Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

Experimental Testing of a High Performance Dehydrator for High Moisture Content Agricultural Crop Samples

Onoroh, F.

Department of Mechanical Engineering, University of Lagos, Akoka, Yaba, Lagos, Nigeria.
fonoroh@unilag.edu.ng

http://doi.org/10.5281/zenodo.12600859

ARTICLE INFORMATION

Article history:
Received 15 May 2024
Revised 15 Jun. 2024
Accepted 17 Jun. 2024
Available online 30 Jun. 2024

Keywords:
Dehydrator
Diffusivity
Temperature
Relative humidity
Drying rate
Crop samples

ABSTRACT

This research developed an innovative agricultural produce dehydrator that uses biomass or natural gas as source of heat. The dehydrator consist of the drying cabinet, dual combustion chamber with integrated air heater and a blower. The cabinet has an inbuilt air plenum to ensure even distribution of heat across the surface of the drying trays to enhance uniform drying. The air heater is a five pass heat exchanger to ensure optimum absorption of heat from the combustion chamber. The dehydrator was tested by simultaneously drying Dioscorea rotundata (yam), Musa paradisiaca (plantain) and Zea mays (corn) at the bottom, middle and topmost trays respectively while monitoring the air velocity, temperatures and relative humidity of inlet and outlet air. The maximum temperatures recorded for the inlet air, bottom tray, middle tray , topmost tray , and the exit air are 191.2 ºC, 106.4 °C, 99.6 °C, 100.8 °C, and 81.4 °C, respectively at a speed of 3 m/s, dehydration rate of 0.3, 0.18, 0.092 kg/h and diffusion coefficient of 14.8×10^{-8}, 17.97×10^{-8} *and* 17.90×10^{-9} *m*^{2}*/s. The developed dehydrator offers a sustainable, faster and energy-efficient solution for drying high moisture contents crops.*

1. INTRODUCTION

Agricultural produce preservation is the science that deals with the process of preventing food from decaying or spoiling, allowing it to be preserved in good condition for future use (Ajunwa et al, 2020). Drying, spray drying, freeze-drying, freezing, vacuum-packing, canning, food irradiation, and adding preservatives or inert gases such as carbon dioxide are all examples of preservation procedures. Pickling, salting, smoking, preserving sugar syrup, and curing are some other procedures that help preserve food and enhance flavor. Foods are dehydrated to prevent microbial growth; bacteria and enzymes that aid degradation of agricultural produce (Chibuzo et al, 2021) and to reduce weight and volume of crop samples.

Foods that are dried are enticing, nourishing, light, simple to prepare, store, and use. Energy usage is lower than when freezing or canning, and the amount of storage space needed is far less than when using canning jars and freezer containers (Akinjola and Balachandran, 2012; Ajunwa et al, 2020). In a drying process the moist crop sample must obtain heat from its surroundings by convection, radiation, or conduction, or by internal generation such as dielectric or inductive heating. For drying to occur, the moisture in the body evaporates, and the vapour is received by a carrier gas. Drying is a labour-intensive, time-consuming process that uses a lot of energy and food can be dried for a variety of reasons; it preserves food for a long time, allowing its availability in and out of season (Keey, 2011). Food shrinks about half its original size and loses up to 90% of its weight when dried.

Sun and solar drying of crops are the most common method of food preservation due to near zero energy consumption (Ronoh et al., 2010; Akinjiola and Balachandran, 2012; Olaniyan and Adeoye, 2014). However, sun-drying and solar drying methods are inadequate or unreliable due to their reliance on prevailing weather conditions, vulnerability to pest infestation and require longer drying period resulting to crop destruction and reduced productivity. Therefore, there is a pressing need to develop an improved drying method that reduces wastages and reduce drying time of agricultural crops while overcoming the limitations associated with direct sunshine and dependence on both electricity and weather conditions.

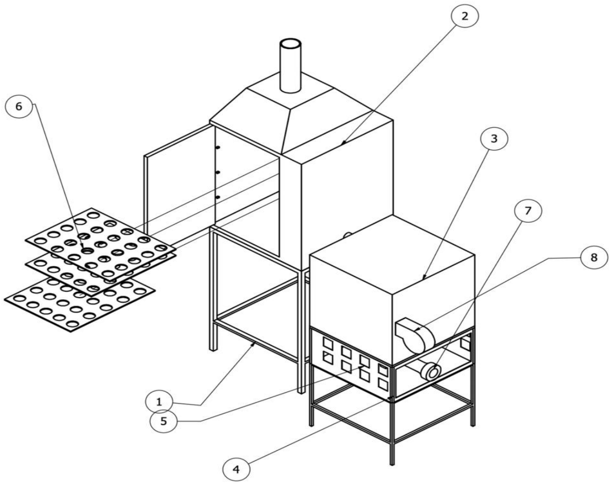
Ndirangu et al. (2020) investigated the design and performance of a solar-biomass greenhouse drier for drying selected agricultural products. They discovered that the heat provided by a solar dryer was insufficient for achieving the best drying rates. As a result, they used bimodal biomass heating systems to supplement the sun energy. Temperature, relative humidity and weight change were monitored to track the dryer's performance. Within the first three hours, the dryer temperature recorded were 49.3 °C, 53.8 °C, and 53.2 °C respectively in the natural, forced and hybrid modes of drying. Tiwari (2016) conducted a review on solar drying of agricultural produce. Different sun dryer developments were examined, as well as an overview of sophisticated solar dryers. Solar energy provides both the heat required to remove moisture as well as the electricity required to drive fans. He concluded that solar dryer had both advantages and disadvantages; the higher drying rate resulted in a larger food throughput as well as a smaller drying surface (about one third) and worse efficiency when compared to modern dryers and that the effectiveness of solar dryers is highly influenced by weather conditions. A combined solar and biomass dryer was conceived, built, and assessed by Okoroigwe et al. (2013). They have a biomass burner as well as a solar drying area in their design. They assert that using a combined solar and biomass dryer has the potential to increase output and, consequently, profitability. They concluded that a combination of solar and biomass as a source of heat enhance drying efficiency, which is in agreement with the report by Udomkun et al. (2020) that reviewed solar dryers for agricultural products in Asia and Africa. Results showed a maximum temperature of 53 °C and a drying rate of 0.0142 kg/h. The mixed-mode natural convection of a solar dryer that is integrated with a straightforward biomass burner and bricks for heat storage was described by Tarigan and Tekasakul (2005). With freshly collected unshelled groundnuts, the drier was tested, and it was discovered that the solar component by itself had a drying efficiency of 23 %. When the daily solar radiation was only an average of 350 W/m^2/day, the burner with heat storage was found to have a 40% efficiency in producing useful heat for drying. The drying chamber's jacket and gap, as well as the strategically placed bricks for storing heat, were important dryer design elements that contributed to an appropriate thermal efficiency and uniform drying air temperature across the trays. Using a track-able solar collector, Kumarasiriwardhana et al. (2020) created, produced, and tested a solar-biomass hybrid dryer. A recently created solar and biomass hybrid dryer consisted of a drying chamber, a solar collector with a sun tracking option, and a backup heater built of biomass. The solar collector in this recently created dryer was created to increase efficiency by following the daily revolution of the sun. The overall effectiveness of the backup heater in a dryer made by Tibebu (2015) was 40 % when rice husk was used as the fuel source. The newly constructed dryer's biomass burner had a poor efficiency of 26.56 %, which was ascribed to heat losses from the duct and air ventilation systems. Toshniwal and Karale (2013) conducted a review on Solar Dryer. Discussed Solar dryers came in a variety of designs, including direct, indirect, forced, and natural convection. They concluded that solar dryers are not without flaws as they have a low efficiency and drying rates when it is cloudy or rainy. Solar dryers are more expensive up front, but they generate better-looking, better-tasting, and more nutritious meals, increasing their nutritional value and marketability. They're also more efficient, faster, and safer than traditional sun-drying methods. Kilanko et al (2019) designed and evaluated a solar dryer with the inner half of the dryer lined with an aluminum foil to act as an insulator. The solar collector is constructed of galvanized sheets with a layer of glass on top and experimentally tested with fresh scotch bonnet pepper dried for three weeks each. Weight reduction was measured using 200 g of pepper that was weighed on a regular balance. Throughout the studies, data loggers were used to record the temperature and humidity of the drying chamber and its surroundings. An average moisture content of 81.3 % wet bulb was removed from the dryer with an efficiency of 28.4 %.

This present research document a unique dual combustion agricultural produce dehydrator with inbuilt air plenum drying cabinet and a multi-pass heat exchanger with biomass and or compressed natural gas as source of energy, this design offers a flexible choice of energy source which makes it readily available for both rural and urban communities.

2. METHODOLOGY

2.1. The Dehydrator Model

Figure 1 shows the model of the dehydrator. The assembly consist of the drying cabinet with three trays, a five pass hot air heat exchanger with direct current air blower and a dual combustion chamber.



1. Dryer cabinet with stand
2. Air plenum
3. Heat Exchanger
4. Combustion chamber and heat exchanger stand
5. Biomass/gas combustion chamber
6. Drying tray
7. Blower

Figure 1: Model of dehydrator

2.1.1. The drying cabinet

Hot air is supplied to the closed air tight drying cabinet through an indirect heating method to eliminate any form of contamination either through combustion gases and or rodent infestation in the course of the drying cycle. The drying cabinet has three trays with overall dimension of 500 mm x 500 mm x 600 mm and tray spacing of 130 mm, the inbuilt air plenum has a dimension of 500 mm x 100 mm x 600 mm. The drying cabinet desired temperature specification limit is between 70 °C – 100 °C, since it will be experimented with *Dioscorea rotundata* (yam), *Musa paradisiaca* (plantain) and *Zea mays* (corn) with optimal drying temperature of 65 °C, 70 °C and 98 °C respectively (Aasa et al., 2012). The amount of dehydration from each crop sample is determined using Equation (1) (Ichsani and Dyah, 2002):

$$m_w = m_i\left(\frac{M_o - M_f}{100-M_f}\right) \tag{1}$$

Where m_i is the initial mass of crop sample kg; M_o and M_f are the initial and final moisture content of crop sample in % (wet basis), for yam the numerical values are 70% and 12%, for corn 30% and 15% while for plantain, 60% and 13% while respectively (Muritala et al, 2022). The quantity of heat required to dehydrate the crop sample can be approximated using Equation (2) (Eke, 2014):

$$Q_v = m_w[2{,}502{,}585.259 - 2{,}385.76424\,(T_d - 273.16)] \tag{2}$$

Where T_d is the drying temperature, K. The quantity of air, V_a , needed for drying can readily be obtained using Equation (3) (Ichsani and Dyah, 2002):

$$V_a = \frac{Q_v}{\rho_a\ C_{pa}\,(T_2 - T_3)} \tag{3}$$

Where C_{pa} is the specific heat capacity of air at constant pressure in J/kgK; T_2 and T_3 are the inlet and exit temperature of drying air respectively in °C; ρ_a is air density kg/m^3. Diffusion co-efficient of the crop sample which is a measure of how quickly moisture flows from inside to its outside surface as it is dehydrated is defined by Equation (4) (Guillermo et al. 2021):

$$D_a = \frac{-4L^2 \ln\left(\frac{\pi^2 m_f}{8m_i}\right)}{(\pi^2 t)} \tag{4}$$

Where L is the thickness of the crop sample slice, m; t is the drying time, s. According to Dhanushkodi et al., (2015), the cabinet efficiency, η_D, is defined using Equation (5):

$$\eta_D = \frac{T_2 - T_3}{T_2 - T_1} \tag{5}$$

Where T_1 is the temperature of air entering the heat exchanger, °C. The inlet and exit air moisture content and relative humidity are obtained using Equation (6) and Equation (7) respectively (Khurmi and Gupta, 2008):

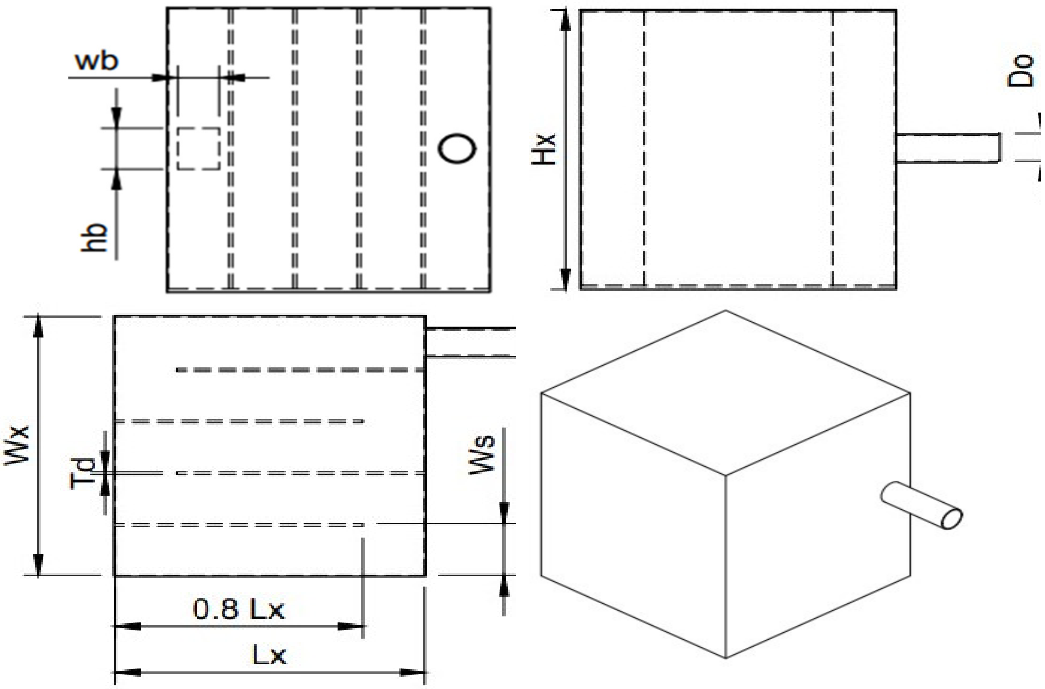
$$MC = \frac{0.622P_v}{P_{atm} - P_v} \tag{6}$$

$$\emptyset = \frac{P_v}{P_{vs}} \tag{7}$$

Where P_v is the partial pressure of water vapour, P_{vs} is the partial pressure of water vapour in a saturated air and P_{atm} is the prevailing atmospheric pressure, Pa.

2.1.2. Heat exchanger

The constructional details of the heat exchanger is as shown in Figure 2. Heat is supplied by combustion in the combustion chamber to the base plate of the heat exchanger and cold air is passed into it using a DC blower. Its dimension is 450 mm x 450 mm x 500 mm consisting of five air passes with passage width of 90 mm. The essence of the dividers is to ensure uniform heating of the air before it exits into the drying cabinet. The air is expected to exit the air heater in the temperature range of 70 °C to 100 °C due to the nature of the products to be dried.



Dimensions in mm: Hx=500, Do=45, Wx=450, Ws=90, Lx=450, Td=5, Wb=58, hb=72

Figure 2: Air heater heat exchanger

The effectiveness of energy conversion is determined using Equation (8):

$$\epsilon = \frac{T_2 - T_1}{T_c - T_1} \tag{8}$$

Where T_c is the combustion temperatures respectively, °C.

2.1.3. Combustion chamber

Figure 3 shows the constructional frame work of the combustion chamber. The combustion chamber is rectangular with air vent to ensure that there is sufficient air for combustion. It is a dual combustion chamber either charcoal and or compressed natural gas can be used as fuel, with a provision for easy dismantling of the gas burner when charcoal is the preferred fuel. The design specification is such that the thermal storage plate of the heat exchanger is maintained at a constant temperature of 1000 ºC.

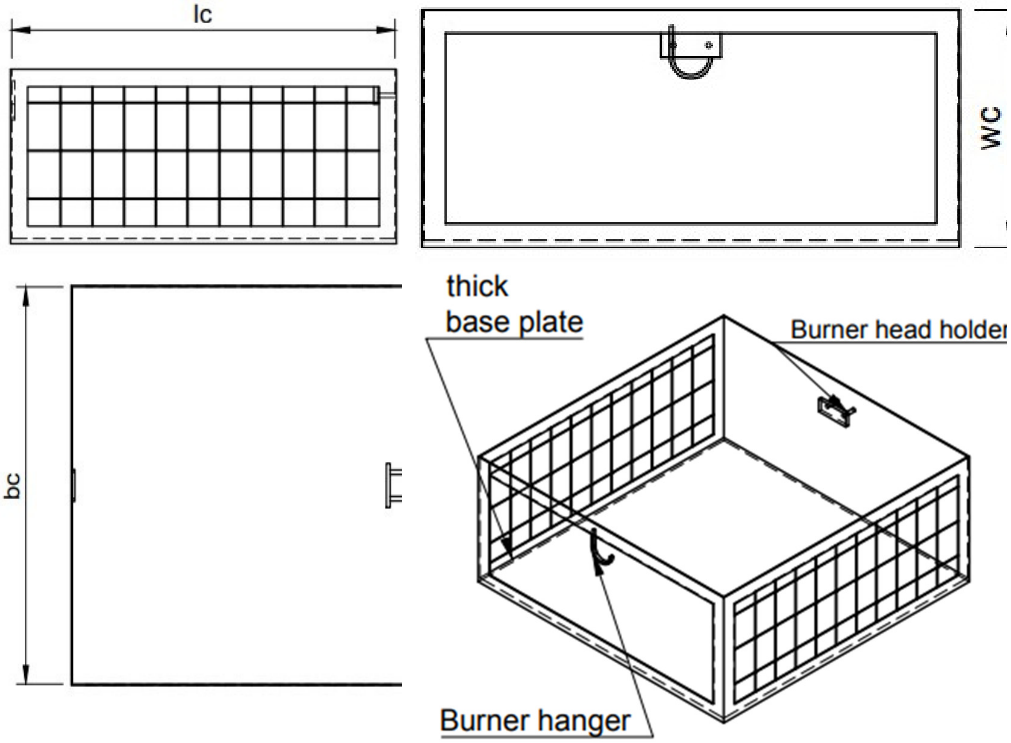
The quantity of heat, Q_c, from combustion of biomass is defined by Equation (9) (Okoroigwe et al., 2013):

$$Q_c = \eta_c m_c c_v \tag{9}$$

Where η_c is the efficiency of the combustion, %; c_v is the heating value of the biomass, kJ/kg; m_c is the mass of biomass, kg. The efficiency of the combustion can be calculated using Equation (10) (Dhanushkodi et al., 2015).

$$\eta_c = \frac{m_f \; x \; c_{pa} \; (T_2 - T_1)}{(m_c \times c_v) + E} \tag{10}$$

Where m_f is the mass flow rate of flue gas, kg/h; E is the energy consumption of the blower, kWh.



Dimensions in mm: Ic=bc=450, Wc=200

Figure 3: Combustion chamber

2.2. Preparation of Samples

This research focused on the development and experimental testing of an agricultural produce dehydrator. It consists of the drying cabinet with three trays, heat exchanger and the combustion chamber properly sized and fabricated. The dehydrator was simultaneously tested using *Dioscorea totundata* (yam), *Musa paradisiaca* (plantain) and *Zea mays* (corn) in each of the trays. These were sliced and weighed before being placed on the drying trays and into the drying cabinet with the exception of corn and reweigh at a time interval of thirty minutes to determine the moisture removal rate. In the course of the experiment the air velocity was measured using a digital anemometer, GM 8908, the inlet and outlet relative humidity, were measured chamber using a digital psychrometer, 8706, a three channel temperature data loggers, MTM-380SD, was used to measure the cabinet inlet temperature, each tray temperature and exit air temperature of the dehydrator respectively while the prevailing solar radiation incident on the photovoltaic module for powering the blower was measured using a Solar Power Meter, TM-206. Figure 4 shows the rig and measurement instrument.

Dehydrator Solar power meter Psychrometer

Anemometer Solar panel Temperature logger

Figure 4: Test rig

3. RESULTS AND DISCUSSION

3.1. Temperature Distribution inside the Dehydrator

Slices of *Dioscorea* (yam), *Musa paradisisca* (plantain) and *Zea mays* (corn) were arranged in the bottom tray, middle tray, and topmost tray respectively and temperatures monitored real time. Figure 5 presents a plot of inlet temperature to the drying cabinet, tray temperatures and the exit temperature of the drying cabinet against time, recorded between the hours of 10:00 am to 5:00 pm on the 21st of June, 2023 using biomass as fuel. The ever-changing temperature profiles is due to uneven combustion of the biomass and heat transfer losses to the environment due to conduction from the walls of the cabinet. The bottom tray consistently registered the highest drying temperature, followed by the middle tray and then the topmost tray though at some points in the course of the experiment the topmost temperature is higher than the middle tray temperature, with the exit outlet temperature been the lowest recorded as expected. The maximum inlet temperature, tray temperatures and exit temperature are 191.2 °C, 106.4 °C, 99.6 °C, 100.8 °C, and 81.4 °C, respectively, with average temperature difference between trays been 5.4 °C.

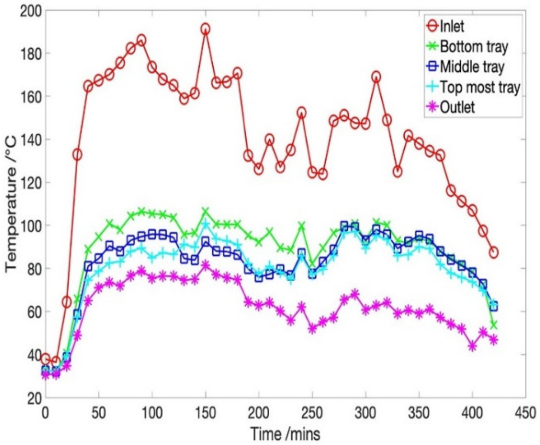


Figure 5: Cabinet temperature vs time

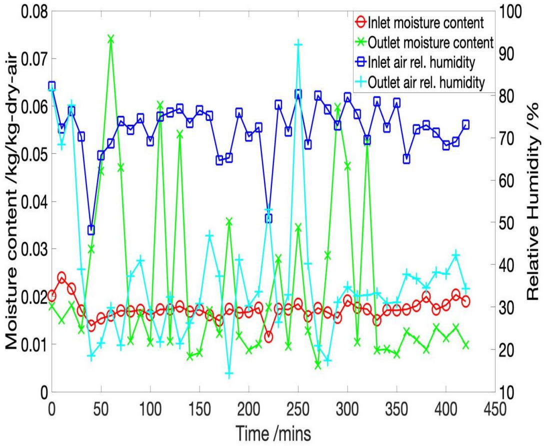


Figure 6: Dehydration and relative humidity vs time of inlet and outlet air

3.2. Moisture Content and Relative Humidity

Figure 6 depicts the variation of moisture content and relative humidity against time, recorded between the hours of 10:00 am to 5:00 pm on the 21st of June, 2023. The relative humidity and content profiles are impulsive as expected due to the dynamic nature of the atmosphere. As expected the moisture content of the incoming air is greater than the moisture content of the outgoing air due to the dehydration of the crop samples while the inlet relative humidity is consistently higher than the outlet relative humidity at the exit of the drying cabinet. Thus a decrease in relative humidity and increase in moisture content of the exit air correspond to a greater weight loss of the crop samples a trend also observed by Tibebu et al. (2016) and Khan et al. (2018).

3.3. Drying Parameters

Table 1 illustrates the drying parameters over time from 10:00 am to 5:00 pm on June 21, 2023 with an air velocity of 3.8 m/s. The initial mass of Dioscorea (yam), Musa paradisisca (plantain) and Zea Mays (corn) before drying were 2.35, 1.6 and 2.75 kg, respectively. After drying, the final mass were 1.6 kg for yam, 1.15 kg for plantain after 2.5 hours and 2.15 kg for corn after 6 hours. The total mass of water removed was 0.55 kg for corn, 0.75 kg for yam, and 0.45 kg for plantain yielding a drying rate of 0.092 kg/h for corn, 0.3 kg/h for yam, and 0.18 kg/h for plantain.

Table 1: Drying parameters

Parameters	Yam	Plantain	Corn
Initial mass /kg	2.350	1.600	2.750
Final mass /kg	1.600	1.150	1.150
Experimental dehydration /kg	0.750	0.450	0.550
Drying time /hr	2.500	2.500	6.000
Drying rate kg/hr	0.300	0.180	0.092
Theoretical dehydration /kg	1.549	0.864	0.485
Initial moisture content /%	72.000	60.000	30.000
Final moisture content /%	12.000	15.000	15.000
Heat required for dehydration /kW	0.387	0.218	0.051
Diffusivity /m/s^2	14.80×10^{-8}	17.97×10^{-8}	17.90×10^{-9}

As expected the quantity of heat required for dehydration is highest for yam with the maximum initial moisture content. The diffusion coefficient which quantifies the rate at which moisture migrates from the interior to the surface of the Dioscorea (yam), Musa paradisisca (plantain) and Zea Mays (corn) is presented in table 1. The diffusion coefficient for yam and plantain after two and half hours of operation are14.80×10^{-8}, 17.97×10^{-8} and that for corn after six hours of steady operation is 17.90×10^{-9} m/s^2 and plantain having the greatest diffusivity coefficient. During the drying process, the rate of moisture transfer changes steadily and the differing diffusion coefficients across the three crop samples is as a result of their unique physical structures and compositions, which influenced the rate of moisture removal.

3.4. Effectiveness of Heat Exchanger and Dehydrator Efficiency against Time

Figure 7 presents the variation of heat exchanger effectiveness and cabinet drying efficiency against time, recorded between the hours of 10:00 am to 5:00 pm on June 21, 2023. The graphs exhibit a dynamic pattern, fluctuating in response to the time of day and atmospheric conditions. The intensity of solar radiation as shown in Figure 8 is crucial for the drying process as it affect the ambient temperature, moisture content and relative humidity of air entering the cabinet which in turn has a great impact on the effectiveness and drying cabinet efficiency.

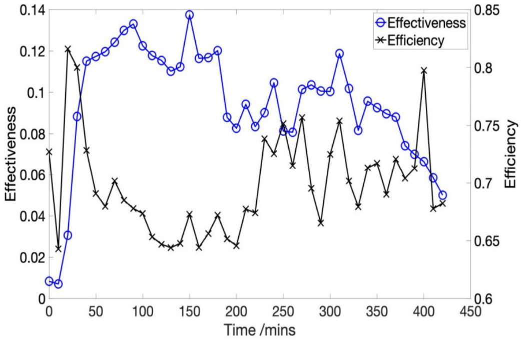


Figure 7: Heat exchanger effectiveness and efficiency of dehydrator vs time

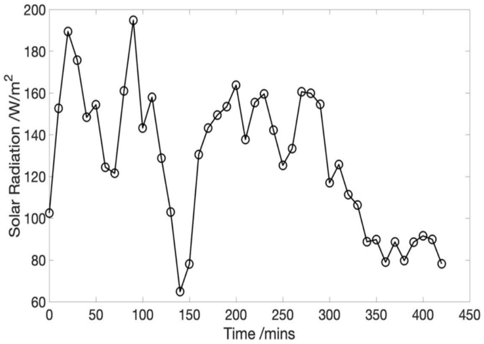


Figure 8: Solar intensity vs time

Before drying Before drying Before drying

After drying After drying After drying

Figure 9: Before and after dehydration of crop samples

The effectiveness of the heat exchanger and efficiency of the dehydrator was observed to fluctuate throughout the duration of the experiment, reflecting the dynamic nature of the drying process and the influence of external factors such as solar radiation intensity and ambient conditions. The highest effectiveness of 0.14 is coincidental with the minimum solar radiation of 65 W/m^2 and efficiency of the dehydrator of 0.82 coincides with a period of high solar radiation intensity of 198 W/m^2, which contributed to the enhanced performance of the solar dryer. These observations underscore the importance of optimizing the operation of the solar dryer to coincide with periods of high solar radiation for maximum efficiency. Figure 9 shows the before and after drying of the Dioscorea (yam), Musa paradisisca (plantain) and Zea Mays (corn) respectively.

4. CONCLUSION

The high performance dehydrator has been developed and test experimenting with *Dioscorea* (yam), *Musa paradisisca* (plantain) and *Zea mays* (corn) using biomass as source of fuel due to its high calorific value. Key parameters such as relative humidity, temperature, weight loss where measured which are used to analyze the moisture content of the inlet and exit air of the cabinet, weight loss and diffusion coefficient of the crop samples over the drying period of six hours. The maximum temperature recorded in the drying chamber was 106.4 °C for yam, 99.6 °C for plantain and 100.8 °C for corn and the corresponding drying rates were determined to be 0.3 , 0.18, and 0.092 kg/h and diffusion coefficient of 14.8×10^{-8}, 17.97×10^{-8} and 17.90×10^{-9} m^2/s respectively. The maximum efficiency of the dehydrator was obtained to be 0.82 and effectiveness of heat exchanger 0.14 with a steady air velocity of 3.8 m/s. The high tray temperatures and improved efficiency of the drying cabinet is a testament that agricultural produce with high moisture contents can readily been dried in a shorter time. Thus, the developed dehydrator offers a sustainable, faster and energy efficient solution for crop drying.

5. ACKNOWLEDGEMENT

The author which to sincerely thank the technical staff of the welding unit of the Faculty of Engineering Central Workshop, University of Lagos, Nigeria, for their assistance in the fabrication and experimental testing of the dehydrator.

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Aasa S., Ajayi O. O., Omotosho O. A. (2012). Design Optimization of Hot Air Dryer for Yam Flour Chunk. *Asian Journal of Scientific Research,* 5(3), pp.143-152.

Ajunwa I., Yawas D. S., Kulla D. M., Ibrahim I. U. (2020). Experimental Evaluation of a Natural Indirect Solar-Biomass Dryer with Automated Single Axis Solar Tracking System for Urban Dwellers. *Jurnal Mekanikal,* 43, pp.106-126

Akinjola O. P., Balachandran U. B. (2012). Mass-Heater Supplemented Greenhouse Dryer for Post-Harvest Preservation in Developing Countries. *Journal of Sustainable Development*, 5(10) pp.40-49.

Chibuzo N. S, Osinachi U. F., James M. T., Chigozie O. F., Dereje B., Irene C. E. (2021).Technological advancements in the drying of fruits and vegetables: A review. *African Journal of Food Science*. 15(12), pp. 367-379.

Dhanushkodi S. Wilson V. H., Sudhakar K. (2015). Life Cycle Cost of Solar Biomass Hybrid Dryer Systems for Cashew Drying of Nuts in India. *Environmental and Climate Changes,* 15, pp.22-33.

Eke B.A. (2014). Investigation of Low Cost Solar Collector for Drying Vegetables in Rural Areas. *Agricultural Engineering International CIGR Journal*, 16(1), pp. 118-120.

Guillermo A., Armando A., Pedro R. (2021). Determination of the Diffusion Coefficient through oil Absorption and Moisture Loss, such as the Porosity of Pieces of Yam (Dioscorea rotundata) during Deep Fat Frying, *Heliyon,* 7(5), pp. 1-9.

Ichsani D., Wulandari. D. A. (2002). Design and Experimental Testing of a Solar Dryer Combined with Kerosene Stoves to dry Fish. *American Society of Agricultural and Biological Engineers,* 028024, pp. 1-3.

Keey R.B., (2011). *Drying*. https://www.thermopedia.com. Retrieved 10th of January 2023.

Khan Y. Kasi J. K. Kasi A. K. (2018). Dehydration of Vegetables by Using Indirect Solar Dryer. *Techno-Science*, 1(1), pp. 22-28.

Khurmi R.S., Gupta J. K. (2008). *A Textbook of Refrigeration and Air Conditioning*. 4th Edition, Eurasia Publishing House Limited, pp. 424-426.

Kilanko O., Ilori T. A. , Leramo R. O. , Babalola P. O., Eluwa S. E., Onyenma F. A., Ameh N. I., Onwordi P. N., Aworinde A. K., Fajobi M. A. (2019). Design and Performance Evaluation of a Solar Dryer. *Journal of Physics: Conference Series,* pp. 1-11.

Kumarasiriwardhana C. A., Kahandage P. D., Weerasooriya G. V. T. V. (2020). Design,Fabrication and Evaluation of Solar and Biomass Hybrid Dryer with Track-able Solar Collector. *Sri Lankan Journal of Agriculture and Ecosystems.* 2(2), pp 164-182.

Muritala A. O., Odediran S. O., Obayopo S. O., Adio S. A. (2022). Study of a Forced Convective Biomass Dryer for Plantain Chips. *Agricultural Engineering International: CIGR*, 24(4), pp. 209-218.

Ndirangu S. N., Ronoh E. K., Kanali C. L., Mutwiwa U. N., Kituu G. M. (2020). Design and Performance Evaluation of a Solar-Biomass Greenhouse Dryer for Drying of Selected Crops in Western Kenya. *Agriculture Engineering International: CIGR.* 22(3), pp. 219-229.

Okoroigwe E. C., Eke M. N., Ugwu H. U. (2013). Design and Evaluation of Combined Solar and Biomass Dryer for Small and Medium Enterprises for Developing Countries. *International Journal of Physical Sciences.* 8(25), pp. 1341-1349.

Olaniyan A. M., Adeoye O. A. (2014). Conceptual Design of a Charcoal-fired Dryer. *International Conference of Agricultural Engineering,* Zurich, pp. 1-13.

Ronoh E. K., Kanali C. L., Mailutha J. T., Shitanda D. (2010). Thin Layer Drying Characteristics of Amaranth Grains in a Natural Convection Solar Tent Dryer. *The Kenya Journal of Mechanical Engineering.* 6(2), pp. 220-232.

Tarigan E., Tekasakul P. (2005). A Mixed-Mode Natural Convection Solar Dryer with Biomass Burner and Heat Storage Back-up Heater. *Air New Zealand Engineering Services, ANZSES,* pp.1-9.

Tibebu T. B. (2015*). Design, Construction and Evaluation of Performance of Solar Dryer for Drying Fruit.* Thesis, Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology, Ghana. *pp. 62-72*

Tiwari A., (2016). A Review on Solar Drying of Agricultural Produce. *Journal of Food Processing and Technology.* 7(9), pp. 1-12.

Toshniwal U., Karale S. R. (2013). A Review Paper on Solar Dryer. *International Journal of Engineering Research and Applications*. 3(2), pp.896-902.

Udomkun P., Romul S., Schock S., Mahayothee B., Sartas M., Wossen T., Njukwe E.,Vanlauwe B., Mủller J. (2020). Review of Solar Dryers for Agricultural Products in Asia and Africa. *Journal of Environmental Management,* 268, pp.1-14.