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Analysis of the Effects of a Flat Plate Solar Dryer Geometry on Drying Rate of Agricultural Seeds

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Abstract: The aim of this study is to evaluate the relationship between solar dryer geometry and the drying rate of seeds; hence the analysis of the effects of a flat plate solar dryer geometry on drying rate of Agricultural seeds is presented using a case study of Ogbono seeds (Irvingea gabonensis). Ogbono seeds were dried using a distributed type, forced convention solar drying system, consisting of a solar collector plate of a geometric area (A), thickness (D) and tilt angle (β). The drying rates of the Ogbono seeds were obtained for collector plate Areas of 0.24, 0.42 and 0.60 m^2; tilt angles of 0, 5, 10 and 15º; absorber plate thicknesses of 1.50, 2.70 and 4.20 mm. The graphs of Area (A) of collector plate against drying rate showed that the drying rates increased linearly with the increase in the area of collector plate. From the graphs of angles of tilt against drying rate, it was evident that the drying rate generally increased curvlinearly to a point with the increase in the tilt angle. From that point of inflection, the drying rate decreased with the increase in the tilt angle of the plate. A maximum drying rate of 10.03% m.c/h was obtained for the Ogbono seeds during the field test. This maximum rate of drying occurred for collector plate area of 0.60 m^2, tilt angle of 5^o and plate thickness of 2.70 mm. The corresponding collector efficiency is 57%.

Keywords: Collector efficiency, drying rate, forced convention, point of inflection

INTRODUCTION

The real thrust into all phases of solar energy development in the world came in the mid-1970s when fossil fuel shortage and the accompanying rise in price, together with the increasing public concern over the safety of nuclear reactors, made it apparent that an alternative energy source was essential. Along with a multitude of ideas for harnessing and using the sun's clean energy were many related to its use in agriculture (Lindley and Whitaker, 1996).

Ogbonoseeds have relatively highmoisture content and at the same time have high oil content. The seeds when harnessed fresh have about 65% moisture content wet basis, but have safe storage moisture content of about 8-10% wet basis. This implies that a reasonable quantity of heat energy should be developed by the solar dryer for the drying of the seeds within a reasonable time. This is because any moisture content of the Ogbono seed, above the safe storage moisture content facilitates rapid deterioration of the seed.

Methods of drying ogbono: The drying and preservation of Ogbono is traditionally achieved in many parts of Nigeria through sun drying. Another method practiced in those days was the drying of Ogbono and other agricultural materials using heat from the fire place in the kitchen. These traditional methods have the disadvantage of producing low quality products, taking a lot of time to dry materials and exposing the materials being dried to the attack of insects and rodents. Also these methods are often hampered by the fact that solar energy is dilute and not always dependable, especially during the rainy season.

Apart from the traditional methods of drying using fire and direct sunlight, many other devices had been produced by scientists and researchers to dry agricultural produce. However, most of the designs of solar drying systems presently available were done without sufficient mathematical investigation and analysis (Oje and Osunde, 1995). This affects the performance evaluation of the dryers. There is therefore, the need to develop a solar system that will maximize the available solar flux at any point, by utilizing the optimum geometric settings of the solar dryer. This study is aimed at achieving this purpose.

MATERIALS AND METHODS

This study was conducted at the Federal University of Technology Owerri, Nigeria in 2010. The component parts of the system are described below:

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Description of the machine: The solar dryer is of the distributed type, forced convention solar drying system. It consisted of the following components viz: the solar collector chamber, the drying chamber, the blower (fan), the air delivery pipe (duct) and the tilting mechanism:

- **Solar collector chamber:** The solar collector was in the form of a wooden box of cross sectional area 0.60 m^2. Omojiba (2005), gave the configurations of length and width for a free convective solar dryer as x and 0.733x, respectively. This implies that for any chosen area A, of a solar collector surface:

  $$A = (x)(0.733x)$$
  $$A = 0.733x^2 \qquad (1)$$

  where, x = Length of the collector plate.

  Substituting for the cross-sectional area of 0.60 m^2 into Eq. (1), the length and width of the collector plate were calculated as 91 and 65 cm, respectively. However, because of convenience, these dimensions were approximated to 100 cm length x 60 cm width. The depth of the chamber was chosen as 20 cm. A mild steel plate painted dull black and fixed at the base of the collector chamber was used as the absorber plate. Plain transparent glass sheet of 4 mm thickness was used as the glazing material. The box has two circular openings of diameters 15 and 8 cm, respectively. These opening served as the air inlet and air exit through the collector chamber.
- **Drying chamber:** The drying chamber consisted of a box, constructed with hard wood and having dimensions 40x30x30 cm. This chamber was demarcated into 2 batches with the help of wire gauze and wooden battens.
- **Fan/blower unit:** The fan system was designed in line with ASTM standard. A fan speed of 5.45 m/s was chosen, which gave a corresponding volumetric air flow rate of 5.77 m^3/min. Pierce and Thompson (1980), recommended air flow rates between the ranges of 2 to 8 m^3/min.
- **Tilting mechanism:** According to Lindley and Whitaker (1996), the maximum solar energy is collected when the surface of the collector chamber is perpendicular to the incident rays of the sun. This necessitated the incorporation of a tilting unit into the solar drying system, which enabled the collector plate to rotate with respect to the sun's direction.

Field test: Large quantities of Ogbono fruits were bought from the village markets in and around Owerri town. The outer mesocarps of these fruits were peeled off carefully with knife thus leaving behind the seeds housed inside the hard shells. These shells were sun dried for about 2 days, to enable them to be cracked so as to remove the seeds undamaged.

At the start of each test, the fabricated solar dryer was positioned at a reasonable distance away from tall buildings and trees, so as to prevent the effect of shading. The dryer was positioned to align with the North-South axis and with the plate titled to face the South Pole. A reasonable quantity of the seeds was taken to the field and cracked. The seeds were extracted and some arranged inside the solar drying chamber, while some others placed on a wooden tray were simultaneously dried in the open sun, as a comparison treatment in the experiment.

The fan was connected to the battery and switched on. With the starting time noted and recorded, the temperature readings on the dryer chamber as well as the ambient temperature readings were taken every 30 min using the mercury in glass thermometer. The masses of 2 pre-marked seeds each for both the dryer and open sun were taken at hourly intervals. At the end of each test, which lasted for 3 h the final masses of the seeds were taken and the dried seeds were oven dried. A total of 36 tests were carried out with the various treatment combinations of area (A), tilt angle (β) and absorber plate thickness (D) of collector plate.

The percentage moisture contents corresponding to different stages of the drying process were determined using Eq. (2):

$$\%\,M.C = (M_s - M_o)/M_s \times 100 \qquad (2)$$

where,
% M.C = Percentage moisture content
M_s = Mass of seed
M_o = Mass of oven dried seed

The drying rate of the Ogbono seeds R (% M.C/h) was calculated using the Eq.:

$$R = (M_{ci} - M_{cf})/ t \qquad (3)$$

where,
M_{ci} = Initial moisture content of seeds before drying
M_{cf} = Final moisture content of seeds after drying
t = Drying time in hours

The energy developed in the solar dryer was calculated, by assuming the dryer to operate as a black body. The total energy emitted by a black body is given by the Stefan-Boltzmann equation as:

$$\sigma_b = \delta T^4 \qquad (4)$$

where,
σ_b = Total energy emitted by a black body (the subscript b designates a black body)
δ = Stefan - Boltzmann constant

Table 1: Drying rates of ogbono seeds dried in the dryer and in the open sun

Treatment combination D β A	R (%) Drying chamber	R (%) Open sun	Treatment combination D β A	R (%) Drying chamber	R (%) Open sun	Treatment combination D β A	R (%) Drying chamber	R (%) Open sun
1 1 1	7.26	4.20	2 1 1	7.33	4.17	3 1 1	7.21	3.90
1 2 1	8.63	4.08	2 2 1	10.03	4.03	3 2 1	8.73	4.13
1 3 1	7.46	4.23	2 3 1	8.77	4.10	3 3 1	7.43	3.80
1 4 1	6.93	4.27	2 4 1	7.33	3.93	3 4 1	6.63	3.80
1 1 2	6.50	3.93	2 1 2	6.87	4.03	3 1 2	6.53	3.93
1 2 2	6.83	3.97	2 2 2	7.97	4.03	3 2 2	6.97	4.20
1 3 2	6.30	4.13	2 3 2	7.76	4.13	3 3 2	6.30	3.73
1 4 2	6.17	3.77	2 4 2	7.03	4.13	3 4 2	6.13	3.87
1 1 3	4.00	3.97	2 1 3	4.47	4.17	3 1 3	4.13	3.77
1 2 3	4.83	3.93	2 2 3	6.13	4.03	3 2 3	5.03	4.20
1 3 3	4.17	3.90	2 3 3	4.60	3.67	3 3 3	4.97	3.77
1 4 3	4.27	4.03	2 4 3	4.60	4.10	3 4 3	4.63	3.80

1 2 3 4 : D (mm) 1.50 2.70 4.20; β^o 0 5 10 15; A (m^2) 0.60 0.42 0.24 where D = Thickness of plate; β = Tilt angle of plate; A = Cross sectional area

= 5.6697×10^{-8} W/m^2/^{o}K^4
T = Absolute temperature (^{o}k)

Efficiency of the solar dryer: From the similar work of Komolafe and Osunde (2005), the solar dryer efficiency was calculated as:

$$\eta = M_a C_{pa} (T_o - T_1)/AG_{sc} \qquad (5)$$

where,
- η = Solar dryer (collector) efficiency
- M_a = Air mass flow rate (kg/s)
- C_{pa} = Specific heat of air J/Kg^{o}C
- T_o = Average dryer temperature (outlet temperature)
- T_1 = Collector air inlet temperature
- A = Cross sectional area of collector plate (m^2)
- G_{sc} = Average daily insolation (W/m^2)

But $M_a = AVET_o \rho/T_1$

where,
- A, T_o & T_1 = As defined in Eq. (5)
- V = Drying air velocity
- E = Effectiveness of openings (given as 0.5 to 0.6 for perpendicular winds)
- ρ = Density of air

RESULTS AND DISCUSSION

The results of the drying tests of Ogbono seeds in the solar dryer and in the open sun are summarized in Table 1. It was observed from Table 1 that the drying rates for the seeds dried in the solar dryer are relatively higher than the seeds dried in the open sun.

Figure 1 shows the effect of the collector plate area of the dryer on the drying rate of the Ogbono seeds for the various tilt angles used and for plate thickness of 2.70 mm. It was evident from Fig. 1 that the drying rate increased as the area of the collector plate increased.

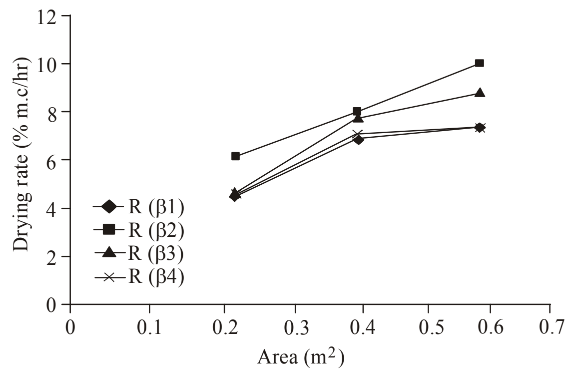

Fig. 1: Effect of area of plate on drying rate for plate thickness of 2.7 mm

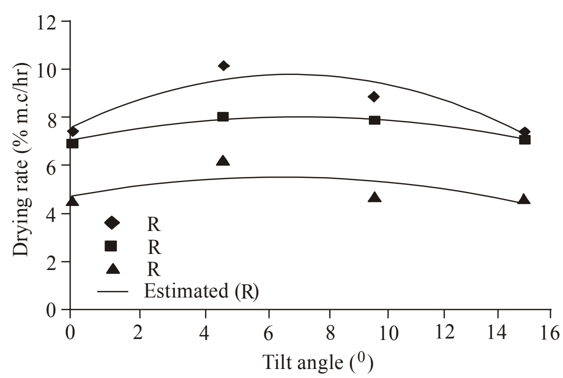

Fig. 2: Effect of tilt angle on drying rate for different collector areas at plate thickness of 2.7 mm

For the tilt angles β = 0, 5, 10 and 15° tested, it was evident from Fig. 1, that the drying rate in the tested solar dryer tended to be relatively at its highest value, when the plate was tilted at an angle β between 5° and 10°. The increase in the drying rate became more significant as the cross-sectional area of the plate increased from 0.24 to 0.60 m^2.

Figure 2 shows the relationship between the drying rate and tilt angle, for observed and estimated values, for plate thickness of 2.70 mm. A look at the individual curves showed that the drying rate had a quadratic relationship with the tilt angle. These quadratic relationships for areas ((A_1-A_3) could be described as relatively n-shaped. The following empirical models were developed for the effect of tilt angle on the drying rate for absorber plate thickness of 2.70 mm:

$$A_1: \ R = 7.519+0.5958\beta - 0.0414\beta^2 \ (r^2 = 0.92) \qquad (6)$$

$$A_2: \ R = 6.9095+0.2799\beta - 0.183\beta^2 \ (r^2 = 0.96) \qquad (7)$$

$$A_3: \ R = 4.706+0.2262\beta - 0.0166\beta^2 \ (r^2 = 0.73) \qquad (8)$$

The maximum drying Rates (R) of the seeds occurred at tilt angles (β), between 6.8º-7.6º. These are in agreement with similar findings in literature that the optimum dryer performance occurred when the tilt angle was approximately equal to the local latitude of the place (USDE, 2004; Oje and Osunde, 1995).

Since Federal University of Technology, Owerri (FUTO) is located at Latitude 5º27′N, Longitude 7º2′E, the range of tilt angles β (6.8º to 7.6º) which produced the maximum drying rate are close to the local latitude of FUTO, the site for the experimental work.

Figure 3 shows the effect of thickness of absorber plate on the drying rate of Ogbono seeds for plate area of 0.60 m^2. The shape of the individual curves could be described as relatively quadratic. It was evident from Fig. 3 that the drying rate increased from 1.5 to 2.7 mm and then decreased slightly as the thickness of the absorber plate increased to 4.2 mm

It was observed from Table 1, that the seeds in the forced convention Solar dryer, dried about 2½ times faster than the seeds dried under ambient conditions. It was also observed that the color of the dried seeds in the solar dryer was dark grey while that of the seeds in the open sun was light brown and some of the seeds were charred.

CONCLUSION

Concerning the solar drying of Ogbono seeds in Owerri, Imo State, it can be concluded that:

- In the design of solar drying system, the maximum possible area of absorber plate should be used to maximize the insulation on the collector surface.
- However, the area used is a function of the heat energy to be developed by the dryer. It also depends on available space and cost of construction materials.
- For any designed or chosen area, the collector plate should be tilted at an angle (β) so that the tilt angle (β) equals local latitude ±5° for the optimum collection of solar energy.
- The thickness of absorber plate used should be within the range of 2.0 to 3.0 mm.
- The solar dryer should be used further, to test for other agricultural materials.

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