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DESIGN AND PERFORMANCE EVALUATION OF A PASSIVE SOLAR CROP DRYER

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ABSTRACT

A domestic passive solar crop dryer for agricultural applications and purposes has been successfully designed and constructed. The dryer is an integral or direct mode type made from locally available materials such as plywood, plane glass, aluminium sheets, hardwood, mild steel, paints, etc. the dimensions of the dryer is 0.7m × 0.5m × 0.7m / 0.5m (length × width × height). The maximum temperature of the dryer recorded was 82^0C and the corresponding ambient temperature was 30^0C. The dryer was used to dry agricultural products such as onions and okro. It took a maximum of six days to dry the onions and okro simultaneously. The average maintained moderate drying temperature was 65°C. The collector efficiency is 62% while the rate of heat flow into the drying chamber per unit area is 434.48 W/m^2. The angle of tilt or slope β was 16^0. The designed and constructed solar crop dryer is appropriate for crops drying during the low temperature and high relative humidity periods of the year. This dryer has helped farmers to facilitate early harvest, permit planning of the harvest season, helped farmers to fetch better income by selling quality products, etc. The solar radiation passes through the glass covers to heat up the air flowing into the drying chamber via the vents provided on the base of the dryer. The area of the top glass cover was taken equal to that of the bottom of the dryer, and the heated flowing air passed through the crops placed in the two trays (upper and lower) in the drying chamber. The crops were heated so that their moisture contents removed through the chimney provided at the top of the dryer.

Keywords: dryer efficiency, relative humidity, rate of heat flow, dryer temperature, ambient temperature

INTRODUCTION

It is well known that food is a basic need of a human being after air and water. Food holds a key position in the development of a country, especially Nigeria. This project deals with drying of food to avoid food losses between harvesting and consumption.

Drying crops by solar energy is of great economic importance in the world, especially in Nigeria where most of the crops and grains harvested are lost to fungi and microbial attacks. These wastages could be easily prevented by proper drying, which enhances storage of crops and grains over a long period of time. Nigeria is within the equator and is blessed with abundant solar energy all the year round. This solar energy is easily harnessed by a proper design of a passive solar crop dryer for crop and grain drying. This method of drying requires the transfer of both heat and water vapour.

Most of our crops and grains are harvested during the peak period of rainy season and so preservation proves difficult thereby making most of these crops and grains perish. High moisture content is one of the reasons for their spoilage during the course of storage at time of harvesting. High moisture crops and grains are prone to fungi infection, attacks by insects, pests and the increased respiration of agricultural produce. The above situation results in the crops and grains not easily available throughout the year and as such hunger and malnutrition set in. Agricultural crops and grains like rice, wheat, tomatoes, pepper, tea, copra, okro, and groundnuts and so on, are routinely seen dumped in the villages, especially Otefe and major cities during peak harvest in Nigeria and other developing countries. This of course, constitutes an environmental hazard. However, the crops and grains can be preserved and stored so that they can be of economic importance both to the farmers and the entire populace in Otefe Community in particular and in Nigeria in general.

Most farmers in the rural areas, using Otefe Community as a case study dry their crops and grains by using open air drying method. This method of drying in the rural areas has some disadvantages. It is unhygienic since the products are easily contaminated by animal droppings and consequent infestation by fungi and bacteria. There is a considerable loss due to various reasons such as rodents, birds, insects and micro-organisms. Human health is endangered as a result of food poisoning resulting from the above situation. The unexpected rainfall or storm further worsens the situation. This method also prolongs drying thereby causing over drying of the produce which results into the deteriorations of quality of the crops and grain by changing their colours and cracking of the crops thereby reducing their international quality standards which will make them not to be sold in the international market.

Moreover, more labour is involved as the crops are moved frequently in and out during the day and night from the rain. They are also watched in order to prevent physical attacks by birds and other animals. It is a well known fact that in rural areas like Otefe, conventional sources of energy like petrol, kerosene and electricity are either totally absent or are not readily available to develop active dryers that have higher rate of performance.

The objective of this paper is to design or construct a low temperature passive solar crop and grain dryer (indirect solar dryer) that will be appropriate for crops and grains during the low temperature and high relative humidity period of the year. The obvious advantage of the low temperature drying is that it enables crops to be dried without cracking and hence minimizes the exposure of the crops to fungi and bacteria infestation and wastage. This is also suitable for bulk drying for long-term storage. Other advantages of solar crop drying are:

i. facilitate early harvest,
ii. permits planning of the harvest season,
iii. helps in long term storage,
iv. helps farmers to fetch better incomes,
v. helps farmers to sell a better quality products,
vi. reduce the requirement of storage space,

vii. helps in handling, transporting and distribution of crops,
viii. permits maintaining availability of seeds

The paper will help to reduce the moisture content of a product to a level below which deterioration will not occur and the product will then be stored for a definite period. Different crops and grains have different level of safe moisture content as shown in Appendix-I.

OPERATION PRINCIPLES

The solar radiation passes through the glass covers to heat up the air flowing into the drying chamber. The area of the top glass cover (plane glass) is taken equal to the area of the bottom of the drying chamber. The heated flowing air entering through the air vents passes through the crops placed in the two trays in the drying chamber. The crops are heated and their moisture contents removed through a chimney provided at the top of the drying chamber. The solar rays entering the glass covers are of short wavelengths (i.e. ultra-violent ray) which degrade into thermal radiation of higher wavelengths (i.e. infra red ray). The higher wavelengths radiation from the absorber plate is not able to pass through the glass cover, hence trapping of the sun's radiation energy.

Drying is a promising area for the application of air heaters and, for that matter, solar energy. It has been the oldest and the most widely used application of solar energy in the developing countries like Nigeria. The methods have been based on open air drying. As a result of extensive research, dryer of various designs have been developed. However, in this project the use drying has been demonstrated as an application of air heaters. Thus, we shall discuss only indirect drying, in which solar energy does not come in direct contact with the crops. On the other hand, hot air from a solar air collector is circulated through the crop to reduce its moisture content. The air can be circulated either by a fan or by natural convention, correspondingly the heater are called ACTIVE OR PASSIVE DRYERS.

It has been said that indirect solar drying minimizes discolouration and cracking on the surface of the crops. The drying is basically achieved by the difference in moisture concentration between the drying air and the air in the vicinity of crop surface. A better control over drying is achieved in indirect type of solar drying systems and the product obtained is of good quality.

CLASSIFICATION OF SOLAR CROP DRYING

The classification of solar crop drying is given in Table-1

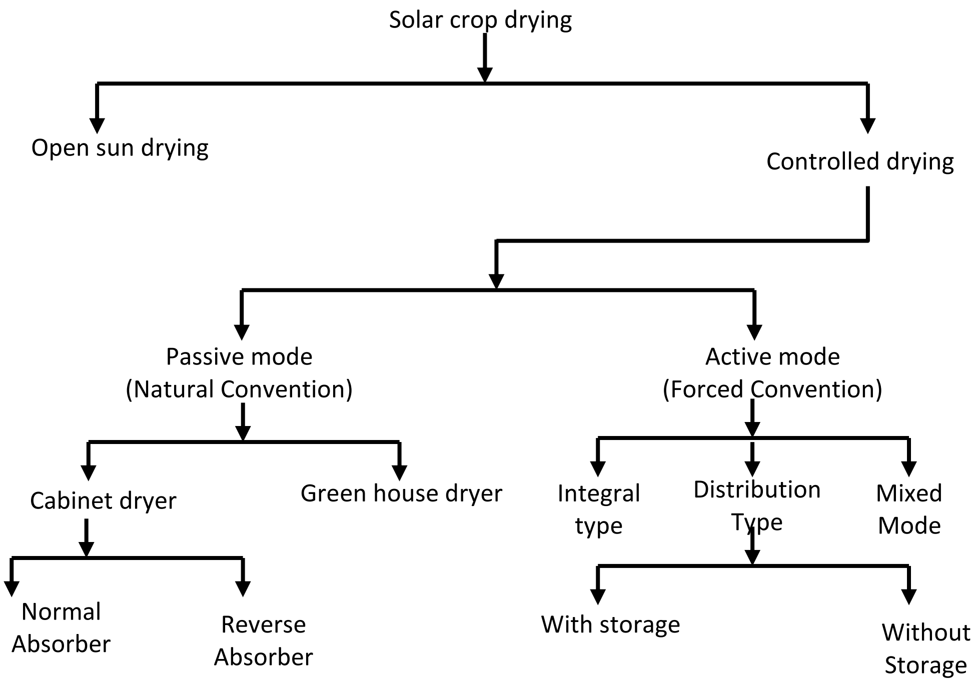

Table-1 : Classification of crop drying using solar energy

In passive solar crop dryer, air is heated and circulated naturally by buoyancy force or as a result of wind pressure or in combination of both.

MATERIALS USED

Haven studied the various previous designs of passive solar crop and grain dryers, we decided to design and construct a simple type by using the available local materials. The materials used in constructing the solar dryer include.

i. Plane glass (top and sides) for radiation purpose,
ii. Absorber plate (aluminum sheet) for heat trapping,

iii. Plywood for casing purpose,
iv. Wire mesh (mild steel) for crop to be dried,
v. hardwood for support of the dryer.

Appendix-II shows the schematic view of the present design. In this design, denser air from the base flows through the crops on the trays to remove their moisture contents. Thereafter, the moist air flows out through a chimney on top of the drying chamber.
The designed and constructed solar crop dryer will be used in drying okro and onions. The initial and final moisture content and their maximum allowable drying temperature of these crops are shown in Appendix-I.

TESTING

The constructed solar crop dryer was tested for six days in drying onions and okro, and the results were very satisfactory. A research of similar crops dried by open sun drying method was carried out in Otefe community and it was found that the onions and okro dried by open sun during method were contaminated by animals dropping and infected by fungi and bacteria. There was also a considerable loss of the crops due to rodents, birds, insect and microorganisms attack.
In addition, the unexpected rainfall and storm further worsens the situation. This result into prolong drying of the crops and over drying gives a poor quality of the produce. It even causes cracking of the crops. However, the constructed passive solar dryer gave a good quality of the produce as a result of absence of the above problems encountered during open sun drying method,
The dryer was tested by placing it on the wooden stand provided and consequently placed under the sun. A good result of solar radiation into the drying chamber of the dryer is obtained when the shadow of the dryer is fully cast behind it. The initial weights of the onion and okro were 343g and 276g respectively on the first day before the drying commenced. The onions were placed on tray 1 (one) and the okro was placed on tray 2 (two).
Table-I in Appendix-I shows that the maximum allowable temperature for drying onions and okro are 55 C and 65 C respectively. The maximum temperature obtained during the testing of the dryer was 82°C as at 9th October 2008 between 8am - 3pm.

RESULTS

MOISTURE LOSS (ML)

For the onions on tray 1

Weight of onions on first day - 343g

Weight of onions on second day = 235g

Weight of onions on third day = I45g

Weight of onions on forth day = 70g

Weight of onions on fifth day = 25g

Weight of onions on sixth day = 3g

Weight of onions on seventh day = 1g.

Hence moisture loss (ML) for day 1 = 342 – 235 = 108g
for day 2 = 235 – 145 = 90g.
for day 3 = 145 – 70 = 75h
for day 4 = 70 – 25 = 45g
for day 5 = 25 – 3 = 22g
for day 6 = 3 – 1 = 2g.

See table 4

For Okro on Tray 2

Weight on lstday = 27g
Weight on 2nd day = 170g
Weight on 3rd day = 90g
Weight on 4th day = 30g
Weight on 5th day = l0g
Weight on 6th day = 5g
Weight on 7th day = 3g.

Hence ML for day 1 = 276 – 170= 112g
ML for day 2 = 170 – 90 = 80g
ML for day 3 = 90 – 30 = 60g
ML for day 4 = 30 – 10 = 20g
ML for day 5 = 10 – 5 = 5
ML for day 6 = 5 – 3 = 2g

See table-5

Similarly, the temperature variation with the local time for every one hour for onion drying was also recorded. Table-6 illustrates the results. In addition the temperature variation with local time for every one hour for okro drying is shown in table 7.

TABLE 4: Moisture Loss (g) Vs Time (Days) for Onion Drying

ML (g)	108	90	75	45	22	2
Time(day)	1	2	3	4	5	6

TABLE 5: Moisture Loss (g) Vs Time (Days) for Okro Drying

ML (g)	112	80	60	20	5	2
Time(day)	1	2	3	4	5	6

TABLE 6: Temperature Variation with Local Time for Onion Drying

Tempt(^{0}C)	30	42	52	54	57	60	65	63	55	53
Time(hrs)	8	9	10	11	12	13	14	15	16	17

TABLE 7: Temperature Variation with Local Time for Okro Drying

Tempt(^{0}C)	30	38	47	49	52	55	60	58	50	48
Time(hrs)	8	9	10	11	12	13	14	15	16	17

DISCUSSIONS

Appendix-IV shows the plots of moisture loss against local time in days for drying onion and okro. It is seen from the plots that nature of the graphs obtained are curves and that the rate of moisture loss in Tray 1 was higher than that in Tray 2 because of the direct contact of Tray I with the rays of the sun.

The moisture loss between days 4 - 6 for onions drying was very high. This is also obtained for okro drying within these days.

Appendix V shows the plots of the temperature variation with the local time in hours for performance evaluation of onions and Okro drying. The ambient temperature, Ta is 30°C. Tray 1 recorded a higher temperature of 65°C while Tray 2 recorded a high temperature of 60°C.

The rate of moisture loss in tray 1 is more than that in Tray 2 due to the fact that Tray 1 receives direct sunlight while Tray 2 is shaded by Tray 1. However, the crops in Tray 2 retained the good the quality more than Tray 1 as a result of its moderate temperatures. The curves in the two plots show rise and fall in temperature during the drying of the two crops.

CONCLUSIONS

A modified passive solar crop dryer has been successfully constructed by using locally available materials in Nigeria. The dryer achieved a maximum temperature of 82°C which is used for passive solar crop and grain dryer. Higher temperature than the one recorded above may lead to cracking of the crops and grains. This will give room for bacteria and insects to easily attack the crops and grains.

However, a moderate temperature of 65°C was used in drying the onions and okro. This moderate temperature is shown in Table I in Appendix I. The collector efficiency for the passive solar dryer was 62%. There was no need of carrying the crops inside during the nights in order to avoid re-wetting since the dryer was sealed with glass and wood including aluminum sheets to protect the samples from dew and rain.

RECOMMENDATIONS

Haven successfully constructed a passive solar crop dryer, we therefore recommend that

i. The dryer should be enlarged for large scale drying and commercial purposes,
ii. The glazing material should be changed to convex lenses to increase radiant energy entering the dryer,
iii. The government should grant fund in research, publicizing and educating people on how to use the solar dryer effectively.
iv. There should be research in creating low cost durable solar dryers.

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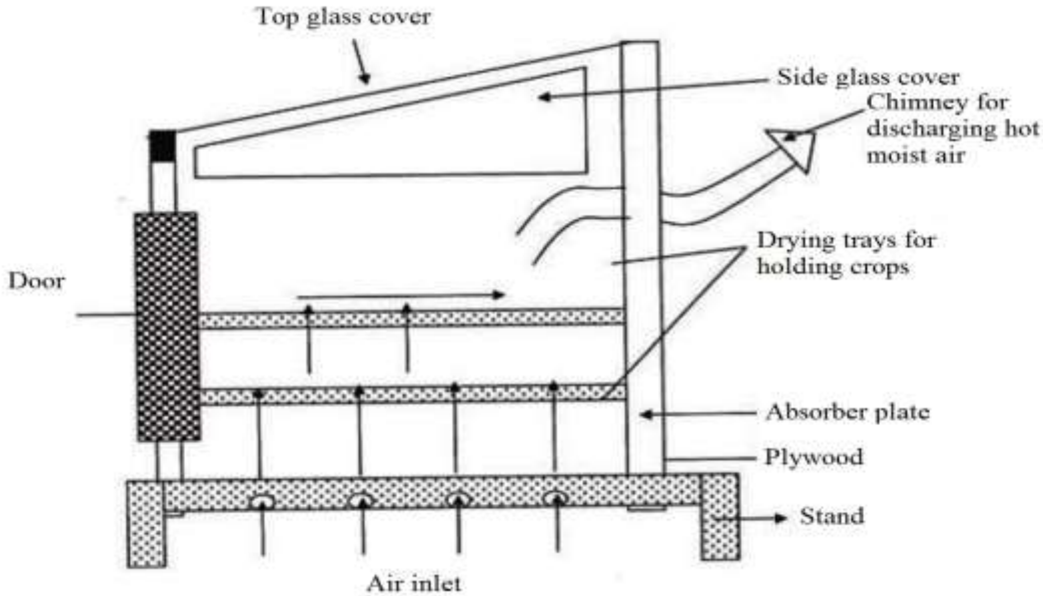
APPENDIX-I

Table 1: Initial and final moisture content and maximum allowable temperature for drying some crops

S/N	Crops	Initial moisture (%,w.b.)	Final moisture content (%, w.b.)	Max. allowable temperature (^{0}C)
1.	Paddy, raw	22 – 24	11	50
2.	Paddy,	30 – 35	13	50
3.	parboiled	35	15	60
4.	Maize	24	14	50
5.	Corn	24	11	50
6.	Rice	20 – 25	7 – 9	40 -60
7.	Oil seed	80	5	65
8.	Green peas	70	5	75
9.	Carrots	70	5	55
10.	Green beans	80	4	55
11.	Onions	80	4	55
12.	Garlic	80	4	55
13.	Cabbage	75	7	75
14.	Sweet potato	80	24	70
15.	Apples	80	15 – 20	70
16.	Grapes	80	1.5	70
17.	Bananas	80	20	65
18.	Okro	80	10	65
19.	Pineapples	96	10	60
	Tomatoes			

Source: (Ref. No.4)

APPENDIX-II



APPENDIX III

TABLE 3. Physical Properties of Metals

Metal	Density (Kg/m^3)	Melting point (^{0}C)	Thermal conductivity (W/m^{0}C)	Coefficient of liner expansion at 20^{0}C (um/m/^{0}C)
Aluminium	2700	660	220	23.0
Brass	8450	950	130	16.7
Bronze	8730	1040	67	17.3
Cast iron	7250	1300	54.5	9.0
Copper	8900	1083	393.5	16.7
Lead	11400	327	33.5	29.1
Silver	10500	960	420	18.9
Steel	7850	1510	50.2	11.1
Tin	7400	232	67	21.4
Zinc	7200	419	113	33.0
Cobalt	8850	1490	69.2	12.4
Vanadium	6000	1750	-	7.75

Source: (Ref. No.8)