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ORIGINAL RESEARCH ARTICLE

# PERFORMANCE IMPROVEMENT OF AN INDIRECT SOLAR DRYER WITH SINGLE AXIS MANUAL TRACKING SYSTEM AND ANGULAR SIMULATION OF THE FLAT PLATE COLLECTOR REFLECTORS

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ABSTRACT

*The need of food preservation cannot be over-emphasised. Crops need to be processed and preserved in times of their abundance to ensure for life and specie sustainability in times of scarcity. Flat plate collectors (FPCs) are often made fixed and the positions of reflectors used on them are not normally specified; in this paper, a report of an experimental test of an indirect solar dryer whose FPC is operated manually in a single axis to track the sun is presented. To avoid incurring extra cost on the existing design, the FPC was rather made to be operated manually instead of the automation process. Using the Engineering Equation Solver (EES) and the TRNSYS 16 softwares, the angular positions of reflectors placed east and west on the FPC were simulated for the first quarter months of the year of the experiment – this included the month of the test. This is to ascertain the best positions for the reflectors in other to achieve maximum insolation. For the month of the test, March, the angular positions of the reflectors placed east and west of the FPC were found to be 40° and 80° respectively relative to the horizontal plane. The performance of the solar dryer in terms of the percentage moisture loss, drying rate, collector efficiency and drying efficiency was evaluated when the FPC was fixed and when it was made to track the sun and the results obtained there from were compared. In comparison, it was found that the dryer tested by manually tracking the sun increased the total percentage moisture loss by 5.11%; the total drying rate by 2.10×10$^{-5}$ kg/s; the average collector efficiency by 3.92% and the overall drying efficiency by 2.0% as compare to when the FPC was fixed, i.e. not tracking the sun. The indirect solar dryer with the ability to manually track the sun in a single axis using the meteorological conditions of Zaria, Nigeria was therefore found to have increased the performance of the system dryer as compare to when tracking of the sun was not done.*



## 1.0 Introduction

In the nations of world with less improved facilities, agricultural products are being wasted year in year out due to lack of proper handling. Bhardwaj et al. (2017) and Chan et al. (2015) reported that a significant percentage of agricultural losses are related to improper and/or untimely drying of foodstuffs such as cereal grains, pulses, tubers, meat, and fish among others. Estimate of the wastages of this agricultural produce is cited by Toğrul and Pehlivan (2004) to be of order of 40% emphasizing that under very adverse conditions, it can be as high as 80%. The use of

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dryers was suggested to serve as a solution to post-harvest wastages and contribute to the availability of food in developing countries (Toğrul and Pehlivan, 2004). In order to reduce postharvest losses and enable farmers increase the quality of their products, Weiss and Buchinger (2002) also suggested that the use of locally manufactured low cost solar dryers could reduce postharvest losses.

One major component needed by a solar dryer is the flat plate collector (FPC). The FPC or solar collector plate serve the purpose of heating up the ambient air before it is passed into use (Ajunwa et al., 2018); that is to say it helps in harnessing the solar insolation and raising its temperature above the ambient before it is passed into the drying chamber. The intensity of solar radiation falling on a FPC can be improved upon by use of reflective mirrors as reported by Maiti et al. (2011) and Shahat et al. (2016).

The flat plate collector can be made to track the sun. Tracking of the sun was is reported to avails extra energy for use. For instance, in their report, Kancevica et al. (2012) emphasized that "the task of the tracking system is to rotate and orientate the equipment of the solar energy collector so that the collector's surface is placed perpendicular to the solar rays all day long to receive maximum solar energy". Thus the primary benefit of a tracking system is to collect solar energy for the longest period of the day. Solar tracking, thus, ensures that the maximum amount of sunlight strikes the collectors throughout the day. It has also been estimated that the use of a tracking system, over a fixed system, can increase the power output by 30 - 60% (Mayank, 2014). Tracking can be achieved manually or by automation. Apart from adding to the initial cost of the system, Mayank (2014) reported that the automated trackers have the disadvantages of additional cost due to regular repair and maintenance. To avoid the aforementioned problems and yet have optimum tracking effect, the manual tracking system was rather reported in this paper.

Going round the world, a lot of solar dryers have been developed and tested for different applications. These include the works of Shanmugam and Natarajan (2007) that built and tested an indirect forced convection with desiccant integrated solar dryer. The useful temperature rise of about 10 ºC was achieved with mirror, which reduced the drying time by 2 hours and 4 hours for green peas and pineapple, respectively. The drying efficiency of the system varied between 43% and 55% and the pick-up efficiency between 20% and 60%.

Ajao and Adedeji (2008) assessed the drying rates of vegetables, tubers and grain crops. They considered four tropical crops in the passive type Solar dryer. Their report showed that high drying rate at an average dryer efficiency of 18% was recorded for yam at an average value of 9.0 g/hr while the lowest of 1.6 g/hr was recorded for pepper.

Bolaji and Olalusi (2008) designed and constructed a simple solar dryer consisting of a black painted, aluminum heat absorber plate mounted on a well-seasoned wood. They placed a foam material having thermal conductivity of .043W/mK in the space between the inner and outer box. They found from their test that the drying rate and collector efficiency for the drying of yam chips to be respectively 0.62 kg/hr and 57.5%. They concluded by stressing that the results of their experiment demonstrated a considerably high drying rate of their device for food products and could be useful in preserving food products at safe moisture levels.

Mohanraj and Chandrasekar (2009) developed an indirect forced convection solar dryer for drying chilies and incorporated it with sensible heat storage material. Their test revealed that the chili was dried from an initial moisture content of 72.8% to a final moisture content of about 9.2% at the bottom tray and about 9.7% (wet basis) on the top tray. With the inclusion of the heat storage material (gravel), they reported an increase in the drying time by about 4 hours per day. The estimated thermal efficiency of solar dryer was about 21% and specific moisture extraction rate was about 0.87 kg/kWh as they concluded.

Maiti et al. (2011) designed and developed an indirect, natural convection batch-type solar dryer which they fit on the solar collector with north-south reflectors. They reported that with the help of the reflectors, the solar collection efficiency with no load was enhanced from 40.0 to 58.5%. They dried a popular Indian wafer, 'papad', with desired moisture content of 12%, wet basis, which was achieved within 5 hours with their dryer.

Amedorme et al., (2013) designed and constructed a simple and inexpensive forced convection indirect solar dryer for drying moringa leaves. They dried a batch of moringa leaves, 2 kg by mass, with an initial moisture content of 80% wet basis from which 1.556 kg of water was needed to be removed to have it dried to a desired moisture content of 10% wet basis.

Eke and Arinze (2011) developed a direct mode natural convection mud type solar dryer used for drying maize. The moisture content was reduced from 29 to12% on wet basis from the conducted test. The dryer in comparison, achieved 55% saving in drying time against the open sun drying. The drying efficiencies for the dryer and the open sun drying systems were respectively reported to be 45.6% and 22.7%.

Adelaja and Babatope (2013) developed and evaluated a thermal and drying analysis on a natural convection indirect type of solar dryer which they tested by drying plantain fillets. The collection efficiency and system efficiency were respectively found to be 46.4 and 78.73% from their test. The collector also had moisture removal efficiency of 77.5% achieved in 20 hours.

Paul and Singh (2013) designed and developed a forced convection mirror booster based solar dryer for drying red chilli (Capsicum annum) in Madhya Pradesh, India. The test showed a reduction in drying time of chillies to be nearly 83% in comparison to open sun drying. The average time required to dry 1.5 kg chillies from moisture content of 89.09% to 4.36% on wet basis was reported to be 16 hours.

Rajagopal et al. (2014) developed an indirect forced convection solar dryer incorporated with evacuated tube collector used for drying of Copra. For the test, there was a reduction from 52.3 to 8% of the moisture content of Copra. It was observed also that the drying time in forced convection mode was less than the natural convection mode.

Chan et al. (2015) designed and constructed a recirculation type of solar dryer for drying rough rice. In the testing of the dryer, the experiment was performed under two different loads. In the first case, with load 104 kg, the moisture content was reduced from 28.4% to 14.3% in 5 hours at a drying air temperature of 50 °C, the efficiency here was 23.6%. While in the second drying process, with a load of 200 kg, the moisture content was reduced from 27.3% to 14.6% within 8 hours, with 35.7% efficiency under drying air temperature of 47 °C.

Fudholi et al. (2016) carried out a novel design of solar dryer for salted catfish in Perlis, Malaysia. In the experimentation, 200 kg of salted catfish divided equally were placed on 8 trays with the drying temperature fixed at 50 °C. The moisture content was reduced from 73% (wb) to 30%

(wb) within 18 hours. 6.3 kg/h and 0.385 kg/kWh were respectively obtained as the moisture extraction rate and specific moisture extraction rate.

Jadhav et al. (2017) presented the design, construction and performance of a mixed-mode solar dryer. Results obtained from the test of the dryer showed that the temperatures inside the dryer and that of the collector were much higher than the ambient temperature during most hours of the day-light. The temperature rise inside the drying cabinet was up to 74% for about three hours immediately after 12.00 noon.

Bhardwaj et al. (2017) carried out an experimental investigation of an indirect solar dryer integrated with phase change material for drying Valeriana Jatamansi in Himachal Pradesh (India). The test for the system showed that, the moisture content of rhizomes reduced from 89% to 9% in 5 days as compared to heat pump drying and shade drying, which respectively took 8 days and 14 days. The drying time using phase change material reduced by 37.50% and 64.29% when compared to heat pump drying and shade drying, respectively.

Abubakar et al. (2018) developed and tested a mixed-mode solar dryers for crop drying with and without thermal storage materials. It was observed that the average drying rates, collector efficiencies, and drying efficiencies of the solar crop dryers with and without thermal storage for June and August 2016 test period were 2.71× 10−5 kg/s and 2.35 ×10−5 kg/s, 67.25% and 40.10 %, 28.75 % and 24.20% respectively. For the experimental results, the efficiency of the dryer with the storage materials is enhanced by about 13 % due to the thermal storage used.

Umar et al. (2018) designed and manufactured a solar dryer at Fadis Agricultural Research Center workshop of Oromia. For no load test, the collector raised the ambient temperature of air of 20°C to 41°C to a warm air of 28°C to 64°C between the morning and midday. Onion sliced at 3 mm thickness were loaded at a rate of 4 kg/m2 and dried in the dryer from an initial moisture content of 87.10% (w.b) to 9.1% (w.b) in 10 hours. For the works reviewed, there are no attempts by the researchers in trying to maximise the solar radiation available by day by tracking the sun with the FPC that has reflectors positioned east and west at optimised (simulated) angular positions.

Shahat et al. (2016) studied the effect of four drying methods such as natural sun drying and electric hot air drying method and compared with solar drying with or without reflective mirrors on grapes and apricot fruits. The results obtained indicated that, drying rate of tested samples using solar drying with reflective mirrors and electric hot air drying methods were faster than those without reflective mirrors and natural sun drying. They also reported that a useful temperature rise of about 10 ºC was achieved with the mirrors.

Lingayat et al. (2016) designed and developed an indirect type solar dryer to dry agricultural products. The experimental test of the dryer showed that moisture content of banana was reduced from initial value of 356% (db) to final moisture content of 16.3292%, 19.4736%, 21.1592%, 31.1582%, and 42.3748% (db) for Tray 1, Tray 2, Tray 3, Tray 4, and open sun drying respectively. The average thermal efficiency of the collector was found to be 31.50% and that of drying chamber was 22.38%.

Musembi et al. (2016) designed and fabricated an indirect natural convection updraft solar dryer suit for mid-latitude applications. The dryer was experimented by drying sliced apples of 2.5 mm thickness spread over the drying trays. For the experiment, 886.64 g of fresh apple with 86% moisture content were dried to a moisture content of 8.12 % (wet basis) within 9 hours 20 minutes at an average irradiance of 534.45 W/m2. The overall dryer efficiency was found to be 17.89%.

Puello-Mendez et al. (2017) constructed and tested a plastic roof solar dryer for drying cocoa beans. The test showed that the dryer was able to dry cocoa beans from 58 to 7 % in 6 days. while the greenhouse drying took only 4 days and produced better quality cocoa beans, protected from direct solar radiation, environmental pollution and animal contact.

Khan et al. (2018) developed and carried out a study on an innovative solar sustained maize dryer along with screw conveyor for unloading the grain and central air perforated duct (throughout aeration chamber length). The dryer was evaluated using 758 kg of freshly harvested maize at moisture content of 24% (wet basis). It was found to have a drying time of 27 hours in drying the whole maize from a moisture content of 24% to 13%.

Deshmukh et al. (2018) evaluated the performance of pop can solar dryer which worked as indirect type passive mode without thermal energy storage for the drying of products. All experimentations were carried at Amravati Maharashtra India. They reported that the use of pop-corn solar dryer reduced the drying time significantly and essentially provided a better product quality compared with conventional drying method.

This paper presents a system of solar dryer that is able to track the sun manually. The manual tracking system was rather chosen (instead of the automated system) to minimize the cost of production and that of regular repair and maintenance Mayank (2014) and yet have optimum tracking effect.

## 2. Materials and Methods

### 2.1 Description of the Dryer System

The system is made up of the flat plate collector, the drying chamber and the biomass combustion chamber as shown in Figure 1.

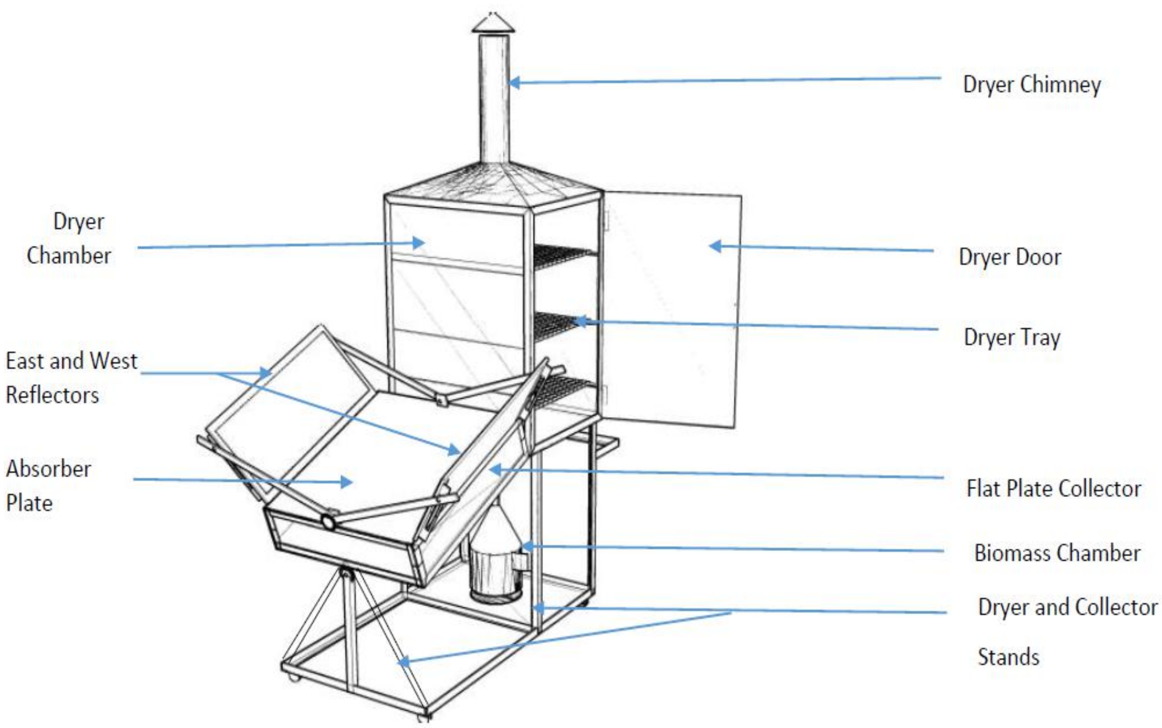


Figure 1: Schematic diagram of the dryer system

#### 2.1.1 The flat plate collector (FPC)

This avails the platform where the solar energy is harvested for drying. Its parts include:

a. Absorber plate: this was made of aluminum sheet metal painted black and of length 797 mm, width 531 mm and thickness 0.08 mm.

b. Glazing or glass cover: this was made of the transparent glass; dimensioned to the length of 797 mm, width 531 mm and thickness 4 mm.

c. Reflectors: two back silvered glasses each with dimensions 797 mm x 265.5 mm were used on both sides of the FPC to serve as reflectors and cover to the FPC.

#### 2.1.2 Drying chamber

This chamber holds the product which is being dried. It is made up of the following parts:

a. Dryer's body: the body of the dryer was made of plywood of thickness 10 mm with 753 mm x 531 mm dimensions.

b. Trays: this was made using the wire mesh with dimensions of 753 mm x 531 mm.

c. Chimney: a mild steel of 2 mm thickness, diameter 53.1 mm and height 407 mm shaped into a cylindrically form was used to make the chimney. This paper presents only the parts and results of the solar dryer (excluding the biomass chamber).

### 2.2 Working-Principle-of-the Dryer-System

The FPC which is tilted at 20° to the horizontal Ajunwa et al. (2018) was opened at one end for inlet air and the other end linked to the drying chamber. The FPC energized by the sun's rays entering through the glazing cover, heats up the FPC by converting high frequency, low wavelength radiations from the sun into low frequency, high wavelength radiations (greenhouse). This energy is boosted by the inner surface of the collector made of aluminum sheet painted black and the reflector mirrors; the trapped energy then heats up the air inside the FPC, creating an updraft of the heated air into the dryer where it is circulates removing water from the product being dried and finally expelled through the chimney. This whole process underwent a repetition until the crop being dried was dried to the desired moisture content.

### 2.3 TRNSYS/EES System Model for Optimum Reflector Angle

TRNSYS (Transient System Simulation) and EES (engineering equation solver) were used to model and simulate the best positions of the east and west mirrors placed on the FPC for optimum absorption. Average daily/hourly radiation over a time period was generated from the Typical Meteorological Year (TMY) weather data of (the location of the experiment) Zaria, Nigeria (latitude 11.2 °N and longitude 7.8 °E) using solar radiation and weather data processor of TRNSYS software. This simulation was performed in 2018; TMY however details the collation of selected weather data for a number of years over a specific location. The EES was linked to the TRNSYS through the Type66a. The equations governing the reflection of solar radiation from the reflectors Kumar et al. (1995) and transmittance – absorptance product were modelled in EES and linked to the TRNSYS model as shown in Figure 2.

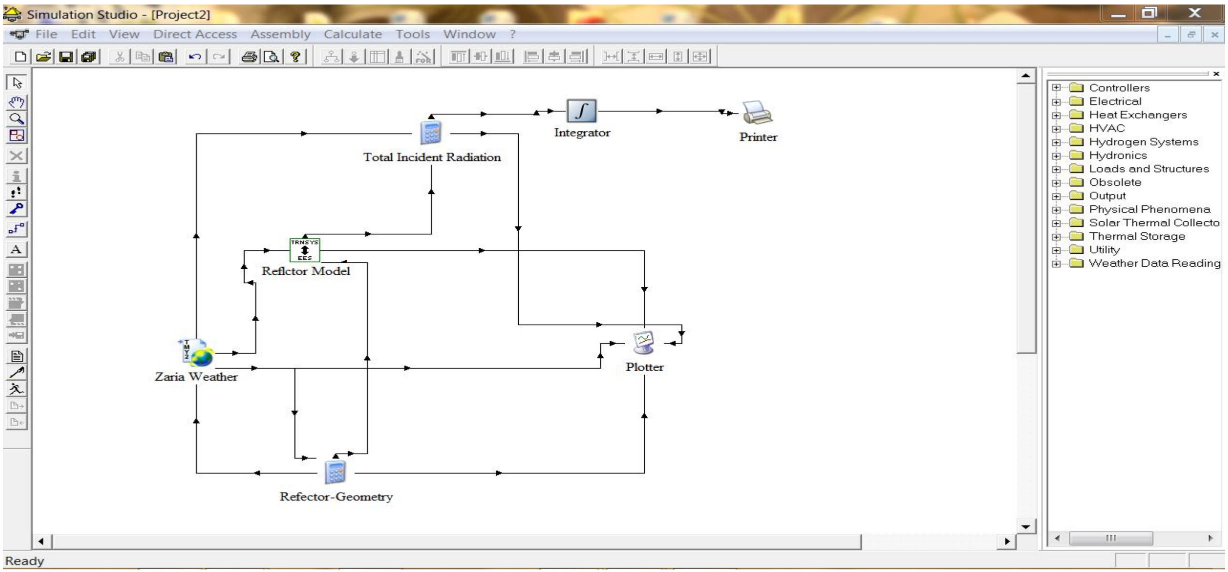


Figure 2: The TRNSYS/EES model of the system for the reflectors positions optimization.

The type TMY-2 weather data component evaluates the radiation values together with the angles associated with directions. The output was sent to the EES reflector model where the angle of incidence of reflected solar beam on the collector, and the exchange and shading factors of the reflectors were processed and returned to the TRNSYS environment. The transmittance – absorptance product was processed for the direct and reflected components of radiation and the output sent to the equations component which finally computes the absorbed solar radiation. The result was integrated by the Type24 quantity integrator. This integrates the absorbed energy over a period of time indicated in the control card. The result is finally displayed in the Type 25c printer component.

## 2.4 Manual tracking motion of the flat plate collector (FPC)

This involves manually reorienting the FPC such that the sun shines directly onto it. The FPC is adjusted by 15° for every 1 hour movement of the sun. Two discs, one affixed with a bearing at the middle and welded to the tip of the collector plate beneath it and the other with a rod at the middle and welded to the collector frame were made to mesh together with a clearance for easy east to west (and vice versa) movement. These discs were bored at the edges with 24, 15° 5 mm holes apart to help in the hourly manual repositioning of the collector plate using nut and bolt, with a hole that makes the collector plate stay horizontally upward by 12.00 noon (serving as the reference point). The FPC is positioned three steps, 45°, from its horizontal position facing eastward (this is its default state by 9.00 am). During the period of drying, 9.00 am to 5.00 pm, the FPC is tilted a step, 15°, for every one hour movement of the sun toward the west and finally repositioned to its default state after the day's drying; waiting for the commencement of the next day's drying process. The pictorial views of the collector facing the sun at noon time, before noon time and after noon time are shown in Figure 3.

## 2.5 Experimentation-of-the-System

### *2.5.1 Instrumentation of the system dryer*

The SL-100 Solarimeter: this measures the combined direct and diffuse solar radiation of the sun and was used to measure the solar radiation on the glazing surface of the collector.

Thermocouple wire and digital thermometer: the ambient air temperatures, collector outlet air temperature and the drying chamber temperature were all measured using copper/constantan thermocouple wires and a digital Kane-May 340 thermocouple device that measures temperature either in Celsius or Fahrenheit.

The digital Camry weighing scale: this was used to measure the weight loss of the tomato slices.

The EL-3 aero vane digital anemometer: This was used to measure the wind speed of the surrounding ambient air.

### *2.5.2 Testing of-the-dryer*

The ASHRAE/ANSI 93-2003 standard test procedure, which requires that during a collector test, the operating collector to be exposed to solar radiation and the fluid inlet and outlet temperatures, the fluid flow rate, radiation on the collector, ambient temperature and the wind speed be measured and recorded as recommended by Duffie et al. (2013) was followed. The testing of the dryer was carried out in March, 2018 in the Department of Mechanical Engineering, Ahmadu Bello University, Zaria, Nigeria (Latitude 11° 7′ 48′′ and Longitude 07° 41′). The moisture removal and thermal analysis which are the basic standard procedures for evaluating solar dryer performances as recommended by Leon et al. (2002) were also used in evaluating the dryer.

The main aim of the experimental setup (as shown in Figure 3) was to determine the performance of the solar dryer at hourly motion of the sun by monitoring the drying rate of 6 kg tomato sample placed in the drying chamber.


Figure 3: Pictorial (real) views of the FPC (a) facing the sun at noon time (b) facing east before noon time (c) facing west after noon time.

The drying procedure involved exposing the solar dryer to solar radiation and loaded with 2.0 kg of tomato slices of about average thickness of 5-10 mm on each of the three trays. In order to maximize insolation centration on the FPC, in this work, reflective mirrors were used on the east and west sides of the FPC at optimized angles of the first quarter months of the year which included the month of the test (March). Energized air (boosted by the black painted aluminum plate and reflector mirrors) from the FPC was siphoned into the drying chamber where it was circulated thereby transferring energy to the sliced fruits and abstracting moisture from it and finally expelled through the chimney. This whole process underwent a repetition until the fruits were dried to the desired moisture content. At an hourly interval, the ambient air temperature, temperatures of the air exiting from the collector, and that of trays 1, 2 and 3, and the hourly weight loss for each of the trays were recorded. The corresponding wind speed and solar radiation were also recorded. The drying started at 9.00 am and ended at 5.00 pm.

### *2.5.3 Evaluation of the dryer*

The following parameters were evaluated using the equations as:

a. Percentage moisture content, $m_{wb}$ on wet basis was calculated from Eqn.1 (Zaman and Bala, 1989):

$$m_{wb} = \frac{w_w - w_d}{w_w} \times 100\% \quad (1)$$

where; $w_w$ = weight of wet product, (kg), $w_d$ = weight of dried product, (kg)

b. Average drying rate, $m_{dr}$ was calculated from Eqn. 2 (Tonui et al., 2014):

$$m_{dr} = \frac{M_w}{t_d} \quad (2)$$

where; $M_w$ = mass of water evaporated from the product, (kg), $t_d$ = drying time, (hr).

c. Solar collector efficiency, $\eta_c$ was calculated from Eqn. 3 (Forson et al., 2007):

$$\eta_c = \frac{\dot{m}_a C_p (T_o - T_a)}{A_c I_T} \quad (3)$$

Where; $I_T$ = total solar radiation (W/m2), $T_a$ = ambient air temperature (°C), $T_o$ = temperature of outgoing air from the collector (°C), $\dot{m}_a$ = mass flow rate of air (kg/s).

d. Dryer efficiency, $\eta_d$ was calculated from Eqn. 4. (Forson et al., 2007):

$$\eta_d = \frac{M_w L_v}{I_T A_c t} \quad (4)$$

where; $M_w$= mass of water evaporated, (kg), $L_v$ = latent heat of vaporization of water, $t$ = drying time, (hours), $A_c$= collector area, ($m^2$).

## 3.0 Results and Discussion

### 3.1 Simulation of the reflectors positions placed west and east of the FPC

Using the TRNSYS 16 software application, simulated energy contribution of each of the reflectors placed on the east and the west (QRE and QRW) of the FPC was determined and plotted as a function of the reflector tilt angle is as shown in Figures 4. – 5.

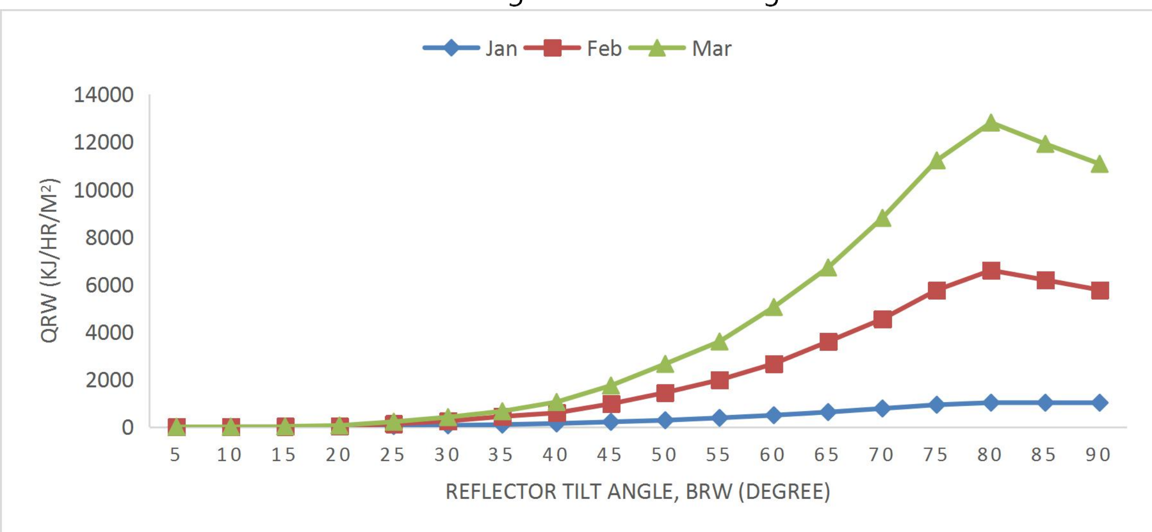


Figure 4: Solar energy absorbed with reflector RW for the first quarter months (January to March) of the year.

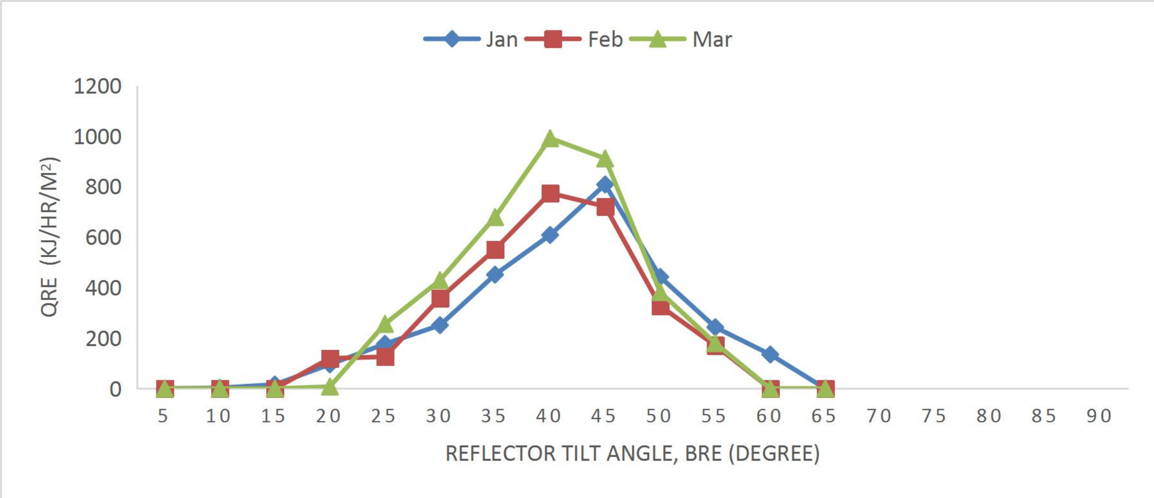


Figure 5: Solar energy absorbed with reflector RE for the first quarter months (January to March) of the year.

The optimum reflector angle for maximum enhancement is the value at the highest point of the curve for each month. Figure 4 shows the solar energy absorbed with reflector placed to the west of the flat plate collector (FPC), RW, for the first quarter months of the year (January to March); which include the month of the experiment, March. Figure 4 shows that, for optimum insolation absorption for the month of January, the reflector if placed on the west of the FPC should be inclined at 80° absorb 1019 kJ/hr/m$^2$, and at 80° to absorb 5572 kJ/hr/m$^2$ for the month of February and at 80° to absorb 6222 kJ/hr/m$^2$ for the month of March. After each of these angles of inclination however, there is a decrease in the amount of energy that can be absorbed by the reflectors. Since the experiment here was carried out in March, for maximum absorption, the reflector on the west of the FPC was positioned at 80° to absorb 6222 kJ/hr/m$^2$ of energy.

Figure 5. shows the solar energy absorbed with reflector placed to the east of the flat plate collector (FPC), RW, for the first quarter months of the year (January to March). This was done to include the month of the experiment, March. The Figure also shows that, for optimum energy absorption for the month of January, the reflector if placed on the east of the FPC should be inclined at 45°to absorb 808 kJ/hr/m$^2$, and at 40° to absorb 774 kJ/hr/m$^2$ for the month of February and at 40° to absorb 991 kJ/hr/m$^2$ for the month of March. After each of these angle of inclination, there was however a declination in the amount of energy absorbed by the reflectors. For maximum absorption, the reflector on the east of the FPC was positioned at 40° to absorb 991 kJ/hr/m$^2$ by March (month of test) for Zaria metropolis.

### 3.2 Fixed and tracking (manual) modes of the FPC

Figures 6 through 9 shows the line graphs for moisture content (%), drying rate (kg/s), collector efficiency (%) and drying efficiency (%) of the dryer for the experimental results for fixed and tracking (manual) modes of the FPC.

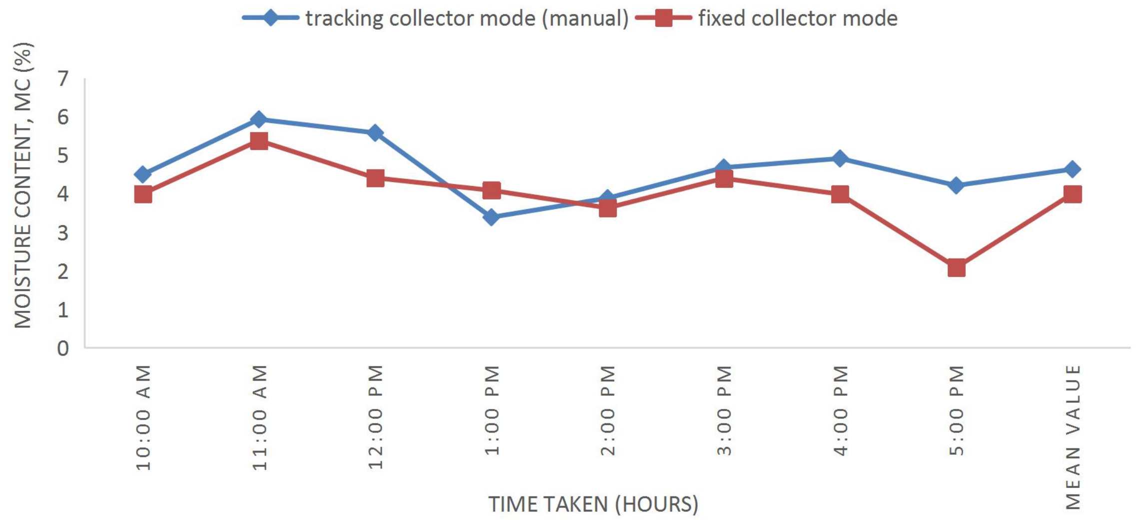


Fig. 6.: Variation of moisture content, MC (%) with time taken (hours) for drying for fixed and manual tracking modes of the FPC.

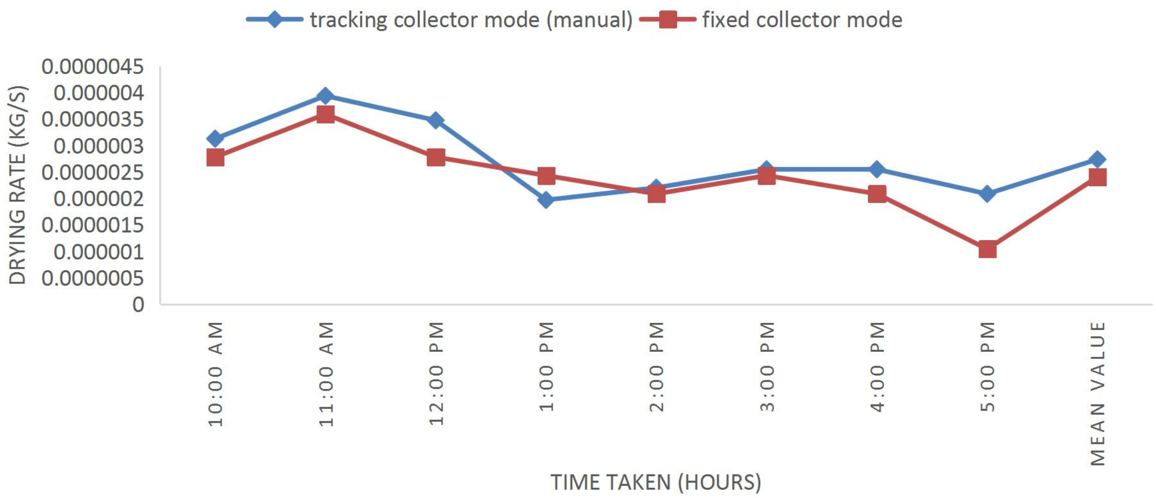


Fig. 7: Variation of drying rate (kg/s) with time taken (hours) for drying for fixed and manual tracking modes of the FPC.

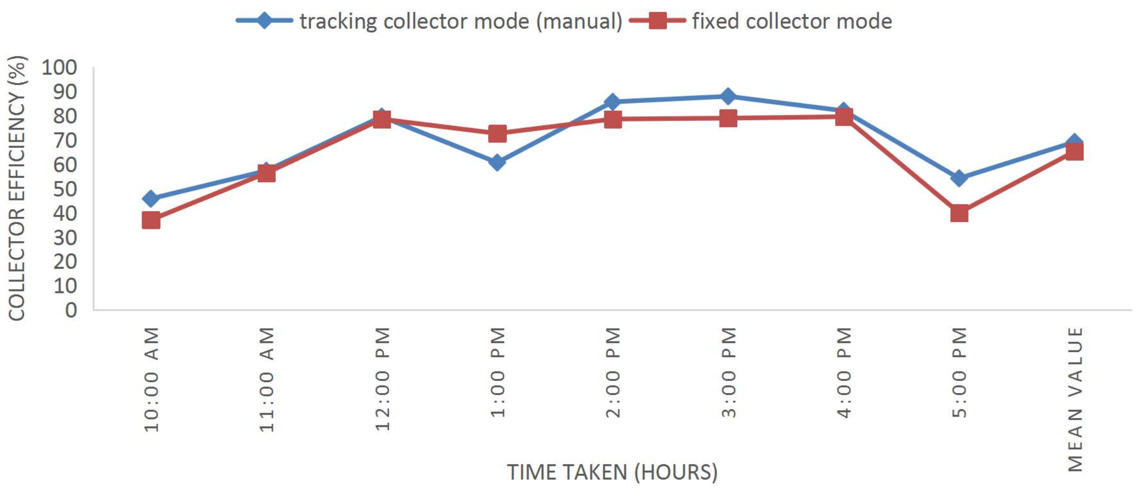


Fig. 8: Variation of collector efficiency (%) with time taken (hours) for drying for fixed and manual tracking modes of the FPC.

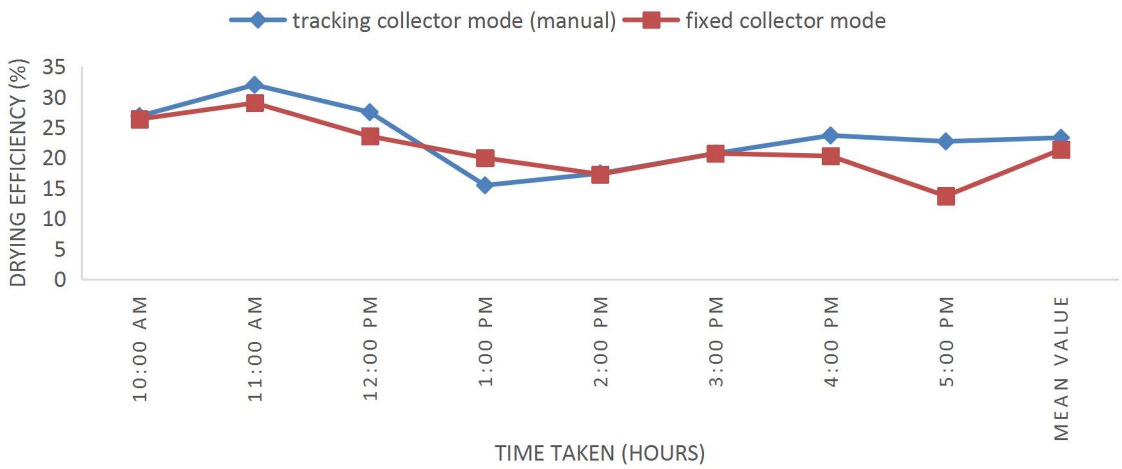


Fig 9: Variation of drying efficiency (%) with time taken (hours) for drying for fixed and manual tracking modes of the FPC.

Figure 6 shows the variation of percentage moisture loss (moisture content, MC) for the experimental values for fixed and manual tracking modes of the collector plate. From Figure 6 it can be observed that except for the period of 12.00 to 1.00 pm when the fixed mode of the collector plate recorded a higher value of 0.7% more than the tracking mode (both collectors being directly overhead at this time of the day); throughout the period of drying, the tracking mode system maintained a higher percentage moisture loss. While an average hourly moisture content of 4.00% was recorded for the fixed mode system, 4.64% was recorded for the tracking mode system. For the entire 8 hours drying period, 31.99% moisture content was recorded for the fixed mode while 37.10% was recorded for the manual tracking mode system with the manual tracking system performing better by 5.11%. The tracking mode system is observed to record higher values of moisture content both in the mornings and evenings of drying; this could be because of the tilting of the collector plate to harvest both the morning and the evening energies. It is observed in this work that there was a decrease in moisture (i.e. increase in percentage moisture loss) of the food product with time as also reported by Paul and Singh (2013), Amedorme et al. (2013) and Musembi et al. (2016).

Figure 7 shows the graph variation of drying rate for the experimental values for fixed and manual tracking modes of the collector plate. From figure 7., it can be observed that, except for the period of 12.00 to 1.00 pm when the fixed mode of the collector plate recorded a higher hourly value; throughout the period of drying, the tracking mode system maintained a higher hourly drying rate. An average hourly drying rate of $2.19\times10^{-5}$ kg/s was recorded for the tracking mode system, while $1.92\times10^{-5}$ kg/s was recorded for the fixed mode system. For the entire drying period, $1.54\times10^{-4}$ kg/s drying rate was recorded for the fixed mode while $1.75\times10^{-4}$ kg/s was recorded for the manual tracking mode system with the manual tracking system performing better by $2.10\times10^{-5}$ kg/s. Bolaji and Olalusi (2008) reported a drying rate of 0.62 kg/hr ($1.72\times10^{-4}$ kg/s) in their designed and constructed simple solar dryer. The manual tracking mode system in this work which recorded an average drying rate of $1.75\times10^{-4}$ kg/s showed a slight improvement over what is obtained by Bolaji and Olalusi. The results of the drying rate obtained for both the fixed and the manual tracking systems reveal a higher performance as when compare with that reported by Ajao and Adedeji, (2008) who obtained an average drying rate of (9.0 g/hr) $2.50\times10^{-6}$ kg/s. This shows good functionality of this dryer in terms moisture extraction rate of the product being dried.

Figure 8. shows the graph of variation of collector efficiency for the experimental values for the test of the dryer for fixed and manual tracking modes of the collector plate. The tracking mode system is observed to record higher values both in the morning and evening of the drying, due to the harvest of the morning and evening radiation by tilting the collector plate. Except for 1.00 pm, when the fixed mode system recorded a higher value of efficiency. While an average collector efficiency of 69.09% was recorded for the tracking mode system, 65.17% was recorded for the fixed mode system throughout the period of drying. While Maiti et al. (2011) recorded a collector efficiency of 40.0% which was enhanced to 58.5% by the use of north-south reflectors, Lingayat et al. (2016) reported an average thermal efficiency of their collector to be 31.50%; the efficiency obtained in this work shows an improvement over that reported by both Maiti et al. (2011) and Lingayat et al. (2016). Moreover, the result here also shows an improvement of 18.77% for the fixed system and 22.69% for the manual system over that reported by Adelaja et al. (2013) who reported a collector efficiency of 46.4% in their work.

Figure 9. shows the graph of variation of drying efficiency for the experimental values for the test of the dryer for fixed and manual tracking modes of the collector plate. From the figure (9.), it can be seen that from 10.00 am to 12.00 pm, the tracking mode recorded an average hourly drying efficiency value of 2.49% higher than the fixed mode system. By 1.00 am however, the fixed mode system recorded a drying efficiency value of 4.50% higher than the tracking mode system. Between the hours of 2.00 and 3.00 pm, both modes (tracking and fixed) recorded approximately equal values. After 3.00 pm, between the hours of 4.00 and 5.00 pm, the tracking mode recorded an hourly average value of 6.19% higher than the fixed mode system. In as much as drying efficiency takes into consideration the weights of the products being dried, it also faces consistency in its graphical (values) representations since it also partly depends on solar insolation and air speed rate which varies periodically. For the entire drying period, 21.33% drying efficiency was recorded for the fixed mode system while 23.27% was recorded for the manual tracking mode system with the manual tracking system performing better by an approximate value of 2.0%.  Mohanraj and Chandrasekar, (2009) and Ajao and Adedeji, (2008) respectively reported drying efficiencies of 21% and 18% in their various works; in this work, while the fixed mode system recorded an approximate same drying efficiency with that reported by Mohanraj and Chandrasekar, the manual tracking mode system showed an improvement of 2.27% over that reported by Mohanraj and Chandrasekar and an improvement of 5.27% over that reported by Ajao and Adedeji, (2008). The overall dryer efficiency (of 17.89%) reported also by Musembi et al. (2016) showed that the dryer efficiency obtained in this work have an improvement over theirs for both the fixed and the manual tracking systems which yielded 21.33% and 23.27% respectively. The use of reflectors and the tracking system employed could have led to the dryer in this work performing better.

## 4. Conclusion

The performance of an indirect solar dryer with the ability to manually track the sun in a single axis was successfully carried out at the Ahmadu Bello University, Zaria using the meteorological conditions of Zaria, Nigeria. The angular positions of the west and east mirrors placed on a flat plate collector was successfully determined for the first quarter months of the year(January to March) which include the month of the test, March. The angular positions of the west and east reflectors on the FPC were respectively found to be 80° and 45° for the month of January, 80° and 40° for the month of February; and 80° and 40° for the month of March, the month of the test.

The test of the dryer carried out by tracking the sun increased its performance as compared to when drying was done without tracking. The dryer tested by manually tracking the sun increased the total percentage moisture loss by 5.11%; the total drying rate by 2.10x10-5 kg/s; the average collector efficiency by 3.92% and the overall drying efficiency by 2.0% as compare to when tracking of the sun was not done.

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