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Performance Evaluation of a Developed Multipurpose Solar Dryer

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ABSTRACT

Post-harvest losses in developing countries have contributed to the unavailability of foodstuff. Estimation of these losses is generally cited to be of the order of 4% but under very adverse conditions, it is estimated as high as 100%. A significant percentage of these losses are related to improper and/or untimely preservation of foodstuffs. This research work is therefore aimed at developing a multipurpose solar dryer. The solar dryer consists mainly of solar collector and dryer chamber compartment. The materials used in this research work include based frame, transparent fiberglass cover, an absorber (oven baked Aluminium), thermometer, wire gauze, etc. The frame was constructed from a wood bars with a dimension of 900 mm x 900 mm x 600 mm. The dryer chamber is a truncated rectangle and it comprises of a double walls made up of a plain ply board measuring 800 mm x 800 mm x by 500 mm with a transparent fiberglass cover inclined at an angle of 15o. Three different samples namely sample A (sliced plantains), sample B (sliced yams), and sample C (fish) were used for test performance evaluation of the developed multipurpose solar dryer. The results obtained reveal that overall heat energy transfer coefficient of 4.91w/m0C, dryer chamber rate of 0.654 kg/hr., and dryer chamber area of 0.659 m2 were required by the solar dryer. Besides, the solar dryer dried the three samples used in this research work within duration of 8 hours (i.e., 9am-5pm). The maximum solar chamber dryer temperature and ambient temperature were recorded as 55.00 oC and 35.46 oC respectively. Besides, the minimum lower temperature values recorded were obtained as 40.45 oC for solar chamber dryer temperature and 29.02 oC for ambient temperature. The improved results obtained with the multipurpose solar dryer were due to improved temperature obtained with the solar dryer chamber.

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KEYWORDS: *Multipurpose solar dryer, solar dryer chamber, ambient temperature, renewable energy, wood fuel*

I. INTRODUCTION

Energy is a major challenge in Nigeria and this has huge effect on the nation economy. The major source of energy in Nigeria is fossil fuel and wood fuel which had led to deforestation and environmental pollution [1-4]. Despite the huge annually solar energy obtained by earth and Nigeria good location that lies between latitudes 40 and 140N, and longitude 20 and 150E of the equator, drying of food crops, fishes, meats, etc., are usually carried out using smoking techniques via fire wood as depicted in Fig. 1.

Fig.1 Drying of fish using smoke from fire wood

Nigeria is located in a tropical hot climate and she receives an average of about 3.5kwh/m^2/day (12.6MJ/m^2/day) in the coastal latitudes and about 7.0kwh/m^2/day (25.2MJ/m^2/day) in far north of the country of incident solar energy [5-6]. Nigeria has an average of 1.804 x 10^{15}kwh of incident solar energy annually [2,6]. The sun is the most powerful heat generator with which neither of the heat sources created by mankind can compete. It means that only a tiny part of solar energy is used for the sake of mankind [7]. Solar energy has been used to dry foods for thousands of years. Solar energy translates to heat during the drying process, so whether product is laid out in the sun (ambient) or placed in a dryer, the heat for drying comes from the same source [8-12].

According to Bassey [13], drying is a dual process of heat and mass transfer of moisture from the interior of the product tothe surrounding air. Michael [14] stated that drying involves the extraction of moisture from the product by heating and the passage of air mass around it to carry away the released vapor. However, the basic essence of drying is to reduce the moisture content of the product to a level that prevents deterioration within a certain period of time as reported by Ezeike [15]. They also reported that thermal drying involves vapourization of water within a product by heat and then evaporation of that moisture from the product. Moreso, drying continues until the vapour pressure of the moisture within a product equals the vapor pressure of the atmosphere, or equilibrium moisture content. Michael [14] has shown that drying under ambient conditions is slow because the process is controlled by the environmental factors of relative humidity and heat, and thus is dependent on local weather conditions. However, this problem can be compounded when a region has a high relative humidity because the equilibrium moisture content will be higher and products cannot be dried to the desired levels [16]. Thus, a solar dryer is designed to increase the heat within the system, which in turn increases the vapour pressure of the product. This increases the moisture content carrying capacity of the air within the dryer, inherently speeding up the drying process because the equilibrium moisture content is much lower.

II. MATERIALS AND METHODS

A. Design Consideration

The following design considerations were drawn:

1. Size of the multipurpose solar dryer
2. Air vent
3. Materials used for the multipurpose solar dryer
4. Effect of temperature variation in the system
5. Functionality of the multipurpose solar dryer
6. Aesthetics of the multipurpose solar dryer
7. Overall size of the multipurpose solar dryer
8. The dryer chamber

B. Design Specification

1. The temperature of the dryer chamber may reach 55^{0}C on a hot sunny day.
2. The solar dryer has a low flow rates through the collector.
3. The dryer chamber has a dimension of 800mm× 800mm x 500 mm.
4. The multipurpose solar dryer is portable for easy carriage.
5. A fiberglass of thickness 6mm and surface area of 0.64m^2 is required.

C. Materials Used

The materials used in this research work are as follow:

1. Base Frame
2. The Dryer Chamber
3. The flat plate solar collector
4. Transparent cover (glass)
5. An absorber (oven baked Aluminium)
6. Wire gauze
7. Carriage

Table 1 shows the summary of materials and equipment used.

Table1. Summary of Materials and Equipment Used

Part	Material/ Equipment Used	Justification/Functions
Dryer Chamber Compart-ment	Wood, Ply board, & transparent fiberglass	Is a good insulator. Wood has a thermal conductivity of 0.15 – 0.2w/m^{2}k. It helped to minimise the heat loss to the surrounding. Attached in the dryer chamber is the air inlet vent that allows the entry of clean natural convection into the system in order to aid drying. It enters the collector from the absorber plate to dehydrate the crops and permit the exit of the resulting damp air through the outlet vents. The air outlet vent allows airflow from the dryer chamber to the atmosphere. The transparent fiberglass is used to cover the dryer chamber.
Solar Collector Compart-ment	Transparent fiberlass, Oven baked Aluminium painted black	The transparent fiberglass is highly transparent to the sun, it transmit short wave radiation but completely opaque to the long wave radiation emitted by the heated collector plate. The transparent glass permits the solar radiation into the system but resist the flow of heat energy out of the system. Aluminium plate has good absorptive surface for solar radiation. It absorbs both direct and diffusion radiation. The surface has high absorptions for solar radiation and low emission for long wave radiation.
Thermo-meter	GESA Thermometer	It has the ability to measure minimum and maximum temperature range
Wire gauze	Black painted mesh stainless steel	Good conductor of heat. The foodstuffs to be dry are put on the wire gauze so that heated air from the collector can easily pass through the gauze and consequently cause drying.

D. Description of the Multipurpose Solar Dryer

The base frame of the solar dryer was constructed using a 2 by 2 wood bars and a ply board with thick of 6 mm. The solar dryer has a dimension of 900mm x 900mm x 600mm. The dryer chamber is a truncated rectangle properly laminated and equally insulated with ply board and fiberglass. It has an additional double walls made up of a plain ply board painted black with transparent fiberglass. Attached is air inlets vent which is located at the top and bottom end, and this allows air flow into the chamber. The solar dryer has a perforation of 10 mm diameter which allows the moist air out of the drying chamber. Also, at the top of the chamber is a hinged main door which permits easy access to the dryer cage. A flat plate collector was fixed in a south-facing position (in the northern hemisphere) and tilled upward from the horizontal at an angle (θ=15^0). The flat plate collectors consists of a plain transparent glass, oven baked aluminium absorber. The function of the transparent plain glass is to transform the short wave radiant energy from the sun into thermal/heat energy which is properly absorbed by the oven baked aluminium absorber and mesh stainless steel gauze that are painted black. This ray comes in wavelength between 0.3um (ultraviolet) and 3.0um (infrared). They are incident on the glass cover of the multipurpose solar dryer. The glass is of relative permittivity; hence, it allows only short wavelength radiation of up to 2.0um through it.

However, the longer radiation wavelength is reflected. The infrared radiation that penetrates into the chamber does the job of drying. The collector plate absorb and collectors radiant heat setting molecules within the collector motion, which constitute a change for increasing temperature. Oven baked aluminium plate, painted black that contains carbon black or graphite was used because it has large surface exposure to the radiant energy. Besides, the cost is considerable and thermal conductivity is high (229W/mk). Also, its absorptivity for solar radiation (L-0.5\Nm) is 0.15 and for low temperature radiation. Drying of crops and fishes take place in the dryer chamber. The dehydration process is to reduce the water content of the items to a point where it can no longer support the growth of micro-organisms. Research has shown that organisms, bacteria and yeasts cease to multiply in the perishable items once the water content is less than 25% of the total body weight and moulds when it is less than 15%. The dryer chamber has an opening, which can be locked or opened with a hinged door and this facilitates the easy sliding in and out of the wire gauze containing the items to be dry.

E. Design Calculation

The rate of dryer chamber is given by Equation (1)

$$D_C = \frac{B_I \times M_{ci} - B_f \times M_{cf}}{100 \times T} \qquad (1)$$

where;

D_C = Rate of dryer chamber

B_i = Initial batch weight

M_{ci} = Initial moisture content of sample

B_f = Final batch weight

M_{cf} = Final moisture content of sample

T = Estimated drying time

The quantity of energy required to initiate evaporation is given by Equation (2)

$$Q_i = M \times C_w \times \Delta T \qquad (2)$$

where;

Q_i = Energy to initiate evaporation

M_{cw} = Specific capacity of water

ξ = Emissivity of the sun as a grey body

ΔT = Change in temperature

The drying chamber area is given by Equation (3)

$$D_C = (L \times B \times H) + \frac{1}{2} Bh \sin\theta \qquad (3)$$

where.

L = Length of the dryer chamber

B = Breadth of the dryer chamber

H = Height of the dryer chamber

θ = Tilted angle of the glass

The rate of energy radiation from the sun is given by Equation (4);

$$E_S = \xi \times \sigma \times T_3^4 \qquad (4)$$

where,

E_s = Rate of energy radiation from the Sun

ξ = Emissivity of the sun as a grey body

σ = Stefan Boltzman constant given as 5.67×10^{-8} w/m^{2}k^4

T^4 = Temperature of radiant energy from the Sun

$E_{sun} = 5.67 \times 10^{-8}\, T^4$

But for grey bodies, emissivity ranges from zero (0) to unity (1) or equal to 1 [17]

The rate of energy radiation is given by Equation (5);

$$E_g = \alpha_g \times \sigma \times T_g \qquad (5)$$

where,

α_g = Absorptivity

T_g = Ambient temperature

The solar collector useful heat gained is given by Equation (6) and Equation (7)

$$Q_C = K_g A_g (T_o - T_{in}) \qquad (6)$$

$$Q_C = h_a A_c (T_{in} - T_d) \qquad (7)$$

where,
K_g = Thermal conductivity
A_g = Surface area of the solar collector
T_o = Temperature of the sun on the outer surface of the collector in °C.
T_{in} = Temperature of collector inner surface
h_a = Convective heat transfer coefficient of air (40w/m²°C)
A_c = Area of dryer chamber
T_d = Design Temperature of the dryer chamber 80°C

The overall heat transfer coefficient is given by Equation (8)

$$U_T = \frac{1}{R_T A} = \frac{1}{U} = \frac{1}{h_g A_c} + \frac{X_g}{K_g A_g} \quad (8)$$

where,
X_g = Thickness of solar collector
h_g = Convective heat transfer of air 40w/m²k

F. Multipurpose Solar Dryer Configuration

Fig. 2 shows the dimensioned view of the solar plate collector

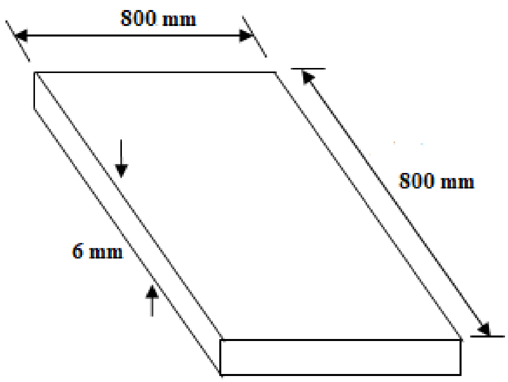

Fig. 2Dimensioned View of the Solar Plate Collector

Fig. 3 shows the dimensioned view of the frame and dryer chamber.

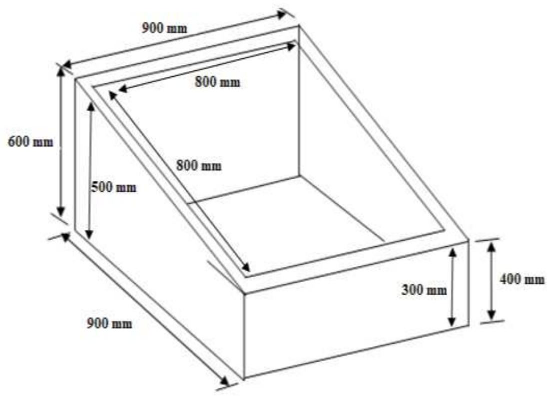

Fig. 3 Dimensioned Views of the Frame and Dryer Chamber

Fig. 4 shows the pictorial view of developed multipurpose solar dryer.

Fig. 4 Pictorial View of Developed Multipurpose Solar Dryer

III. Experiment and Result

The developed multipurpose solar dryer was evaluated for performance using sliced plantains (Sample A), sliced yams (Sample B) and fish (Sample C). In each case, the initial weight of the samples was measured using a universal weighing balance. The samples were then placed on the wire gauze inside the dryer chamber for drying to take place. GESA thermometer was used to monitor the ambient and solar dryer chamber temperature. The weight of the samples was measured hourly and the corresponding temperature was recorded. The results obtained were tabulated as shown in Table 2, Table 3, and Table 4 respectively. The percentage moisture content was calculated using Equation (9)

$$M_C = \frac{W1-W2}{WI} \times 100 \qquad (9)$$

where,
W_1= Initial weight of sample
W_2 = Final weight of sample
M_C = Percentage moisture content
T_A = Ambient temperature
T_{SCD} = Solar chamber dryer temperature

The result of the test shows a satisfactory overall heat energy transfer coefficient of 4.91w/m^{o}C. The dryer chamber rate was evaluated as 0.654 kg/hr. The area of the dryer chamber was calculated as 0.659 m^2. Fig. 5 shows the plot of weight of sliced plantain (Sample A) before and after drying against drying time. It can be deduced that the weight lost as aresult of moisture in the sliced plantain increases gradually as drying continued throughout the duration of drying. Also, minimal moisture lost was observed in the initial first three hours in comparison to the rest hours. This variation can be attributed to lower temperature recorded in the first three hours. Furthermore, there was a steady decreased in the weight of the sliced plantain and this simply shown the effectiveness of the multipurpose solar dryer. These results agree with the work of Enibe [18] that reported improved temperature readings led to proper drying of crop. According to him, a temperature drops below 41^{0}C leads to drop in drying efficiency. Fig. 6 shows the plot of temperature readings against duration of drying for sample A. From the plot, it can be deduce that better temperature readings were achieved with the solar chamber dryer. Throughout the test, the ambient temperature readings were lower. The maximum solar chamber dryer temperature and ambient temperature were recorded as 55.00 ^{o}C and 35.46 ^{o}C respectively. On the other hand, the minimum lower temperature values recorded were obtained as 40.45 ^{o}C for solar chamber dryer temperature and 29.02 ^{o}C for ambient temperature. Fig. 7 shows the graph of percentage moisture content against duration of drying for sample A. It can be deduced that there was a steady increase in the percentage moisture content of sample A and this can be credited to the effectiveness of the multipurpose solar dryer. Fig. 8 shows the variation of weight loss of sliced yam (Sample B) with drying time duration in hours. It was further confirmed that variation in temperature has huge effect on the drying process of sample B. Thus, more weights were lost with a higher temperature variation. Although, more weight loss was obtained when compared to sample A and this could be as a result of more moisture content associated with sample B than sample A since the same weight of samples is used and exposure was carried out within the same environmental condition of temperature. Fig. 9 shows the graph of weight of fish (sample C) before and after drying against duration of drying in hours. Just as in case of sample A and sample B, steady increased in weight loss was achieved. However, unlike case sample A and sample B, the losses recorded were higher with sample C and this can be attributed to higher moisture content. Thus, higher average percentage moisture content was achieved with sample C, followed by sample B, and sample A as depicted in Fig.10. In general, the improved results obtained with the multipurpose solar dryer were due to improved temperature obtained with the solar dryer chamber.

Table 2 Sliced Plantain (Sample A)

Test	W_1(kg)	W_2 (kg)	%M_C	T_A (^{0}C)	T_{SCD} (0C)	Duration of Drying (Hrs.)
1	1.05	1.02	2.86	29.02	45.08	11.00 am-12.00pm
2	1.05	0.90	14.29	32.15	54.95	12pm-1.00pm
3	1.05	0.88	16.19	34.55	55.00	1.00pm-2.00pm
4	1.05	0.70	33.33	35.45	54.16	2.00pm-3.00pm
5	1.05	0.65	38.10	34.07	45.34	3.00pm-4.00pm
6	1.05	0.62	40.95	34.85	42.54	4.00pm-5.00pm
7	1.05	0.60	42.86	32.95	40.45	5.00pm-6.00pm
∑	7.35	5.37	188.58	233.04	337.52	7 Hours
Ave.	1.05	0.77	26.94	33.29	48.22	I hour

Table 3 Sliced Yams (Sample B)

Test	W_1(kg)	W_2 (kg)	%M_C	T_A (^{0}C)	T_{SCD} (0C)	Duration of Drying (Hrs.)
1	1.05	1.00	4.47	30.02	44.08	11.00 am-12.00pm
2	1.05	0.89	15.24	32.15	53.20	12pm-1.00pm
3	1.05	0.85	19.05	34.65	54.98	1.00pm-2.00pm
4	1.05	0.65	38.10	35.45	54.76	2.00pm-3.00pm
5	1.05	0.58	44.76	34.07	53.34	3.00pm-4.00pm
6	1.05	0.56	46.67	34.55	44.54	4.00pm-5.00pm
7	1.05	0.55	47.62	33.95	41.45	5.00pm-6.00pm
∑	7.35	5.08	215.91	236.84	346.35	7 Hours
Ave.	1.05	0.73	30.84	33.83	49.48	I hour

Table 4 Fish (Sample C)

Test	W_1(kg)	W_2 (kg)	$\%M_C$	T_A (^{0}C)	T_{SCD} (0C)	Duration of Drying (Hrs.)
1	1.05	0.95	9.92	31.02	45.08	11.00 am-12.00pm
2	1.05	0.81	22.86	32.15	53.20	12pm-1.00pm
3	1.05	0.72	31.43	34.65	54.95	1.00pm-2.00pm
4	1.05	0.60	42.86	35.46	54.99	2.00pm-3.00pm
5	1.05	0.53	49.52	35.07	53.34	3.00pm-4.00pm
6	1.05	0.52	50.48	34.85	42.54	4.00pm-5.00pm
7	1.05	0.45	57.14	33.95	41.45	5.00pm-6.00pm
∑	7.35	4.58	264.21	237.15	345.55	7 Hours
Ave.	1.05	0.65	37.74	33.88	49.36	I hour

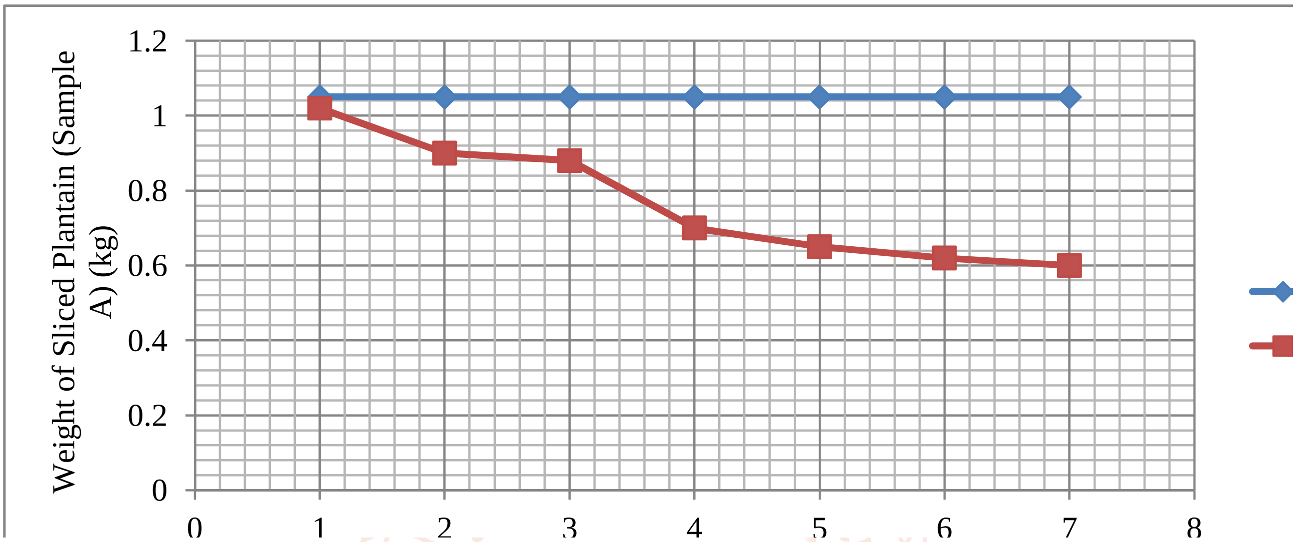

Fig. 5 Graph of Weight Variation of Sliced Plantain (Sample A) against Duration of Drying

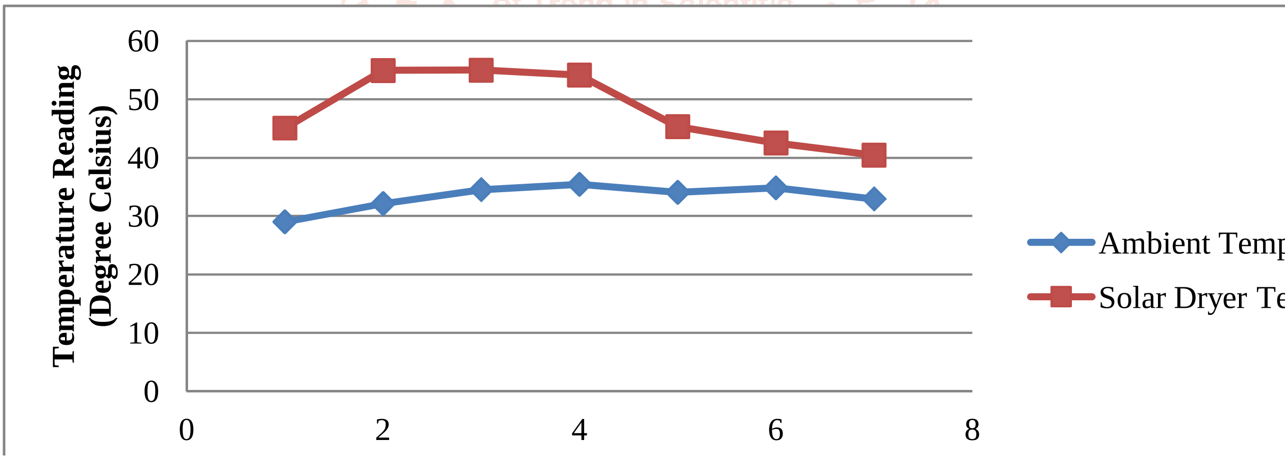

Fig. 6 Graph of Temperature Readings against Duration of Drying for Sliced Plantain (Sample A)

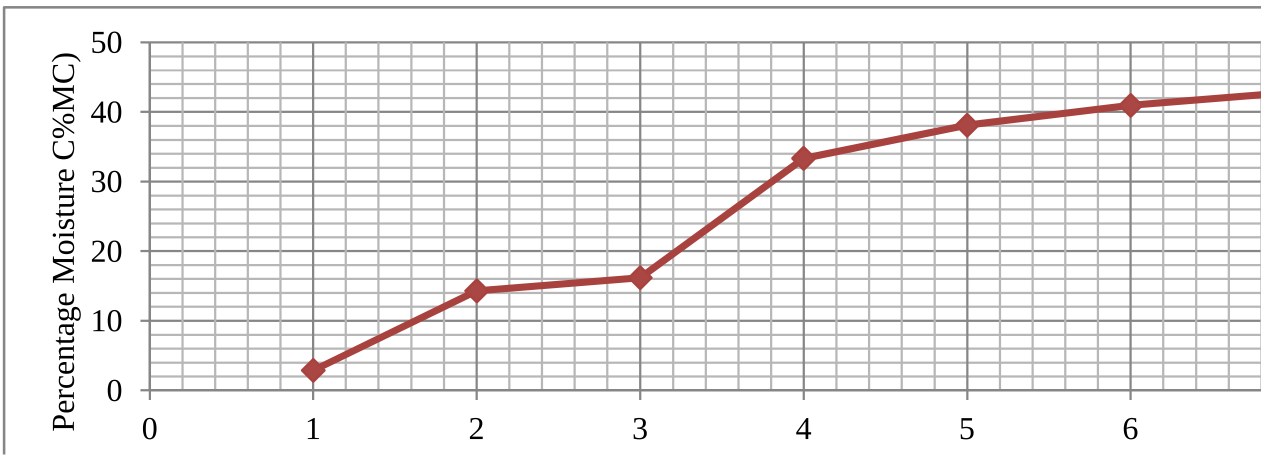

Fig. 7 Graph of Percentage Moisture Content against Duration of Drying for Sliced Plantain (Sample A)

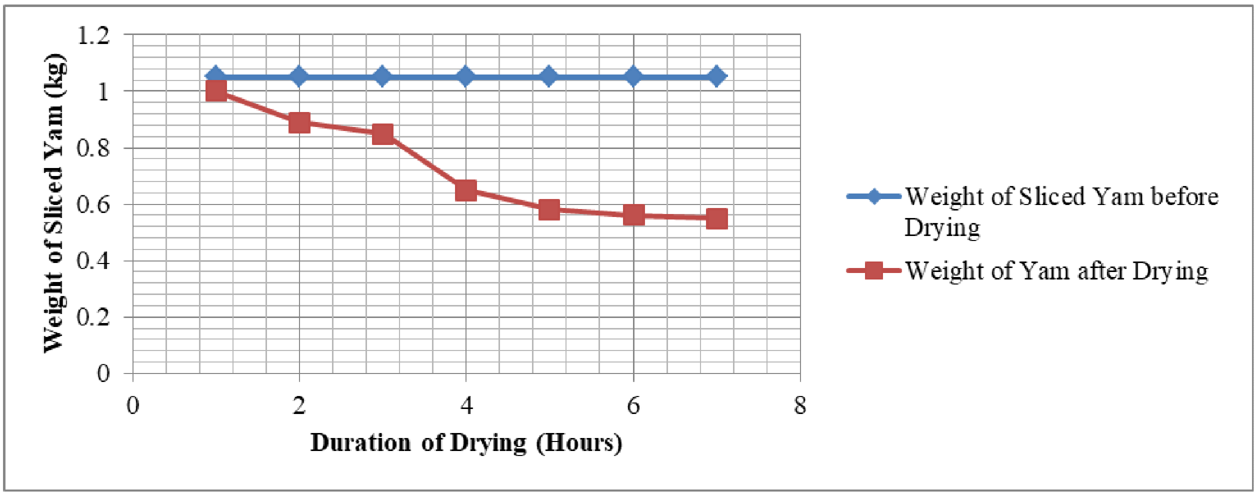

Fig. 8 Graph of Weight Variation of Sliced Yam (Sample B) against Duration of Drying

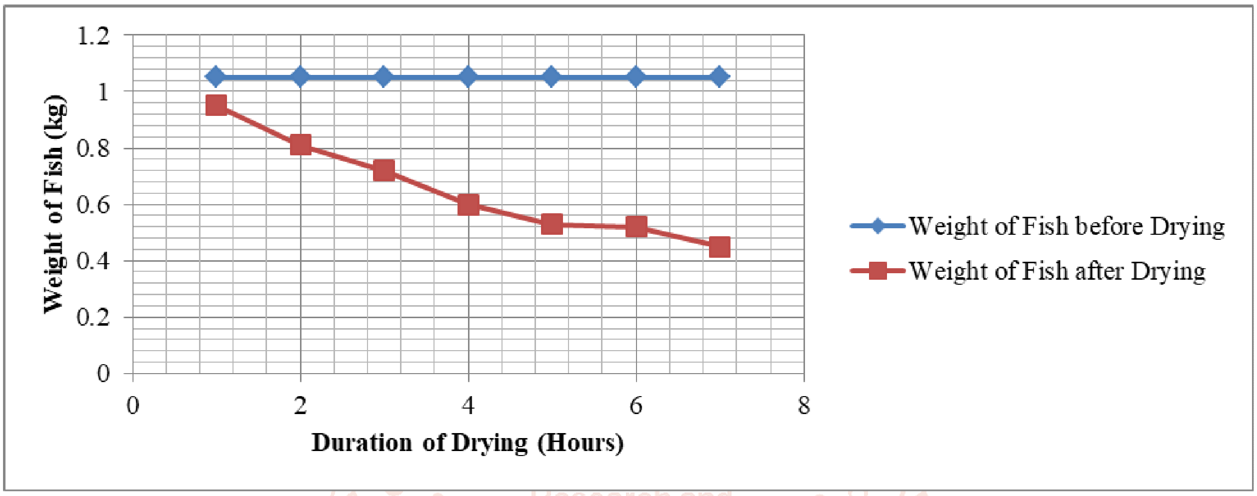

Fig. 9 Graph of Weight Variation of Fish against Duration of Drying

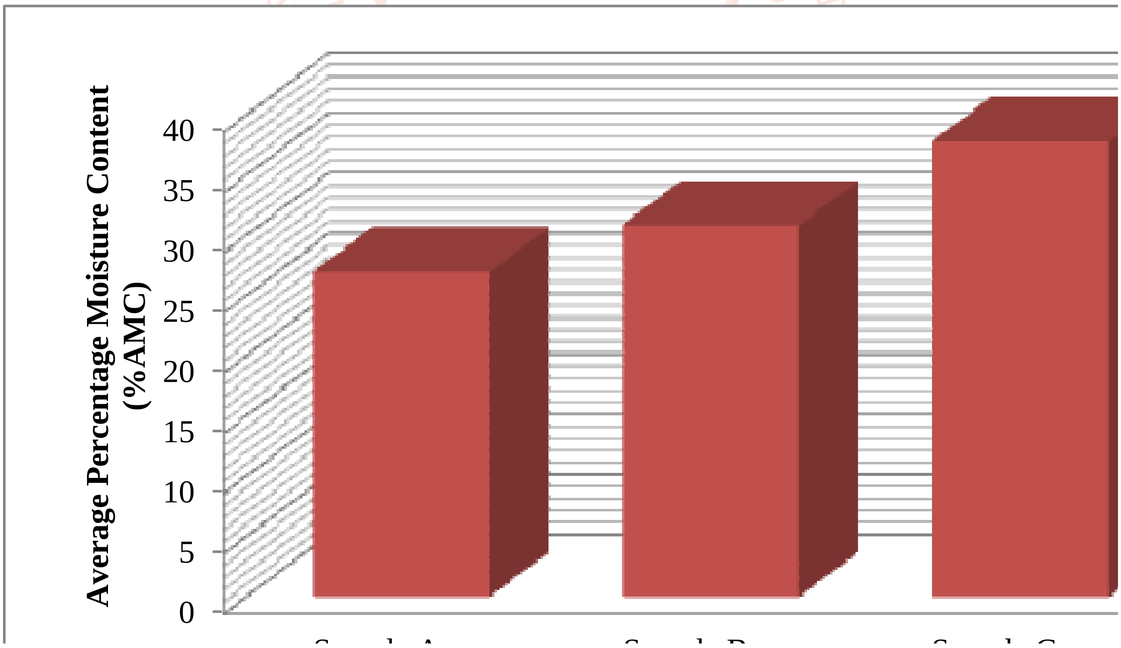

Fig. 10 Bar Chart of Average Percentage Moisture Content

IV. CONCLUSION

A multipurpose solar dryer was developed for drying of crops and fish. The developed solar dryer makes use of the sun energy, which is renewable and none polluting. Besides, it does not required difficult construction techniques. It was evaluated for performance and the result of the test shows a satisfactory overall heat energy transfer coefficient of $4.91 w/m^{2 0}C$. The dryer chamber rate was evaluated as 0.654 kg/hr and the area of the dryer chamber was obtained as 0.659 m^2. The dryer was able to properly dry the three samples used via sliced plantains, sliced yams, and fish. The samples were properly dried within the duration seven (7) hours of experimentation. Also, the colour and texture of the samples after drying were satisfactory.

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