International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 3 No. 2, February, 2013

Development of Small Scale Direct Mode Natural Convection Solar Dryer for Tomato, Okra and Carrot

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ABSTRACT

Three small scale direct mode natural convection solar dryers were developed with locally affordable and available materials, to solve the problems local farmers encounter in handling vegetables such as, tomato, okra and carrot. Each of these crops was sliced at the thickness of 15mm and each sample loaded in single layer in a particular dryer and dried at the same time. The samples were also dried in open sun as control. Weather factors that affect crop drying, heat energy generated by the dryers and the rate of crop drying were monitored at the intervals of two hours in the day time. Results showed that sliced samples of tomato, carrot and okra dried with solar dryers, achieved 54.55, 52.88 and 50.98 percent gain in drying time respectively, when compared with open sun drying. Results equally indicated that tomato, carrot and okra, were dried at average daily solar dryer temperature of 49.9°C, 51.17°C and 52.29°C respectively. The analysis revealed that tomato, carrot and okra dried in solar dryers attained 21.80, 21.18 and 24.95 percent system drying efficiencies for tomato, carrot and okra respectively. While the open sun achieved 10.59, 12.71 and 15.19 percent system drying efficiencies for tomato, carrot and okra respectively. These results showed that drying of vegetables can best be achieved by solar dryers than open sun drying. This work indicated that onion cannot be dried in open sun because the pungent aroma is usually lost when exposed to unconfined space.

Keywords: *Vegetables, Moisture, Solar, Dryer, System drying efficiencies.*

1. INTRODUCTION

Nigerian farmers lost about 20 to 60 percent of fruits and vegetables such as tomato, okra, carrot and others yearly due to inadequate processing and preservation methods (Karikari, 1989). Hence the convectional abundant supplies of fruits and vegetables at give-away prices and great wastage during their peak period have persisted. Thus, the scarcity or non-availability of these crops in their off seasons has continued to be a common and ugly experience of the poor farmers. Eke, (1991), Fargna (1985), and Luh and Woodroff (1975) stated that, the length of time an agricultural product can be preserved is a direct function of its moisture content, chemical and physical compositions as well as the environmental conditions of the crop in question, and that the processing temperature will not exceed 60 °C.

Olukosi et al. (1990) indicated that farmers in Nigeria slice small and medium sizes ripen tomato into two halves, while those of big size are cut into four equal parts. Slicing of okra has no pattern, it is decided based on the farmers' choice and dried in the open sun. Farmers encounter great loss by this traditional open sun drying. Lutz and Hardenburg (1967) gave the initial moisture content wet basis of tomato as 94 percent, while Peter and Raymond (1964) presented 4 percent moisture content wet basis as the safe storage moisture content of tomato. Researchers have worked on solar dryers for drying grains and lower moisture content crops which farmers equally dry in open sun (Web 1, Gbaha**,** Yobouet, Kouassi, Saraka, Kamenan, and Toure, (2007) and Web 2). Arinze, at al. (1990) and Arinze, at al. (1992) presented prototype solar dryers. Eke (1995) and Akani (1990) reported that the industrial methods of preserving vegetables, tomato in particular, involve high skilled technology, which is capital-intensive and out of reach of the local farmers.

The aims of this work are; to fabricate simple natural convection direct mode solar dryers for drying tomato, onion and okra, using local materials and to conduct preliminary test on the dryers' performances based on the dryer system drying efficiencies.

2. MATERIALS AND METHOD

2.1 Dryer Capacity

Eke (1995) reported that farmers in Hunkuyi , Marabadanja , sabon-gari and Samaru villages in Zaria, Nigeria, dry on the average 2 kg to 15 kg of sliced tomatoes per batch drying. Therefore tomato which the farmers can dry in the open sun and is of high moisture content was chosen for design consideration at the batch drying capacity of 10 kg.

2.2 Design of Solar Collector Area

The solar collector area of the dryer was calculated with equation 1 as given by (Duffie and Beckman, 1980 and Holdman, 1980).

$$A_c = \frac{Q}{F_R t\left[IT_r - U_L\left(T_c - T_a\right)\right]} \qquad (1)$$

Where: A_c = Solar collector area, m^2, Q = Collector useful heat energy gain required to dry a given quantity of agricultural product.(J), t = Drying time (seconds), F_R = Collector heat removal factor (dimensionless), I = Total solar radiation incident on the dryer (W/m^2), T_e =Glass transmittance (dimensionless), T_c = Collector air outlet temperature (^oC), T_a = Ambient temperature (^oC), $U_{L=}$ Overall heat transfer coefficient W /$m^{2o}C$.

2.3 Collector Useful Heat Energy Gain

The collector useful heat energy gain required to dry a given quantity of agricultural product, was obtained by using equation 2 (Eke, 2003).

$$Q = \left[C_p W_p\left(T_c - T_a\right) + L_v D_m\right)\right] \qquad (2)$$

Where: C_p = Specific heat capacity of the product (J/ kg ^oC), W_p = Initial weight of product before drying (kg), L_v = Heat of evaporation of moisture from the product (J/ kg), D_m= Dry matter of product. (kg). Q = quantity of useful heat energy gain require to dry the product, J.

2.4 Quantity of Moisture Removed from the Product

Equation 3, a model given by Henderson and Perry (1980), was employed to determinate the quantity of water removed to dry the product from initial moisture content to safe storage (final) moisture content.

$$W_w = \frac{MC_i - MC_f}{100} D_m \qquad (3)$$

But

$$D_m = \left(W_p - \left[\frac{W_p M_{wi}}{100}\right]\right) \qquad (4)$$

Where: M_{wi} = Initial moisture content of product (percentage wet basis), MC_f = Final moisture content of product (percentage dry basis), MC_i = Initial moisture content of product (percentage dry basis), W_w = Quantity of water removed.(kg)

The values of Fr, U_L, I, Te of glass and Tc were obtained from (Eke, 2003)

Other values such as Cp and Lv were obtained from product thermal table, given by (Heldman and Singh 1980) and Ta was obtained from IAR meteorological unit. The parameters were used to calculate the collector area of the solar dryer as 1 . 0 m^2

2.5 Fabrication of Five Solar Dryers

The design specifications were followed to fabricate three similar direct mode natural convection solar dryers in the Department of Agricultural Engineering, Faculty of Engineering, Ahmadu Bello University, Zaria, Nigeria. The dryers were fabricated with wood, 5cm average sizes of stone, polythene sheets, nails and black oil paint, and mounted on a wooden stand inclined at an angle 21^o at a horizontal position sloping toward south. The inclination enhanced trapping of maximum solar radiation on the dryer and free convection flow of air from the collector unit to the drying chamber where moisture is picked from the crop. Figure 1 showed the five solar dryers.

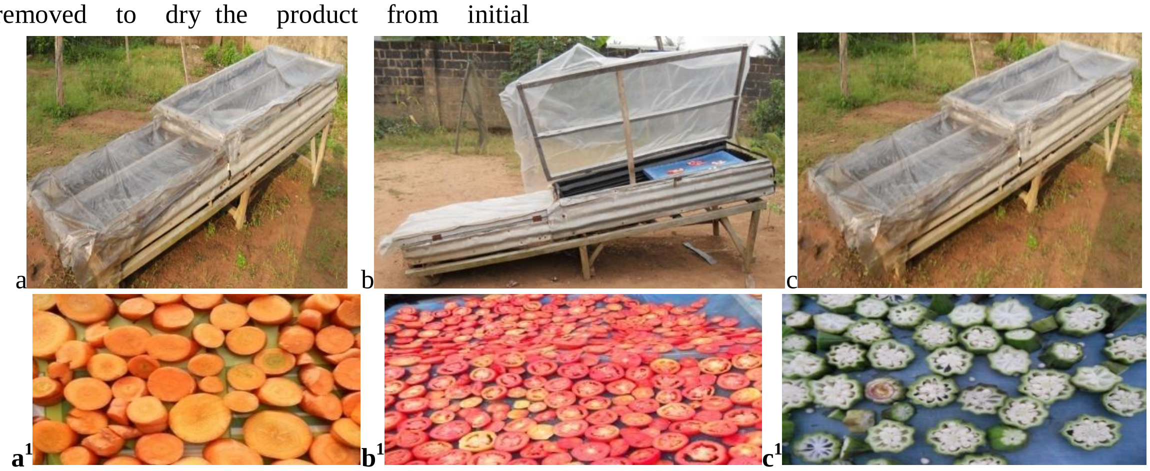

Figure 1: Three direct mode solar vegetable dryers, (a, b and c are solar dryers for carrot, tomato and okra respectively. While a^1, b^1 and c^1 are carrot, tomato and okra respectively)

2.6 Drying Test

Tomato, okra and carrot were used to evaluate the performance of the dryers. Each of these crops were sliced at the thickness of 15mm and dried with solar dryers while some samples were dried in open sun as controls.

The drying sliced crops in each solar dryer and open sun were sampled out periodically for moisture content determination with oven drying method, and the heat energy generated by the dryers were monitored. Measurements were done at two hours intervals in the day time for each batch drying. Data collections were replicated three times. The drying took place in the months of January, February March and April. In each of these months, three batches of samples were dried and the average values of the parameters of the drying samples in three dryers and the corresponding open sun drying were taken under the same ambient weather conditions.

2.7 Solar Dryer Drying Efficiency

The system drying efficiencies of the dryers was one of the basis for assessing the performance of the solar dryer and the control System drying efficiency free convection solar dryer ($\int_{sd}$) was obtained from the following relationship (Brenndorfer et al. 1987 in Akani 1990).

$$\int_{sd} = \frac{M_w L_v}{ITAt} \qquad (5)$$

3. RESULTS AND DISCUSSION

Figure 2, 3, 4 and 5 showed the results of the drying curves of average values of collector (Tc)-°C and drying chamber (Td)-°C air outlet temperatures, Weather factors monitored during drying test, these are solar radiation (I)-W/m^2, ambient (Ta)-°C, ambient relative humidity (Rh)-% and wind speed (wsp)-m/s) and the moisture contents (M)-% of the drying products.

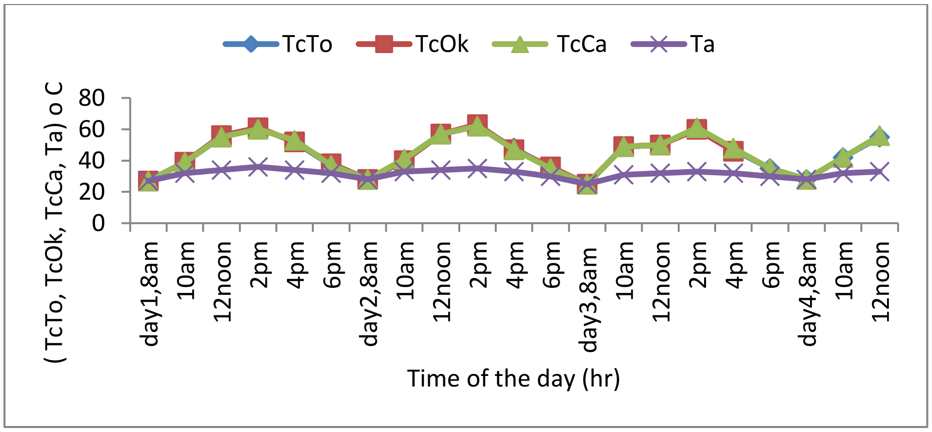

Figure 2: Average values of solar collector and ambient temperature response of TcTo, TcOk, TcCa and Ta, solar collector air outlet Temperature for collectors drying tomato, okra and carrot respectively and ambient temperature

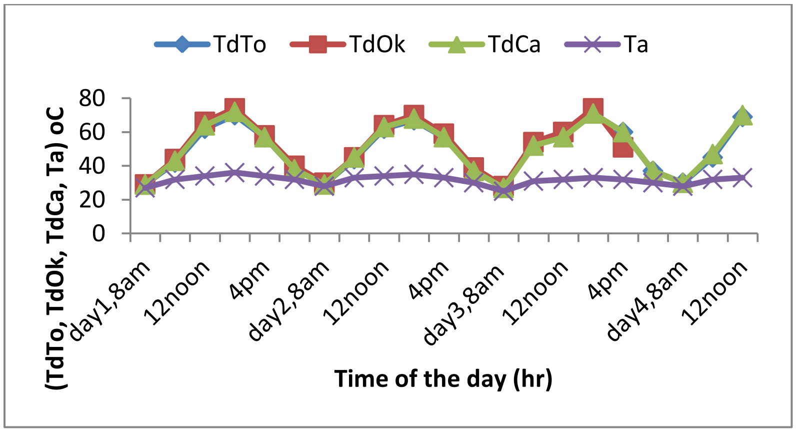

Figure 3: Curves of average values of TdTo, TdOk, TcCa and Ta, solar drying chamber air outlet Temperature for dryers drying tomato, Okra and carrot respectively and ambient temperature

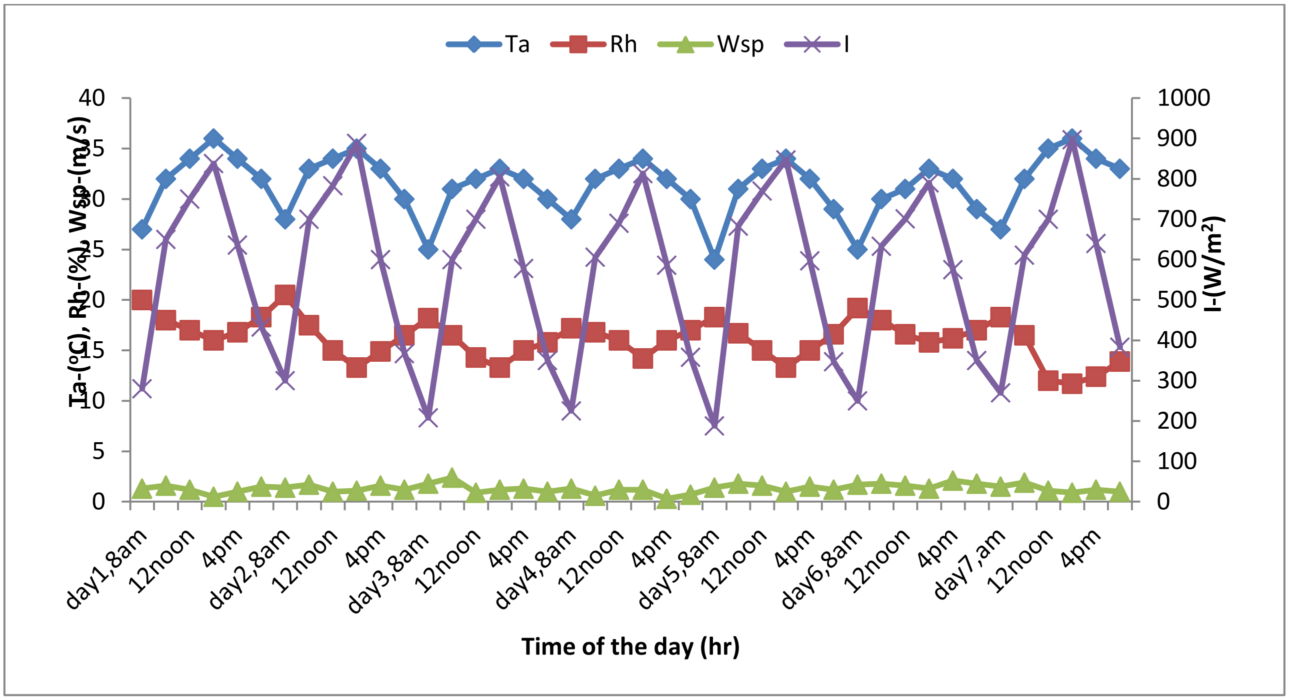

Figure 4: Curves of average values of weather factors during solar and open sun drying of crops (ambient temperature (Ta), wind speed (Wsp), relative humidity (Rh), solar radiation (I)).

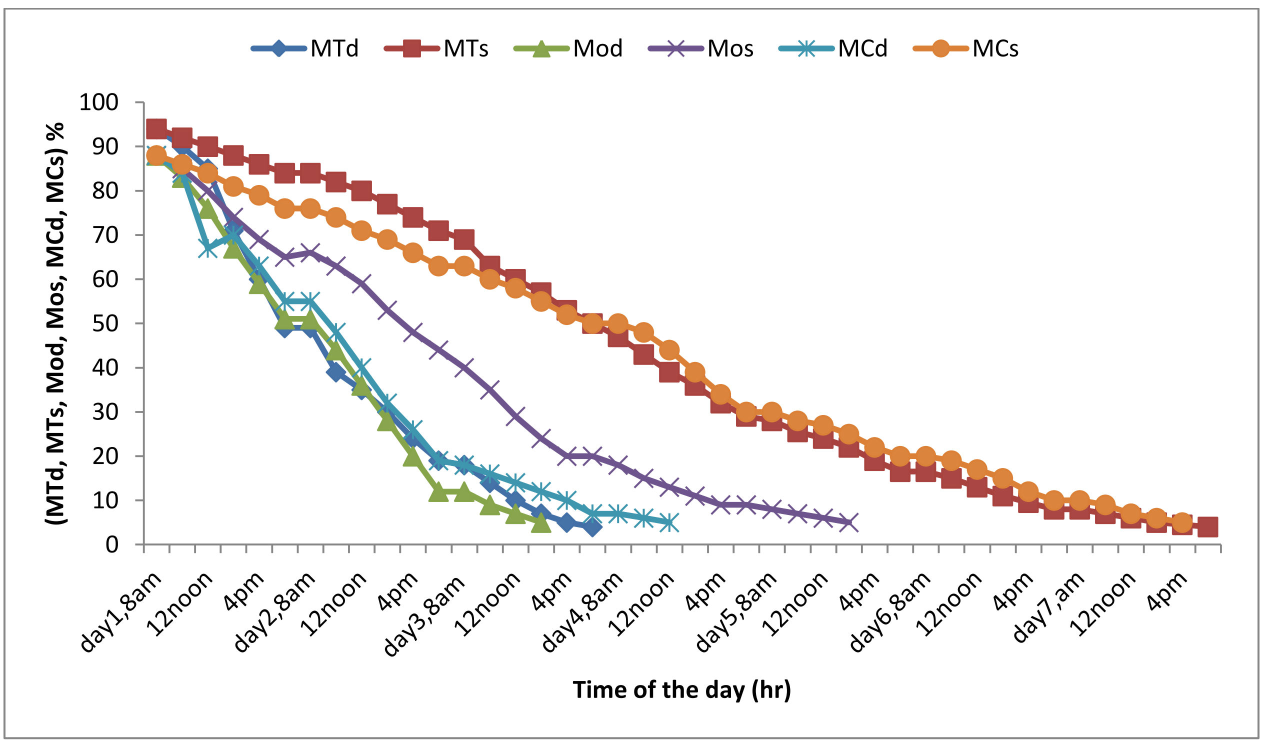

Figure 5: Average values of moisture contents – wet basis (%) of tomato (MTd), (MTs), okra, (Mod), (Mos) and carrot (MCd), (MCs) dried with solar dryer and open sun respectively

Table 1 is generated from the analysis of results in figure 5 to 8.

Table 1: Effect of solar dryer and open sun drying on tomato, okra and carrot and the system drying efficiencies of the dryers.

S/N	Crop	Nature of crop	Method of drying	Thickness of slices (mm)	Total drying time (hr)	Effective drying time(hr)	Moisture content (MC) wet basis(%)		System drying Efficiency %
							Initial MC	Final MC	
1	Tomato	Fresh	-	-	-	-	93	93	-
		Dried	Solar dryer	15	76	34	93	4	21.80
			Open sun	15	154	70	93	4	10.59
2	Okra	Fresh	-	-	-	-	88	88	-
		Dried	Solar dryer	15	56	28	88	4	24.95
			Open sun	15	102	46	88	4	15.19
3	Carrot	Fresh	-	-	-	-	88	88	-
		Dried	Solar dryer	15	77	35	88	5	19.96
			Open sun	15	152	68	88	5	10.29

Results on the effect of solar dryers and open sun drying on crops as well as the system drying efficiencies of the dryers for the crops in question are summarized in Table 1 and the results are discussed as follows; The sliced samples of tomato, okra and carrot dried with solar dryers, achieved 54.55, 50.98, and 55.26 percent gain in drying time respectively, when compared with open sun drying method. Figure 2 to 5 equally indicated that tomato, okra and carrot were dried at average daily solar dryer temperature of 49.9^{o}C, 52.29^{o}C and 49.9^{o}C respectively. These average daily solar dryer temperatures are within the limit of the recommended 60^{o}C drying temperatures for fruits and vegetables. All the crops dried were of high moisture content, however, the air outlet temperatures of the drying chambers were not the same, although the dryers were similar in size and of the same quantity of samples by weight. These differences in temperature of the drying chambers might be due to the crops, thermal properties as well as the quantity of moisture evaporated from the product. Thus the higher the quantity of moisture removed the lower the dryer outlet temperature.

Generally the system drying efficiencies are characterized with low percentage values. This is because single layer drying of sliced crops require large drying area. Hence a given drying area can only contain relatively small quantity of the drying sliced crop. Equation 5 was employed to analyze the system drying efficiencies and this revealed that tomato, okra, and carrot dried in solar dryers attained 21.80 % and 10.59 % for tomato; 24.95 % and 15.19 % for okra; 19.96 % and 10.25 % for carrot, for the system drying efficiencies of the samples dried with solar dryers and in open sun respectively. The solar dryer system drying efficiencies for drying tomato, okra and carrot are 105.85, 64.25 and 94.73 percent respectively higher than the open sun system drying efficiencies. These indicate that drying of tomato, okra, carrot and such like products of high moisture content can best be achieved by solar dryers than open sun drying.

4. CONCLUSION

Three similar natural convection direct mode solar vegetable dryers were designed and constructed with locally available and affordable materials. Evaluation of the dryers' drying performances on the given crops indicated that over 50 percent savings in drying time when compared with open sun drying, can be achieved with the use of the solar dryers.

Based on the data analysis of the dryers and the traditional open sun drying, it is concluded as follows: The system drying efficiencies of tomato, okra and carrot dried in solar dryers were determined. The overall average solar dryer temperature was not higher than 60^{o}C and heat flow was by natural convection. In the rural areas where there is no scientific instrument to measure moisture content of the drying crop, it can be determined when tomato, okra and carrot are dried to safe storage moisture content by its brittleness when squeezed within the palm.

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