PERFORMANCE EVALUATION OF A SOLAR CASSAVA DRYER WITH A SUBSIDIARY HEATING SOURCE

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ABSTRACT

A solar cassava dryer with subsidiary heating source has been designed, constructed and tested. The performance was evaluated as follows: using a load of 60kg, the average efficiency is 41.74% for solar with subsidiary heating and 25.77% for solar drying respectively; using a load of 50kg the solar with subsidiary heating source has an average efficiency of 35.79%, and 29.35% for solar drying. The average drying rates using 60kg load is $2.01x10^{-3}$kg/s, $1.56x10^{-3}$kg/s and $1.09x10^{-3}$kg/s for both solar with subsidiary heating solar drying and open air drying respectively; using 50kg load the average drying rates are $1.44x10^{-3}$kg/s, $0.89x10^{-3}$kg/s and $0.54x10^{-3}$kg/s for solar with subsidiary heating solar drying and open air drying respectively. The results shows that the method of drying using solar with a subsidiary heating had a higher drying rate with higher efficiency, higher initial moisture loss, higher temperatures and less drying time.

SIGNIFICANCE: The knowledge of solar drying is important to predict time reduction in drying compared to other methods, heat transfer rate as well as the quality of the dried product. The study also provides useful information on the effects of slow drying by traditional method.

KEYWORDS: Solar radiation, Drying time, Subsidiary heating, Average efficiency, Drying rate.

1.0 INTRODUCTION

Cassava (monihot esculenta crantz) is a woody shrub of family of **Euphorbiacea** possessing tall, thin and straight stems which when fully grown, attains an average height of 2.4m in 12 – 15 months after planting (RMRDC, 2004). The roots may be up to 100cm long and about 8cm thick depending on the variety and the age of the plant.

Cassava tubers have moisture content of about 75% wet basis, while the average moisture content for safe storage of dried cassava is about 10% (Asiedu, 1989). The essential steps of processing cassava include: peeling, washing, slicing, cutting, grating, drying, grinding and milling. Hence drying is an important operation in the cassava processing and utilization cycle.Solar food drying can be fun, easy and near free due to the abundance of solar radiation on the earth's surface. However, solar food drying is far more practical way of drying your farm produce than open air-drying; hence a research in the design an construction of simple, higher performance cassava dryer to harness the energy of the sun is necessary (Dan-Shehu, 1996).

From the foregoing, considering the constraints of the rural farmers with regards to preserving their products by drying and present interest of Nigerian government in agriculture, it is imperative to develop an efficient drying system for these products.

2.0 LITERATURE REVIEW

Research and development have been conducted in several research institutes in Nigeria. Extensive researches in the field of solar heating and drying have been carried out nation-wide for the drying of agricultural products. An assessment of solar dryer for drying cassava and plantain chips in humid tropics was conducted at Federal University of Technology Akure by Adesuji (1991). Due to the problem of slow drying and moldiness' being encountered in the drying of plantain and cassava chips in humid southern Nigeria, the newly fabricated solar dryer was tested simultaneously with open-air drying method whole solar dryer temperature was over 80°C the combatant temperature was less than 40°C The result obtained showed that the solar dryer was significantly better in drying cassava and plantain chips than present cabinet drying method. It was therefore recommended for use by the farmers and food processors in humid areas of southern Nigeria (Adesuji, 1991).

Oti (1989) designed and fabricated a solar crop dryer at the Mechanical Engineering Department of Kaduna polytechnic, Kaduna. He used the dryer to carry out certain experiment on crop drying, and results indicate that crops like tomatoes (with high moisture content) could efficiently dry within five hours. The drying rate decreases as drying time increases which is obvious because intensity of solar radiation decreases with time. The efficiency of the dryer reaches its peak halfway the drying time and then drops as drying time increases. Therefore, he concluded that applying the technology of solar drying, the needs of rural farmers in Nigeria can be met because they are cost effective and has simple design features.

An experimental study on the performance on different types of cabinet solar drying as well as that of open air drying was conducted at Sokoto Energy Research Centre. In this test four dryers were used namely; direct, indirect, combined (direct and indirect) and combined with rock bed storage. The result shows that the temperature in the dryer compartment rose to a maximum of 60°C. The dryer with rock bed storage was found to be more effective in terms of final moisture content and drying time (Sambo, 1990).

3.0 MATERIALS AND METHOD

3.1 Drying process

The dryer was first tested with load and later without load. Before the beginning of the operation, preparation and pre-treatment of the cassava sample was carried out. Cassava was peeled and palletized to about 15-25mm thick. Kerosene stove containing 1 litre of kerosene was manually pressurized and lightened. The pressurized stove was allowed for 5 minutes until a blue flame appears. A cylinder pot of capacity 3 litres containing 2 litres of fresh water was heated from the kerosene stove so as to generate steam. The steam passed through the heat exchanger, circulated in the drying chamber and returned to the bottom portion of the pot as condensate. The weight of empty trays was recorded and also the weight or trays containing load were recorded. The dry-bulb and wet bulb temperature were recorded hourly. The inlet temperature, outlet temperature and ambient temperature were recorded hourly. The hourly solar radiation was recorded using a solarimeter. Equal weight of cassava was used for comparison of both solar, open air drying and solar with subsidiary heating source and hourly weights were recorded for both. The data were taken from 9.00am to determine the hourly moisture loss, cassava weight loss, relative humidity of dryer and hourly drying rate (HDR) for the three methods of drying.

The drying process was carried out in order to dry cassava with moisture content of 75% to 10%. Mass of water removed can be calculated from (Earle, 1983):

$$M_{wl} = M_c\left[\left(w_i - w_f\right) \big/ \left(100 - w_f\right)\right] \quad ...... (1)$$

Where: Mass of cassava (Mc) =60kg, Percentage moisture content (W_i) =75%, Percentage moisture content of dried cassava (W_f) =10%

The quantity of heat needed to evaporate water is given by the equation

$$Q = M_{wi} \times hfg \quad .... \quad (2)$$

The following calculations were made during the performance evaluation of solar cassava dryer with subsidiary heating source.

3.2 Determination of moisture content

The hourly moisture content of the drying material removed as recorded in tables was calculated as:-

$$M_{WB} = \frac{W_i - W_f}{W_i} \times 100\% \quad \ldots\ldots \quad (3)$$

Where W_i =mass of cassava at start; W_f = mass of cassava after a time.

Hence calculations of the hourly moisture content (M_{WB}) for the dryer during the operation of the solar drying with subsidiary heating source were carried out using the formula above.

3.3 Determination of hourly drying rate (H.D.R)

The hourly drying rates for the different drying operations were calculated as

$$H.D.R = \frac{M_i - M_f}{3600} \quad \ldots \quad (4)$$

Where M_i=initial weight of cassava; M_f=final weight of cassava.

4.0 RESULTS AND DISCUSSION

4.1 Results

The hourly drying rates for the drying of 60kg load of cassava by employing the method of solar drying with subsidiary heating source was used to design the dryer (Table 1).

Table 1: Summary of design parameters

S/N	PARAMETERS	VALUES
1.	Mass of fresh cassava; M	60 kg
2.	Initial moisture content, w_i	75%
3.	Final moisture content, wf	10%
4.	Total mass of water removed, mw	43.33 kg
5.	Latent heat of vaporization of water, hfg	2395 kJ/kg H_2O
6.	Quantity of heat needed to evaporate water, Q	103,775.35 kJ
7.	Average drying rate, Md	4.3 kg/hr
8.	Mass flow rate of air	0.427 kg/s
9.	Heat total heat transfer	857.2 W
10.	Length of heat exchanger pipe, l	10.5m
11.	Amount of kerosene used	0.60 litres
12.	Rate of fuel consumption	0.086 L/hr
13.	Air speed	0.085 m/s
14.	Exit temperature through the chimney	45.02 ^oC
15.	Ambient temperature	25^oC
16.	Calorific value of kerosene	35,000 kJ/L
17.	Quantity of heat produced by burning kerosene	2.94 x 10^{-4} kJ
18.	Volumetric flow rate of air, Va	0.05819 m^3/s
19.	Mass of dry matter	16.27 kg

The dryer was positioned so that the inlet is facing East direction to enhance proper flow of air. The inlet, dryer, outlet and ambient temperatures were presented in Tables 2-7 below.

Table 2: Solar drying of 50kg cassava on 3/02/2010

Time (hrs)	Dryer temp. (°C)	Inlet temp. (°C)	Outlet temp. (°C)	Ambient temp. (°C)	R.H of dryer (%)	Wt of Cas. (kg)	Hrly Wt loss (kg)	Hrly mois. Loss WB (%)	H.D.R (kg/s)X10^{-3}	Incident solar radiation I (W/m^2)
9.00	38	24	28.5	22.5	62	50				367.02
10.00	42	28	30	25	56	44.8	5.2	10.4	1.44	496.65
11.00	42.5	31.5	33	26.1	48	36.5	8.3	16.6	2.30	731.43
12.00	44	32	34.5	30	51	32.5	4	8.0	1.10	848.82
13.00	47	35	35.5	32	49	30	2.5	5.0	0.70	966.21
14.00	49	35.5	38	33.5	40	29	1.0	2.0	0.30	884.94
15.00	52	35	38.5	31	38	28.2	0.8	1.6	0.20	785.61
16.00	49.5	34	37	24.8	44	27.5	0.7	1.4	0.19	749.49
17.00	47.5	33.6	35.4	24.1	30	27.5	0.0	0.0	0.0	415.38

Mean inlet temp. = 32.07°C; Mean ambient temp. =27.28°C; Mean dryer temp. =46°C; Mean outlet temp. =34.49°C; Mean solar radiation = 694W/m^2

Table 3: Open air drying of 50kg cassava on 3/02/2010

Time (hrs)	Ambient temp. (°C)	Wt of Cas. (kg)	Hrly Wt loss (kg)	Hrly mois. Loss WB (%)	H.D.R (kg/s)X10^{-3}	Incident solar radiation I (W/m^2)
9.00	22.5	50				367.02
10.00	25	46.5	3.5	7.0	0.9	496.65
11.00	26.1	41.5	5	10.0	1.39	731.43
12.00	30	38.4	3.1	6.2	0.86	848.82
13.00	32	36.5	1.9	3.8	0.53	966.21
14.00	33.5	35.7	0.8	1.6	0.22	884.94
15.00	31	35.2	0.5	1.0	0.14	785.61
16.00	24.8	34.7	0.5	1.0	0.14	749.49
17.00	24.1	34.3	0.4	0,8	0.11	415.38
18.00	23.8	34.3	0.0	0.0	0.00	343.14

Mean solar radiation = 694W/m^2, Mean ambient temp. = 27.28°C.

Table 4: Drying of 50kg cassava using solar drying and auxiliary heating on 4/02/2010

Time (hrs)	Dryer temp. (°C)	Inlet temp. (°C)	Outlet temp. (°C)	Ambient temp. (°C)	Wt of cas. (kg)	Hrly wt loss (kg)	Hrly mois. Loss (%)	H.D.R (kg/s)X10^{-3}	Incident solar radiation I (W/m^2)
9.00	28	20.5	22.5	19	50				357.02
10.00	30.5	22.0	23.8	21.2	42.5	7.5	15.00	2.08	470.53
11.00	34.5	24.6	25	24.0	31.2	11.3	22.60	3.14	715.31
12.00	35.2	28.0	29.6	27.5	25.6	5.6	11.20	1.56	842.70
13.00	39.3	30.0	31.5	29.3	22.5	3.1	6.20	0.86	950.09
14.00	40.5	32.5	34	31.5	20.3	2.2	4.40	0.61	868.82
15.00	41.5	33.4	36.5	31.8	18.0	1.3	2.60	0.36	759.49
16.00	41	31.8	35.4	30.5	19.0	0.0	0.00	0.00	743.37
17.00	39.5	29.5	31.5	28.5					399.26
18.00	35.8	28.7	30.0	28.2					355.08

Mean solar radiation =647.2W/m^2; Mean inlet temp. = 28.1°C; Mean ambient temp. =27.15°C; Mean dryer temp. = 36.90°C; Mean outlet temp. = 29.98°C.

Table 5: Drying of 60kg cassava using solar drying and auxiliary heating on 5/02/2010

Time (hrs)	Dryer temp. (°C)	Inlet temp. (°C)	Outlet temp. (°C)	Ambient temp. (°C)	Wt of cas. (kg)	Hrly wt loss (kg)	Hrly mois. Loss (%)	H.D.R (kg/s)X10^{-3}	Incident solar radiation I (W/m^2)
9.00	29.5	24	26.5	21.5	60				343.14
10.00	33.5	27.5	29	26.0	47.5	12.5	20.83	3.5	478.59
11.00	36	30.2	32.3	28.5	35.8	11.7	19.5	3.25	713.37
12.00	38.5	33.4	35	31	28.7	7.1	11.83	1.97	830.76
13.00	41.5	36.5	37.2	32.5	23.5	5.2	8.67	1.44	948.15
14.00	46	37	39.5	34	18.6	4.9	8.17	1.36	866.88
15.00	48.5	37.3	41	34	16.5	2.1	3,5	0.58	767.55
16.00	45.5	35	37.5	33.2	16.5	0.0	0.0		731.43
17.00	41	31.5	33	30					379.32

Mean solar radiation = 675.24W/m^2; an outlet temp. =34.57°C; Mean dryer temp. = 40°C; Mean inlet temp. =32.49°C; Mean ambient temp. =30°C.

Table 6: Open air drying of 60kg cassava on 5/02/2010

Time (hrs)	Amb. Temp. (°C)	Wt of cas. (kg)	Hrly wt. Loss (kg)	Hrly mois. Content W.B (%)	H.D.R (kg/s)X10^{-3}	Incident solar radiation I (W/m^2)
9.00	21.5	60				343.14
10.00	26	53	7	11.7	1.94	478.59
11.00	28.5	46.5	6.5	10.8	1.81	713.37
12.00	31	41	5.5	9.2	1.53	830.76
13.00	32.5	37	4	6.7	1.11	948.5
14.00	34	33.5	3.5	5.8	0.97	866.88
15.00	34	30.5	3	5	0.83	717.55
16.00	33.2	29.0	1.5	2.5	0.42	731.45
17.00	30	28.7	0.3	0.5	0.08	392.32
18.00	29.6	28.7	0.0	0.0	0.00	397.32

Mean solar radiation = 675.24 W/m^2, Mean ambient temp. =30°C

Table 7: Solar drying of 60kg cassava on 6/02/2010

Time (hrs)	Dryer temp. (°C)	Inlet temp. (°C)	Outlet temp. (°C)	Ambient temp. (°C)	Wt of cas. (kg)	Hrly wt loss (kg)	Hrly mois. Loss (%)	H.D.R (kg/s)X10^{-3}	Incident solar radiation I (W/m^2)
9.00	30	23	25	22	60				343.14
10.00	33.5	25.5	27	24	51.5	8.5	14.2	2.4	478.59
11.00	35.5	27	28.5	25.5	44	7.5	12.5	2.1	713.37
12.00	38.5	30	31.5	28.5	37	7.0	11.7	1.9	830.76
13.00	41.2	32.5	34	31	32	5.0	8.3	1.4	948.15
14.00	43.5	34	40	32.5	27.3	4.7	7.8	1.3	866.88
15.00	45.0	31.5	38	29	23.5	3.8	6.3	1.1	767.55
16.00	42.5	27.5	32.5	23.5	21	2.5	4.2	0.7	731.43
17.00	40.5	25	29.6	22.8	21	0.0	0.0	0.0	397.32

Mean solar radiation = 675.24W/m^2; Mean outlet temp. =32.23°C; Mean dryer temp. = 38.91°C; Mean inlet temp. =28°C; Mean ambient temp. =26.5°C.

4.2 Discussion of results

The results obtained in the drying process as shown in Tables 2 to 7, were used to evaluate the performance of solar drying with subsidiary heating. The results of the drying operations from 4th to 9th December 2009, 3rd; 4th and 5th February 2010 are shown in Figure 1. The dryer temperature attained for the dual heating system is higher than that of solar and open air. On the average, the efficiency of solar heating at 60kg was 25.77%. But when the operation of dual cassava heating was considered with respect to this load it could be seen that the efficiency was 41.74% respectively. The drying rate decreases as the drying time increases as shown in Tables 2 to 7.

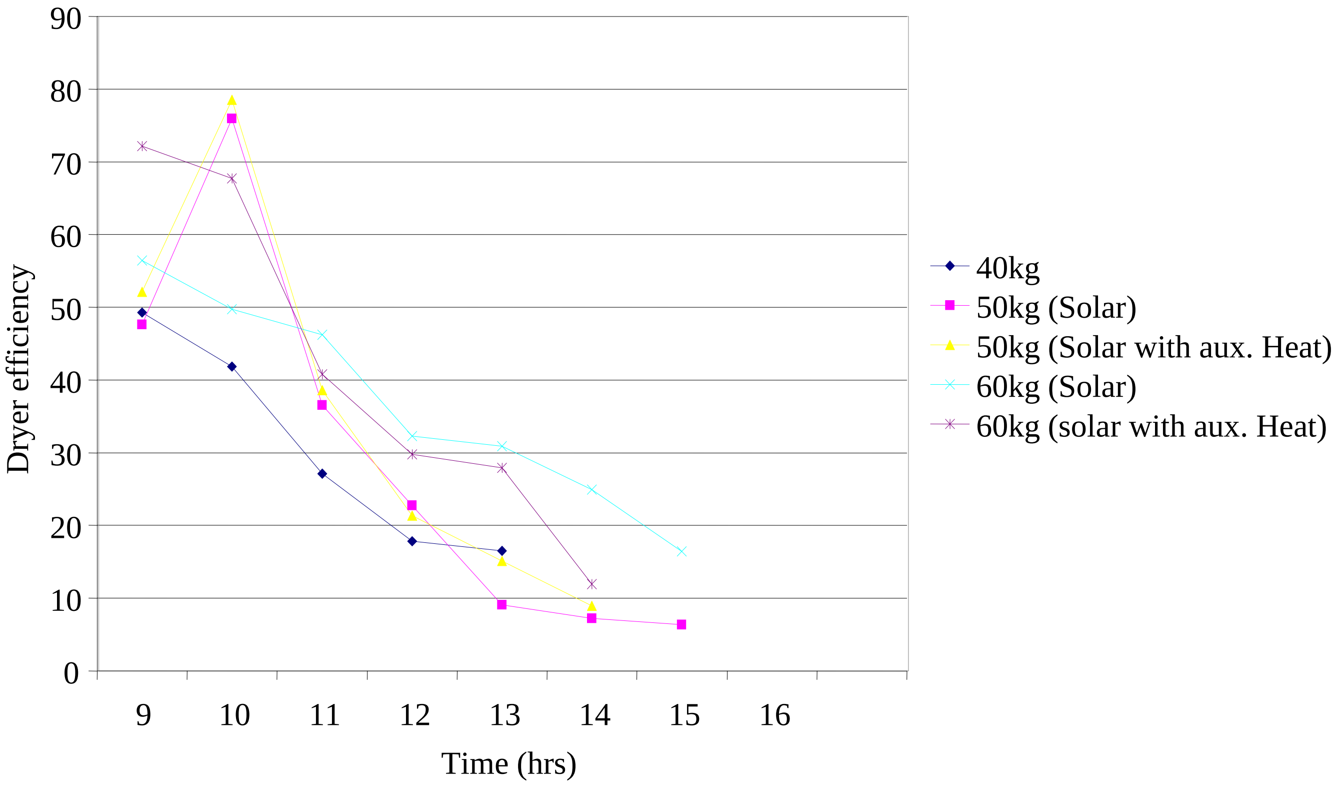

Figure 1: Variation of dryer efficiency with time

5.0 CONCLUSION

A solar cassava dryer with a subsidiary heating source of 60kg capacity was design, constructed and tested. The possibility of contamination with foreign particles as in open air drying was eliminated, since the chamber is an enclosed unit. The performance of the dryer revealed its ability to attain high temperatures than open air and solar drying methods. Hence, on comparison the two other methods it indicated that the solar drying with auxiliary heating has shorter drying time as indicated in Figure 1.

The average weight loss during the drying of 60kg cassava are 7.25kg, 5.57kg and 3.91kg for dual heating system, solar drying and open air drying respectively. These values indicate that the dual heating system removes more moisture than the other two methods. The hourly drying rate for all kind of loading indicate that the rate of drying are higher when using dual heating than solar and open air drying.

REFERENCES

Adesuji S. A. (1991); "Assessment of Solar Dryer for drying Cassava and Plantain Chips in Humid Tropics" Nigerian Journals od Solar Energy Vol. 10 p. 8.

Danshehu B. G., Musa M. and Atiku A. T. (1996); Design and Development of 2-Tonnes Multibooster Solar Dryer. Proceeding of World Renewable Energy Congress Vol. 3 (Ed) Pp. 15-21 Dancer. Colarado USA.

RMDC (Raw Material Research and Development Council), (2004); Cassava Report on Survey of Agro

Raw-Materials in Nigeria; Federal Ministry of Science and Technology. Abuja.

Earle R. L. (1983); "Unit Operation in Food Processing" NIZIFST Inc. Pp 1-40.

Oti, M. I. (1983); Design, manufacture and performance evaluation of solar crop dryer. Nigerian Journal of Solar Energy Vol. 8 pp 194.

Chakravanty A. (2006); Post Harvest Technology of Cereals, pulses and oil seeds. 3rd edition pp 65-87.