Design and Construction of an Adjustable and Collapsible Natural Convection Solar Food Dryer

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ABSTRACT

A new model of a box type adjustable and collapsible natural convection solar food dryer, capable taking 14,688 pieces equivalent to 16.52kg of fresh groundnut with maximum moisture content of 35%, maximum capacity of 3.39m^2, and 3,672 pieces equivalent to 4.06kg of groundnut at minimum capacity 0.8475m^2, was designed and constructed using locally available materials.

KEY WORDS : *Adjustable, Collapsible, Solar, Food Dryer*

I. INTRODUCTION

Drying is one of the oldest methods of food preservation. For several thousand years, people have been preserving dates, figs, apricots, grapes, herbs, potatoes, corn, milk, meat, and fish by drying. Until canning was developed at the end of the 18th century, drying was virtually the only method of food preservation (Ekechuku & Norton, 1999; Whitefield,2000). The dried fruits and vegetables are lightweight, do not take up much space and do not require refrigerated storage. The food scientist have found that by reducing the moisture content of food to between 10% and 20%, bacteria, yeast, moulds and enzymes are all prevented from spoiling it since micro organisms are effectively killed when the internal temperature of food reaches 14 ^{o}f (Harringshaw,1997). The flavor and most of the food nutritional value of dried food is preserved and concentrated (Scalin,1997). Moreover dried food does not require any special storage equipment and are easy to transport (Scalin1997). In ancient time of alchemy, drying was by natural "sun drying" and today in most rural communities of developing countries it is still being practiced. The diverse crops are spread on the ground and turned regularly until sufficiently dried so that they can be stored safely.

Direct sun drying is associated with numerous shortcomings, as products are affected by ultraviolet radiation, dust, rain showers, morning dews, animal and human interference, to mention but a few. In addition, open sun drying is slow, has no quality control and has a risk of contamination, creating a potential health hazard. The product's quality is seriously degraded, sometimes to the extent that they are inedible (Whitefeild,2000;Diamante & Munro 2004). These caused huge post harvest losses and significantly contributed to non availability of food in some developing countries. Estimation of these losses are generally cited to be order of 40%, but they can be nearly 80% (Bassey,1989; Togrul and Pehlivan,2004). Artificial mechanical drying method such as electric dryers, wood fueled dryers and oil burn dryers were therefore introduced mostly in developing countries (Nejat.1989). However increase in the cost of electricity and fossil fuel has made these dryers very non-attractive. Although the spreading of the crop on the ground or on a platform and drying it directly by sun drying is cheap and successfully employed for many products throughout the world, where solar radiation and other climatic conditions are favorable, because of the disadvantages of open-air sun drying process, high cost of mechanical drying mentioned above and a better understanding of the method of utilizing solar energy to advantage, have given rise to a scientific method called solar drying (Aklilu.2004). In solar drying, solar dryers are specialized device that controls the drying process and protect agricultural produce from damage by insect, pest, dust and rain, and in comparism to the natural sun drying, solar dryers generates higher temperatures lower relative humidity, lower produce moisture content, and reduce spoilage during the drying process, in addition, it takes up less space, take less time and relatively inexpensive compared to artificial mechanical drying method (Geda- Gujurat Energy Development Agency, 2003, www.geda.com). Studies showed that food item dried in a solar dryer were superior to those which are sun dried when evaluated in terms of taste, color and mould contents (Nandi, 2009). According to Oguntola. et,al.(2010), solar dried food are quality products that can be stored for extended periods, easily transported at less cost while still providing excellent nutritive values. Thus solar drying is a better alternative solution to all the drawbacks of natural sun drying and artificial mechanical drying.

II. MATERIALS AND METHOD

2.1. MATERIALS

The materials used for the construction of the solar dryer includes: Wood, paint (black and red), plastic cover, iron sheet, iron rod. Drying material was groundnut.

2.2.Design Considerations

The dryer was design such that it could be adjustable and collapsible, the following factors were taken into consideration; (i) The Dryer's capacity and design dimensions - were such that the dryer has maximum drying chamber area of (2.60m x1.30m) equals to 3.39m^2, and minimum drying chamber area of (0.615m x 1.30m) which is equal to 0.8475m^2. It could be adjusted by (0.615m x 0.23m) which is equal to 0.14145m^2 at each moment to get the maximum or minimum size of the drying chamber. The reasons for these dimensions are because of the adjustable and collapsible nature of the solar dryer, and the fact that according to (Seyed et.al, 2011), the mean length and width of one fresh groundnut with maximum moisture content of 35% taken from four varieties (Goli, Velencia, Iraqi-1 and Iraqi-2) are 20.450mm and 10.575mm respectively. Converting the length and width to metres, the mean length and width are 0.02045m and 0.01058m respectively. This implies that a groundnut has a mean area of (mean length x mean width) which is equal to (0.02045m x 0.01058m) which is equal to 0.000230796m^2. If we divide the maximum area of the drying chamber by the mean area of a groundnut, the dryer is capable to taking 14,688 pieces of fresh ground a maximum moisture content of 35%, at maximum capacity, and 3672 pieces at minimum capacity. Also according to (seyed, et.al, 2011) the mass of one fresh groundnut is 1.125g at maximum moisture content of 35%. This implies that one groundnut has a mass of 0.001125kg. Multiplying 0.001125kg by 14,688 pieces, the dryer can carry 16.52kg of fresh groundnut with maximum moisture content of 35% at maximum capacity, and 4.06kg at minimum capacity.

[1] Temperature – the minimum temperature for drying food is 30^{o}C and maximum temperature is 60^{o}C, 45^{o}C is consider average and normal for drying vegetables, fruits, roots, tuber crop chips and some other crops (Whitefield 2000). According to (Ronoh et.al,2010), if drying temperature is too low at the beginning, micro organism may grow before the grain is adequately dried, that care should be taken to ensure that the temperature is not too high that will affect the color, texture and flavor of the food

[2] Air gap – air gap of 5cm is recommended for hot climate passive solar food dryer (Oguntola et,al 2010). For the purpose of this design, an air inlet and outlet gap or vent of diameter equals to 10.0 cm was created with the view of allowing more air flow into the dryer and decreasing it temperature in order to remove the free water molecules which is important at the initial stage of drying.

[3] The glass cover used for the design of the dryer is 4mm thick and the solar collector is iron sheet, 0.9mm thick. Both the glass cover and solar collector are approximately (130.0 x 61.5) cm x 4. This is because the dryer is made up of four segments integareted into one. Each of the segment is (130.0 x 61.5) cm.

[4] The dryer is a direct and passive dryer in which both the drying chamber and solar collector's chamber are in the same place, it has no drying trays, but could be fixed if desired.

[5] (vi) The solar collector and drying chamber are painted black because black paint is good absorber of heat and poor radiator of heat, so it absorbs the solar energy falling on the solar collector and coverts it to heat energy required for drying of food crops in the drying chamber.

[6] The bottom cover is a plywood of size (61.5 x 130.0 x1.0) cm, multiplied by 4 segments of the dryer. The bottom covers are painted red to prevent water and moisture from spoiling them quickly. Wood is a poor conductor of heat, as such, it will minimize heat lost due to conduction at the bottom of the dryer. The iron sheet which was painted black was used as a solar collector, and placed directly on top of the plywood, to form the solar collector's chamber.

2.3. Design Calculations / Theory

(i) Angle of tilt (β) of solar collector

According to Sukhatme (1996), angle of tilt (β) of solar collectors is

$$\beta = 10 + \text{lat } \phi \qquad (1)$$

Where lat ϕ = latitude of the place that the drier was designed, which is Sokoto. For the purpose of this design, β = lat ϕ , since there was no angle of tilt. The dryer could function satisfactorily without angle of tilt.

(ii)There are three major factors affecting food drying: temperature, humidity and air flow. They are interactive. Increasing the vent area by opening vent covers will decrease the temperature and increase the air flow, without having a great effect on the relative humidity of the inlet air. In general more air flow is desired in the early stages of drying to remove free water or water around the cells and on the surface. Reducing the vent area by partially closing the vent covers will increase the temperature and decrease the relative humidity of the inlet air and the air flow

(Wave Power Plant Inc. 2006). Oguntola et,al (2010) reported that volumetric flow rate of air V_a can be expressed as $V_a = v(m/s) \times h(m) \times w(m)$ Where v is the average air wind speed in(m/s), h is the height of the air gap or vent in(m), w is the width of collection, which implies the width of the air gap or vent in (m). $V_a = v(m/s) \times A(m^2)$, A is the area of air gap or vent in (m^2). For the purpose of this design, the air inlet and outlet gaps or vents are circular in shape, therefore, the formula used to calculate the volumetric flow rate of air is average wind speed (m/s) multiply by the area of the air gaps or vents which are circular in shape. It is expressed as

$$V_a = A \times v \times n \quad (2)$$

Where V_a = Volumetric flow rate of air (m^3/s)

A = Area of air gap or vent (m^2)
v = average wind speed (m/s)
n = number of air vents
But $A = \pi r^2$, r = radius of air or vent
so that, we obtain

$$V_a = \pi r^2 \times v \times n = \pi v r^2 n \quad (3)$$

(iii) Mass flow rate of air is expressed (Oguntola, 2010) as

$$m_a = \rho_a V_a \quad (4)$$

Where m_a = mass flow rate of air, ρ_a = density of air (kg/m^3) and V_a = volumetric flow rate of air (m^3/s)

(iv) Solar insolation is given by Olaloye(2008) as

$$I_c = H \times R \quad (6)$$

Where I_c = solar insolation (W/m^2)
H = average daily solar radiation on horizontal surface Olaloye (2008)
R = average effective ratio of solar energy on tilt surface to that on the horizontal surface= 1.0035.

For the purpose of this design, I_c = H, because the solar collector was not tilted to any surface hence no any effective energy ratio R.

(v) Energy Balance on the Absorber.

The total heat energy gained by the collector's absorber is equal to the heat lost by heat absorber of the collector (Bukola et,al 2008)

$$I_c A_c = Q_u + Q_{cond} + Q_{convec} + Q_R + Q_p \quad (7)$$

I_c = rate of total radiation incident on the absorber's surface (W/m^2)

A_c = collector's area (m^2)

Q_u = rate of useful energy collected by the air (W)

Q_{cond} = rate of conduction losses by the absorber (W)

Q_{convec} = rate of convective losses from the absorber (W)

Q_R = rate of long wave re – radiation from absorber (W)

Q_P = rate of reflection losses from the absorber (W)

Putting $Q_l = Q_{cond} + Q_{convec} + Q_R$ (8)

where Q_l is the total heat loses(the three heat losses)

If τ is the transmittance of the top glazing and It is the total solar radiation incident on the top surface, therefore,

$$I_c A_c = \tau I_c t A_c \qquad (9)$$

The reflected energy from absorber is given by expression

$$Q_p = \rho \tau I_c t A_c \qquad (10)$$

ρ = reflection co- efficient of absorber.

Substituting eqn (8), (9) and (10) into (7), yields

$$\tau I_c t A_c = Q_u + Q_l + \rho \tau I_c t A_c$$

$$Q_u = \tau I_c A_c (1 - \rho) - Q_l$$

For an absorber, (1- ρ) = α and hence ,

$$Q_u = (\alpha\tau) I_c t A_c - Q_l \qquad (11)$$

Q_l composed of different convection and radiation parts. It is presented in the following form (Bansel et,al. 1990)

$$Q_l = U_l A_c (T_c - T_a) \qquad (12)$$

U_l = overall heat transfer co – efficient of the absorber (W/m^2K^{-1})

T_c = temperature of collector's absorber (K)

T_a = ambient air temperature (K).

$$Q_u = (\alpha\tau) I_c t A_c - U_l A_c (T_c - T_a) \qquad (13)$$

If the heated air leaving the collector is at the collector's temperature, the heat gained by the air Qg is

$$Q_g = m_a c_{pa} (T_c - T_a) \qquad (14)$$

m_a = mass of air leaving the dryer per unit time (kg/s) ≡ mass flow rate of air ≡ $\dot{m}$

c_{pa} = specific heat capacity of air at constant pressure ($jkg^{-1}k\text{-}^{1}$)

The collector's heat removal factor, F_R, is the quantity that relates the actual useful energy gain of a collector in eqn (13) to the useful energy gained by air in eqn (14) expressed by (Bukola and Ayoola,2008) as

$$F_R = \frac{m_a c_{pa} (T_c - T_a)}{A_c [\tau\alpha I_c t - U_l (T_{c-} T_a)]} \qquad (15)$$

Equation (14) can be re- written in terms of F_R

$$Q_g = A_c F_R [(\alpha\tau) I_c t - U_l A_c (T_c - T_a)] \qquad (16)$$

The thermal efficiency of the collector is defined as the ratio of heat output to the heat input or ratio of energy output to energy input, which is the same as the ratio of the energy addition to the air as it passes through the collector to the energy incident on the collector.

$$\eta_c = \frac{Qg}{I_c A_c} \qquad (17)$$

(vi) The total energy required for drying a given quantity of food item can be estimated using basic energy balance equation for the evaporation of water (Youcef et,al. 2001, and Bolaji 2005) as in equation 18, where the oil and fat evaporated from groundnut is negligible at that temperature change.

$$m_w L_v = m_a c_{pa} (T_1 - T_2) \qquad (18)$$

m_w = mass of water vapour evaporated from the food item (kg)

L_v = latent heat of vaporization of water (kj/kg)

m_a = mass of drying air (kg)

T_1 and T_2 = the initial and final temperatures of drying air respectively (K)

C_p = specific heat capacity of air at constant pressure (kjkg^{-1}k^{-1}
(vii) The dryer's efficiency (ηd) is expressed as follows

$$n_d = \frac{ML_v}{I_c A_c t} \qquad (19)$$

η_d = dryer's efficiency (%)
M = Mass of moisture evaporated (kg)
L_v = Latent heat of vaporization of water (kj/kg)
I_c= Solar insolation (W/m^2)
A_c= Area of solar collector (m²)
t = Time of drying (hrs)
(viii) The collector's efficiency (ηc) is expressed (Ezekoye et,al.2006) as follows

$$nc = \frac{\rho V_a C_p \Delta T}{I_c A_c} \qquad (20)$$

ηc = Collector's efficiency (%)
Cp = Specific heat capacity of air (kj / kg k)
$\Delta T = (T_c - T_a)$ = Temperature elevation (K)
A_c = Area of solar collector (m^2)
I_c = solar insolation (W/m^2)
ρ = Density of air (kg/m^3)
V_a = Volumetric flow rate of air (m^3/s)
(ix) Moisture content on percentage wet basis is expressed (Senger2009) as follows

$$MC_{wb} = \frac{W_1 - W_2}{W_1} \qquad (21)$$

MC (w_b) = Moisture content on percentage wet bases.
W_1 = Weight of sample before drying in kg.
W_2 = Weight of sample after drying in kg.
(x) Moisture content on percentage dry bases is expressed (Senger,2009) as

$$MC_{db} = \frac{W_1 - W_2}{W_2} \qquad (22)$$

(xi) Drying rate is expressed (Ceankoplis, 1993) as

$$R_c = \frac{M_d(Q_1 - Q_2)}{A_s t} \quad (23)$$

Where R_c = drying rate (kg/mol), M_d = total weight of dried sample, A_s = surface area of dried solid (m^2), t = drying time (hrs), Q_1 = initial moisture content (% wb) and Q_2 = final moisture content (% wb)

(xi) Relative humidity is the mass of moisture present in air to the mass of moisture the air is capable of holding at that temperature.

III. CONSTRUCTION.

The solar dryer was constructed such that it could be collapsible and adjustable. The sketch and pictorial views are shown in Figure 1 and Figure 2 respectively. It is made of the following component parts: solar collector's chamber, dryer's chamber, air vent or gap. The following parts were assembled to form the component parts Yamma, Zaci, Maik, Kwa, Bosso, Shako, Shiwe, Mawo, Gbaiko, Shanu, Kpi, solar collector and plastic covers. The words in italics are some words in my dialect. They were used in this work because the work is my intellectual property and also to project my dialect. The English meaning of the words are as follows: Yamma is a traditional title in my village, Zaci is also a traditional title in my village, Maik is a short form of Maikunkele which is the headquarters of Bosso Local Government Area of Niger State- Nigeria, Kwa means well done, Bosso is my town and as well the name of my Local Government, Shako is a District in my Local Government Area, Shiwe means look, Mawo means I have heard, Gbaiko is a name of a village in my Local Government Area, Shanu and Kpi are also names of Villages in my Local Government Area Bossos are the two opposite ends that form the part of the box shape of the dryer. Each Bosso is (260.4 x 24.5 x 2.0) cm in size that could be adjusted by 65.1cm at a time, to give a minimum length of 61.5cm and maximum length of 260.4cm depending on the desired length required. A Bosso is made up of four yammas, each of size (61.5 x 24.5 x 2.0) cm. Each Yamma has two maiks and an air vent of 10.0cm in diameter. The four yammas are coupled together with the aid of zaci which are pieces of iron each of length 7cm long, and 20 kwas, ten at the top and ten at the bottom. Each kwa is a bolt about 2.5cm long slotted into two maiks and tied with a nut at the other end to keep the yammas firmly held together.

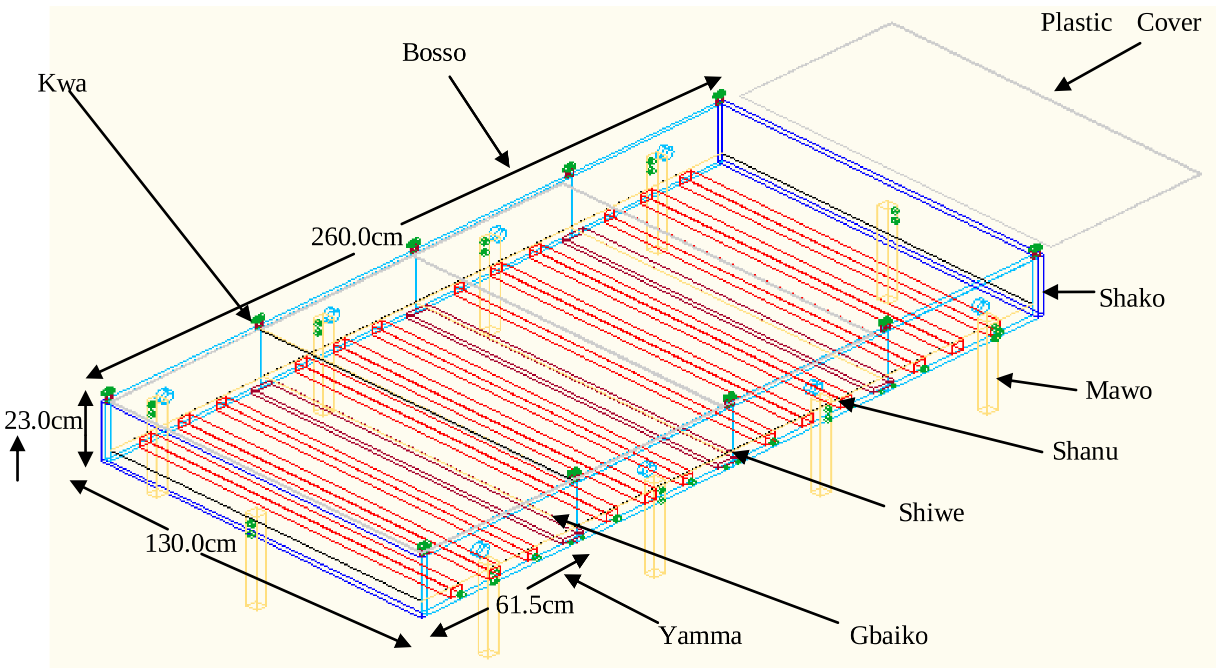

Figure 1, The sketch of the Solar Food Dryer

Shakos are the other two opposite ends of the dryer that gives it a box shape, each *shako* is (134.0 x 24.5 x 2.0) cm. It is none adjustable. This implies that when the two *Bossos* and two *Shakos* are coupled together, a box shape solar dryer is formed which could be (260.4 × 130.0 x 23.0) cm^3 or (184.5× 130.0 x 23.0) cm^3 or (123.0× 130.0 x 23.0)cm^3 and (61.5×130.0) cm^3 in size, depending on the adjustment. The dryer has 10 *Mawos*, which are the legs. Each *Mawo* is (38.0 x 4.0 x 4.0) cm. The solar dryer has a total of 12 *Shanus*, each *Shanu* is (123.0 x 4.0 x 4.0) cm in size, each *Shanu* is supported to the two *Bossos* by two slotted nails at the two ends. The *Shanus* provides the support for the bottom cover, the solar collector and drying chamber. Since the whole dryer has four segments integrated together as one, at each boundary between two segments there is one *Shiwe*. Each *Shiwe* is (123.0 x 8.0 x 2.0) cm in size, and is supported to the two *Bossos* by four slotted nails, two at the opposite ends. *Shanu* provide the base in which two different bottom covers and two different solar collectors overlap to seal any gap that heat could possibly escape from the bottom of the dryer. There are total of three *Shiwes* in the whole dryer, located at the three boundaries between the segments. The dryer also has three *Gbaiko's*, each *Gbaiko* is and iron rod of length 137.2 cm and 1.0cm thick. It has threads at the two ends which nuts are used. *Gbaikos* are located close to the boundaries between the segments, *Gbaikos* helps to straighten any bend at the boundary/joint between segments to ensure that *Bossos* remain straight with the aid of nuts at it two ends, as shown in figure 1. The bottom covers and solar collectors are held very firmly on the *Shiwes* and *Shanus* which are the base support, with the aid of Kpi. There are total number of 8 *Kpis*, and the average size of each *Kpi* (54.0 x 2.5 x 2.5) cm. Each *Kpi* is supported by three screw to the *Bosso*. The four plastic covers are supported to the dryer by four slotted frames, each frame is (123.2 x 61.5) cm in size. The frames are constructed such that they fit and overlap very well into the dryer's frame to ensure that heat does not escape from the sides. The pictorial view of the dryer is shown in figure 2.

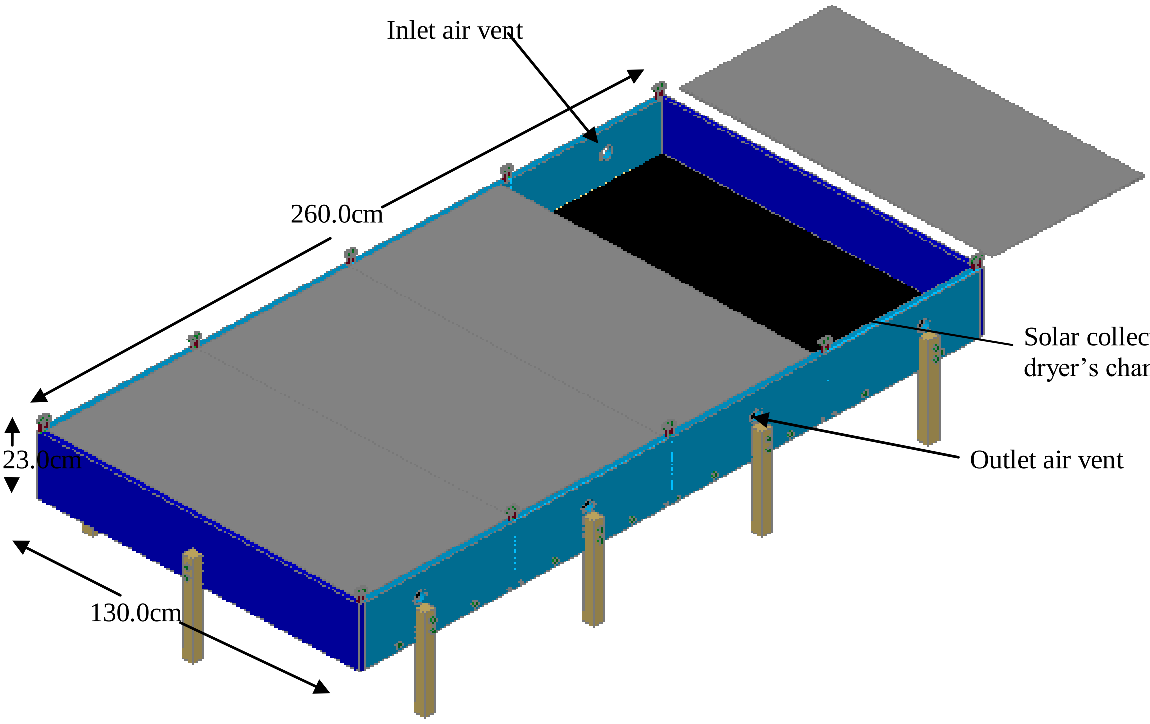

Figure 2. The Pictorial view of Solar Food Dryer. As seen in figure

figure 3, it shows how *Kwa* clearly looks. It shows how the bolt was slotted into the *maiks* and tied with a nut at the other end.

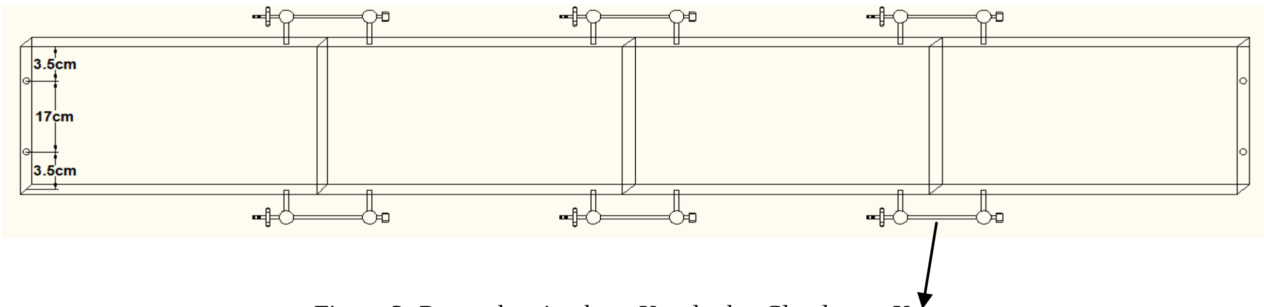

Figure 3. *Bosso* showing how *Kwa* looks, Clearly. *Kwa*

Likewise, Figure 4, shows how *Zaci* and *Maik* were used in the construction, and how the four *Yammas* were coupled together

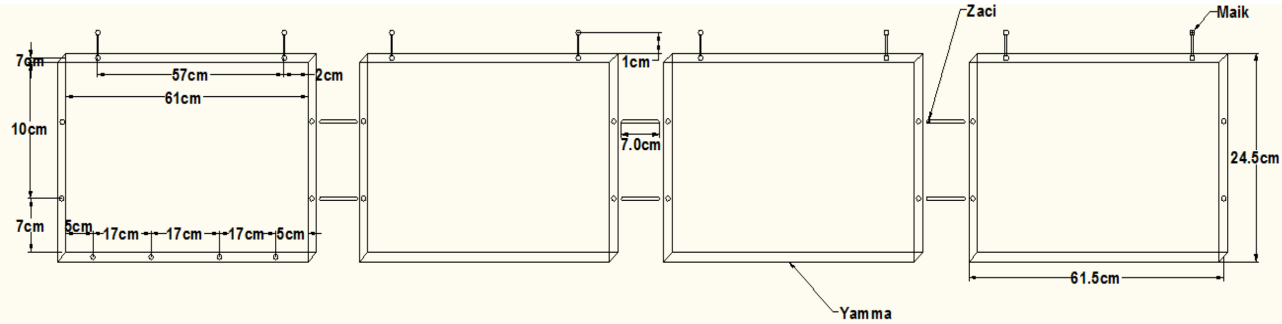

Figure 4. The use of *Zaki* and *Maik* in the construction, and how the four *Yammas* were coupled together

IV. CONCLUSION

A new model of a box type adjustable and collapsible natural convection solar food dryer, capable of taking 14,688 pieces equivalent to 16.52kg of fresh groundnut with maximum moisture content of 35%, at maximum capacity of 3.39m^2, and 3,672 pieces equivalent to 4.06kg of groundnut at minimum capacity of 0.8475m^2, was successfully designed and constructed using locally available materials.

REFERENCES

[1] Aklilu, T. (2004): "Experimental Analysis for Performance Evaluation of Solar Food dryer". Research Thesis. Department of Mechanical Engineering. School of Graduate Studies, Addis Ababa University.

[2] Bukola, O. B ; Ayoola, P. O. (2008): Performance Evaluation of a Mixed- Mode Solar Dryer. *A.U.J.T.* 11(4): 225- 231

[3] Bolaji, B. O (2005): Development and Performance Evaluation of a Box Type Absorber Solar Air Collector for Crop Drying. *Journal of food technology* **3** (4): 595 – 600.

[4] Bassy, M.W (1989) :Development and Use of Solar Drying Technologies. *Nigerian Journal of Solar Energy*. **89**:133- 64

[5] Ceankoplis, C. J (1993) : Transport Process and Unit Operations. 3rd Edition Prentice Hall, Englewood: 508-512

[6] Diamante, L.M ; Munro, P.A, (2004), Mathematical Modelling of Thin Layer Solar Drying of Sweet Potatos, *Solar Energy*,(**51**) 176 - 271

[7] Ekechukwu, O.V ; Norton B. (1999), Review of Solar Energy Drying Systems iii: Low Temperature Air- Heating Solar Collector For Drying Application: *Energy Conversion and Management* **40** 615-655

[8] Ezekoye, B.A ; Enebe, O.M (2006): "Development and Performance Evaluation of Modified Integrated Passive Solar Grain Dryer". *Pacific Journal of Science and Technology*. **7**(2) : 185- 190.

[9] Geda- Gujurat Energy Development Agency, 2003, www.geda.com

[10] Harringshaw, D. (1997): All About Food Drying, The Ohio State University Extension Facts Sheet – hyg – 5347- 97, www.ag.ohio-state.edu/

[11] Nejat, T. V, (1989): Alternative Energy Sources viii, *Hemisphere Publishing Company*, 1

[12] Nandi, P (2009): Solar Thermal Energy Utilization in Food Processing Industry in India, *Percific Journal of Science and Technology* 10 (**1**) :123- 131

[13] Olaloye, D. O (2008) : The Design and Construction of Solar Incubator, 2008 Project Report, Submitted to Department of Mechanical Engineering, University of Agriculture, Aboekuta.

[14] Oguntola, J. A ; Collins, N. N ; Olayinka, A. (2010): "Design and Construction of a Domestic Passive Solar Food Dryer". *Leonardo Journal of Sciences*. **16**

[15] Ronoh, E. K ; Kanali, C. L ; Mailutha, J. T ; Shitanda, D (2010) : Thin Layer Drying Characteristics of Amaranth Grain in a Natural Convection Solar Tent Dryer. *Kenya Journal of Mechanical Engineering*.**6** (2) : 7-10

[16] Sayed, H. P. ; Fatemeh, R. A. ; Iraj, B. ; Mohammed, R. A. (2011) : Effect of Moisture Content on some Engineering Properties of Peanut Varieties. *Journal of Food, Agricultural and Environment*. **9** (3&4) : 326 – 331.

[17] Senger, S.H; Khandetod Y.P; Mohod, A.G (2009) : "Low Cost Solar Dryer for Fish". *African Journal of Environmental Science and Technology*. **3**(9) 265-271.

[18] Sukhatme, S. P. (1996) : Solar Energy Principles of Thermal Collection and storage, Tata McGraw Hill Publishing Company Limited, 1996.

[19] Scalin, D. (1997): The Design, Construction and Use of an Indirect Through Pass Solar Food `Dryer. *Home Power Magazine*. **57** : 62 – 72.

[20] Togrul, I.T; Pehlivan, D. (2004): Modelling of Thin Layer Drying Kinetics of some Fruits Under Open Air Sun Drying Process, *J.Food Engin*. **65**:413- 25

[21] Whitefield, D.E. (2000) Solar Dryer Systems and Internet, Important Resources to Improve Food Preparation. 2000 Proceedings of International Conference on Solar Cooking, Kimberly, South Africa.

[22] Yousef- Ali, S; Messaoudi, H ; Desmons, J. Y ; Abene, A ; Le Ray, M (2001) : Detrmination of the Average Co – efficient of Internal Moisture Transfer During the Drying of a Thin Bed Potato Slices. *J. Food Engin*. **48** (2): 95 – 101.