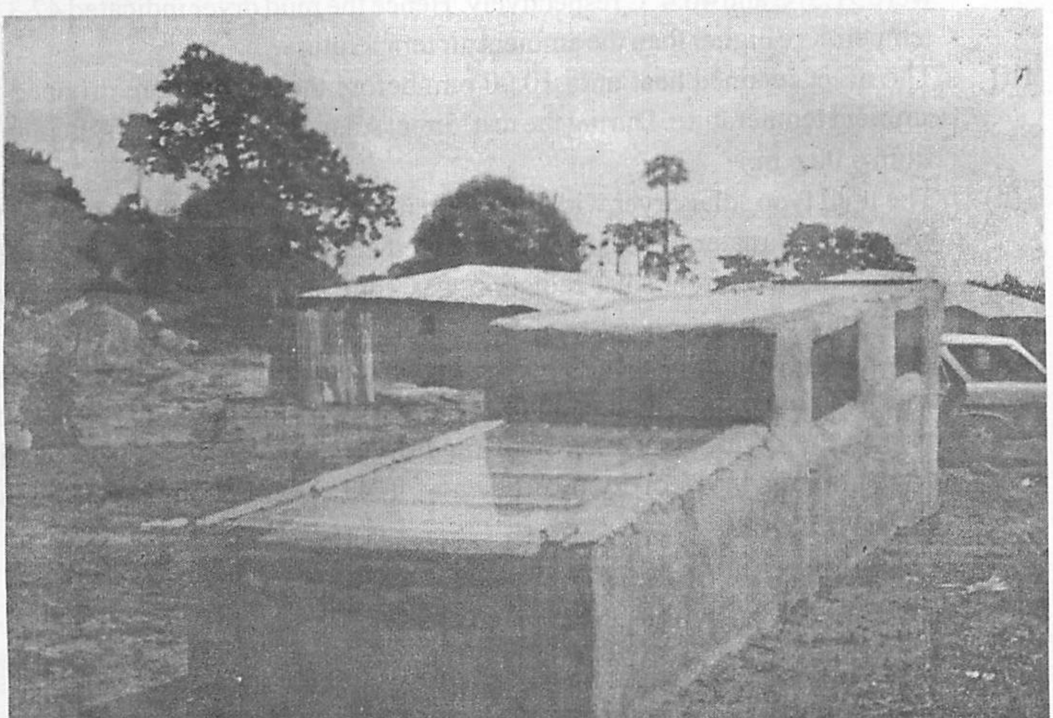

Plate 3: Plan- View Of Mud Type Solar Crop Dryer At Kwaka Village (Niger State)

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3.3 Instrumentation

The moisture content of the drying product was measured at two hours interval with oven method of moisture content determination and with Dole 400 moisture meter. Temperatures at different locations of the drying chamber, collector section and the ambient air were determined with type-T thermocouple omega digital thermometer, and solar radiation was monitored with Omega digital solar radiometer. Relative humidity was measured by digital Omega hygrometer and the wind speed at a height of 1.0 m above ground level was measured with a wind - vane anemometer.

4.0 RESULTS AND DISCUSSION

4.1 Laboratory Test

The results of the analysis of the prototype solar mud dryer is shown in Figure 1. From the figure (Figure 1), the test showed that;

(i) The average ambient temperature and drying chamber air outlet temperature were 31.5 °C and 46.4 °C respectively. Hence the mud dryer indicated 47.3 % temperature higher than the ambient air temperature.

(ii) The dryer retained heat until 10.00 pm. before the temperature dropped to ambient temperature. During the test, direct solar radiation was not available from 6.00 p.m.

(iii) The mud type solar dryer with the internal surfaces painted black proved to be a thermal material because, it generated and retained heat for up to four hours after the direct solar radiation was gone and without any extra heat storage system.

(Iv) The heat retention capacity and the higher temperature generation of the dryer above ambient temperature level enhanced the quick drying of the crop in the dryer. Hence the solar mud dryer achieved 60.5% savings in drying time and system drying efficiency of 43 %, when compared with the open sun drying.

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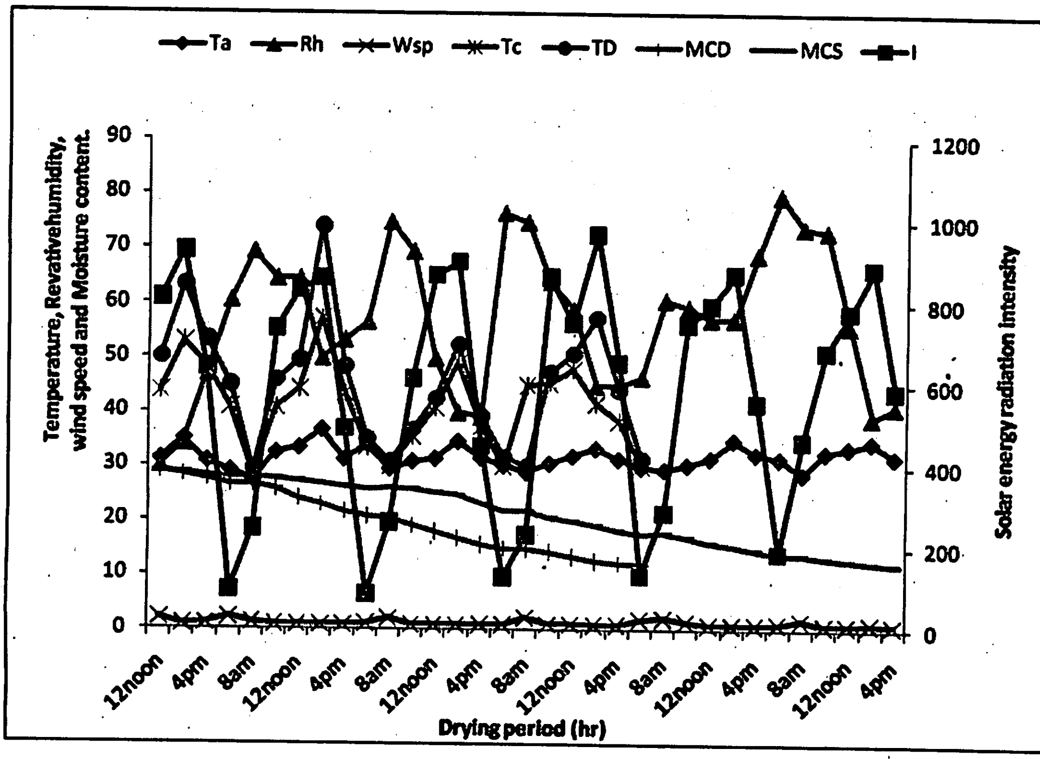

Figure 1: Curves of moisture contents, temperatures, wind speed, relative humidity and, solar energy radiation intensity versus drying time, for dryer in Department of Agricultural Engineering, Faculty of Engineering, Ahmadu Bello University, Zaria.

where; Ta = ambient temperature, ^{0}C

Rh = relative humidity, %

Wsp = wind speed, m/s

Tc = solar collector air outlet temperature, ^{0}C

TD = solar drying chamber air outlet temperature, ^{0}C

MCs = moisture content of maize dried in open sun, %

MCd = moisture content of maize dried in solar dryer, %

I = solar radiation intensity, W/m2

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4.2 Field Test of the Mud Type Solar Dryers

Drying test was conducted at the beginning of harvest, when rains normally destroy most of the crops dried in open sun in the middle-belt. During the test, samples spread for drying in the open sun were packed in at any time it threatened to rain, while the crops loaded in the mud solar dryer were not removed until they dried down to the final moisture content. However, crops both in the solar dryer and open sun were turned periodically for uniform drying.

Figures 2, 3 and 4 represented the drying behaviour of natural convection mud type solar dryers in Jere, New-Wase and Kwaka.

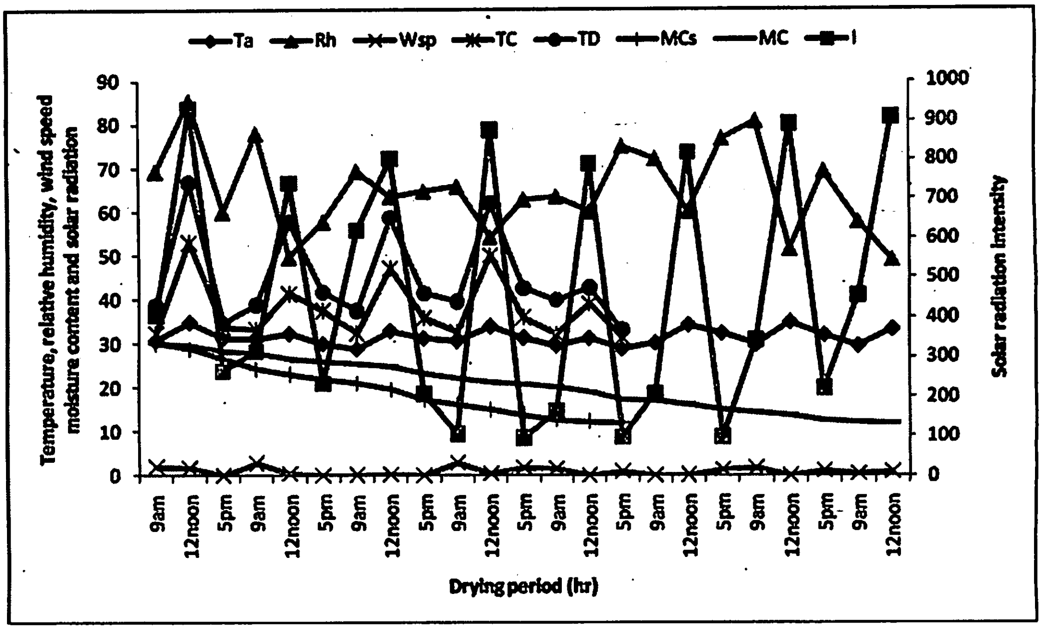

Figure 2: Curves of moisture contents, temperatures, wind speed, relative humidity and, solar energy radiation intensity versus drying time, for dryer in Jere Niger State The legends remain as defined..

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Figure 4: Curves of moisture contents, temperatures, wind speed, relative humidity and, solar energy radiation intensity versus drying time, for solar mud dryer in Kwaka, Niger State. The legends remain as defined.

From the drying curves, the system drying efficiencies and the percentage savings in drying time of the mud type solar dryers above the open sun drying (control) are presented in Table 1.

Table 1: System drying efficiencies and the percentage savings in drying time of the mud type solar dryers above the open sun drying (control).

S/N	Drying location	Drying operation	System drying efficiency (%)	Percentage saving in drying time above the open sun drying (%)
1	Jere	open sun	22.87	57.9
		mud solar dryer	47.01	
2	New Wuse	open sun	24.78	56.1
		mud solar dryer	49.12	
3	Kwaka	open sun	20.24	61.8
		mud solar dryer	40.55	

The higher system drying efficiency exhibited by the dryer in Kwaka, might be due to higher thermal energy conservation as a result of brighter weather condition. Crops dried with the mud solar dryer were generally of better quality in appearance and without contamination, when compared with the samples dried in the open sun. Hence farmers will save about 55% of their drying time by using this dryer. The saved time can either be used to attend to other issues of life or increase crop production to about 55 %. The method of on farm training specified by Joseph (2010)was employed in preliminary training of farmers, on how to use and maintain the passive mud type solar dryers.

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5.0 CONCULSION

A large- scale mud type solar dryers of 400 kg capacity of maize grain, was each constructed at Jere, New-Wase and Kwaka, in Kaduna and Niger states of Nigeria respectively. Tests conducted with newly harvested crops from the farmers revealed that the dryers achieved about 55 % savings in drying time, with high quality dried crops when compared the open sun drying. The open sun drying method served as control. Likewise the dryers and open sun drying methods attained an average system drying efficiencies of 45.56 and 22.63% respectively. Farmers showed willingness to adopt mud type solar dryer for drying their crops, because their crops dried faster with the dryer and were of better quality than that of the open sun drying. The farmers could easily construct and maintain natural convection mud type solar dryer because the drying operation is closely related to open sun drying. The mud type solar dryer will go a long way in solving the crop-drying problems in the middle-belt and southern parts of Nigeria, where it still rains during the beginning of harvest.

It was found that most of the farmers in Nigeria do not know about mud type solar dryer. This called for the need of extensive extension services to create awareness of mud type solar dryers among farmers.

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