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Design and Construction of a Solar Dryer for Agricultural Products with Temperature Monitoring

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ABSTRACT

An effective method for preserving agricultural produce is by solar drying which is mostly used in places with abundant sunlight. Most rural dwellers used the traditional open- air drying methods for drying of agricultural produce. However, this method of drying though simple has its challenges which include; contamination, uneven drying and lack of precise temperature control, which can impact negatively on product quality and shelf life. This paper therefore presents the design and construction of an indirect solar dryer integrated with temperature sensors and microcontroller for real-time temperature and humidity monitoring of the dried products. This system consists of a solar collector, drying chamber, DC fans, PTC heaters and a 12V battery for uninterrupted operation in absence of sunlight. The test result shows a significant moisture reduction with an increase temperature which indicates that the solar dryer effectively utilizes solar energy to optimize the drying process. This solar dyer is very easy to operate and it offers an environmentally friendly solution to post-harvest losses for farmers in developing countries

Keywords: *Solar dryer, Indirect solar dryer, Agricultural produce, Temperature sensors, Microcontroller, Post harvest losses.*

1. Introduction

Preservation of Agricultural products is an essential process required for long time storage without the quality of the product being affected. In developing countries large quantities of farm produce get spoiled due to inadequate infrastructure and insufficient processing capacities(Giz Hera, 2022). Food preservation methods include dehydration,canning and freezing (Ogundana et al., 2022). Drying is probably one of the oldest food preservation methods employed to reduce post-harvest losses and ensure all year round supply since production is seasonal (Alamu et al., 2010).It involves the removal of moisture from food products to inhibit the growth of microorganisms thereby preventing decay and spoilage (Salisu et al., 2020;Dare-Adeniran & Areola, 2022). Reducing the water content leads to the physical and chemical stability of the product. In addition, the weight and volume of the product are reduced, thereby reducing transportation costs (Shikhare et al., 2018).

In Nigeria open-air (sun) drying frequently done on the ground is commonly practicedsince the source of energy is free and sustainable with no complexity(Soumendra et al., 2015;Gatea, 2018). Despite the advantages of this method, it still has significant drawbackswhich are; contamination from dust, insects, and birds, as well as dependency on favourable weather condition, thereby affecting the product quality.Also, the process is labour intensive; it requires large area of land and the time required for drying a given commodity is quite long which may results in post-harvest losses(Seveda & Jhajharia, 2012)(Gupta et al., 2017).Therefore, open-air drying method typically fails to meet the necessary quality standards which may prevent the items from being sold in the global market(Elwakeel et al., 2023)

Among the rural populacein Nigeria, fire wood is also used to provide hot-air for drying agriculturalproducts, but this method increases the level of air pollution and deforestation level which according to the United Nation Collaborating Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries(UN-REDD) is estimated at 3.7% which is one of the highest in the world .Apart from the effect on the environment, the quality of the products may also be affected adversely(Salisu et al., 2020;Deng et al., 2021).

The disadvantages highlighted above of the traditional methods of drying and the concern of the rising population, climate change and food security there is needs to minimize the over-dependency on fossil fuels as a step in reducing the level of greenhouse gas emissions. Applications of renewable energy have been the subject of much research as a result. In addition to improving the environment, renewable energy boosts the economy by creating job opportunities and increases food security by changing food preservation systems like solar dryers (Maundu et al., 2017).

The need for solar dryers and their implementation has drawn the attention of researchers due to it taking up less space and time for drying and also being relatively cheap when compared to artificial mechanical drying. Lower relative humidity, lower product moisture content, higher temperatures, and less spoilage during the drying process are further advantages. Thus, the solar dryer can be regarded as one of the answers to the world's food and energy crises and is a superior substitute for all the drawbacks of natural drying (Oria & Palconit, 2022; Alamu et al., 2010). There is still more to be done to assist farmers in drying their agricultural products, which will enhance the nation's hygienic food production and safety. The Federal Government is committed to constructing solar dryers in each federal constituency in order to alleviate the post-harvest difficulties that farmers are facing (Shittu, 2020).

2. Overview of Solar Drying Technologies

Solar drying technologies have evolved over the years, ranging from simple direct solar dryers to advanced hybrid systems that combine solar energy with additional heating sources. According to Fudholiet al., (2018). Solar dryers can be divided into four types: direct solar dryers, indirect solar dryers, mixed-mode solar dryers and hybrid solar dryers.

With the direct solar dryer, the products are placed in a drying unit where the drying process takes place. This type of solar dryer is commonly used in areas that receive direct sunlight for long periods during the dayand in this type of solar dryer, the products are exposed directly to sunlight through a transparent material such as glass but they often suffer from issues like uneven drying and alteration of vitamin A and C in due drying products due to direct exposure to sunlight (Islam et al., 2018;Rizalman et al., 2023).

An Indirect solar dryer, makes use of two components; a drying chamber and a solar collector which consist of a black absorbing surface thatabsorbs solar radiation and is used to heat the air coming into the collector which is then circulated through the drying chamber.The products are placed inside the chamber unexposed to sunlight, where the heated air from the solar air collector enters and dries it thereby offering better protection and more consistent drying results(Shikhare et al., 2018). The air velocity and drying temperature can be controlled in the indirect solar dryer (Okonkwo & Ertekin, 2022).

The mixed-mode type, which blends direct and indirect drying techniques into one dryer, is the third kind of solar dryer. The mixed-mode dryer heats the incoming ambient air by utilizing a solar air collector, which harnesses the thermal energy of solar radiation, just like the indirect dryer. The drying chamber, like the direct dryer, is covered with a transparent material to allow sunlight to directly touch the products within. The products dry at a faster rate thanks to the mixed-mode solar dyer's combined properties(Rizalman et al., 2023).More advanced designs, such as hybrid solar dryers, incorporate additional heating sources like electric heaters in order to maintain the drying conditions when solar radiation is insufficient(Shikhare et al., 2018). This type of dyers have a drying efficiency of 87.020% (Aduewa et al., 2023).

Table 1 summarizes the key features of each of the solar dryer types such as, the mechanism, advantages, disadvantages and application.

Table 1: Comparison of solar dryerstypes

S/N	Solar dryer types	Mechanism	Advantages	Disadvantages	Application
1.	Direct solar dryer	The products are exposed directly to the sun using transparent materials	Low cost and simple to design	Uneven drying, vulnerable to weather changes and potential contamination from dust and insects. Also, direct exposure to sunlight affect product quality.	Suitable for small scale drying e.g vegetables
2.	Indirect solar dryer	Uses a solar collector to heat air which is then circulated to dry the crops without direct exposure to sunlight.	Better quality retention, reduced nutrient loss, consistent drying conditions.	It is more complex to design and has higher cost than direct solar dryer.	Suitable for higher quality drying e.g fish
3.	Mixed-Mode solar dryer	Combines direct and indirect method utilizing both solar radiation and preheated air for drying efficiency.	Faster drying rate, efficient air circulation, versatile for various products.	It is more complex in construction and has higher cost than direct solar dryers	Used for large scale drying where quality is important
4.	Hybrid solar dryer	It integrates solar energy with other sources of energy e.g electricity	Improved efficiency and reliability, suitable for diverse climates. Can be used either day or night.	It involves higher operational costs in design and maintenance.	Suitable for industrial drying or regions with variable weather conditions

3. Methodology

3.1 Design of the Solar Dryer

An indirect-type solar dryer was designed for this study and the major components are: solar collector, drying chamber, trays, DC fan and a 12V battery. Other materials used for the construction includes the following; mild steel, wire, cotton fibre, transparent glass and black paint. The solar collector is painted black in order to maximize solar absorption and covered with a transparent glass having a thickness of 4mm with an area of 0.13844 m^2 to trap the heat from the sun. The absorbed heat is used to warm the air, which is then channeled into the drying chamber where the products are placed on trays. The drying chamber is constructed using metal sheets with a volume of 0.600m^3, with thick cotton fibre enclosed in between the metal sheets as an insulator to reduce heat loss, and equipped with two trays each with an area of 0.4556 m^2 for drying of the products.

The trays were constructed using mild steel of equal dimensions and are designed in a way that allows free airflow around the products ensuring even drying; the drying chamber was also protected by a door, with the inner and outer layers enclosed with cotton fibre. Ventilation openings are provided at the top of the chamber to facilitate air circulation and remove moisture-laden air from the chamber. In order to minimize heat loss, keep dust and rain from getting to the absorber, and make it easier for sunlight to pass through the absorber plate, a transparent glass was used to cover the solar collector that encloses the absorber plate. In order to easily absorb solar radiation, an absorber plate made of black painted mild steel was used. This was placed under the transparent glass to absorb the solar radiation transmitted by the transparent glass and thus heat the air between it and the cover. The interior of the solar collector was painted black to improve the absorption of solar radiation. Two dc fans are used at top of the drying chamber for air circulation (one for air inlet and the other for air outlet). A solar battery has been attached with the drying chamber to run the fan. The constructed solar dryer is shown in figure 1.

Figure 1: The constructed solar dryer

3.2 Design Consideration

1. Temperature - A minimum temperature of 35°C and a maximum temperature of 65°C are required to dry food. Therefore, a temperature of 50°C and above is considered average and normal for drying fruits, vegetables, roots and tubers, and crop seeds (Gupta et al., 2017). For this design, the maximum temperature was set at 65°C and the minimum temperature at 35°C, which corresponds to an outdoor temperature.

2. Dimension – A spacious drying chamber and continuous air exchange are essential for efficient drying. The drying chamber was designed to be as roomy as possible, measuring 76.3 × 74.7 × 105.3 cm and featuring an air vent.

3. Dryer Trays – To facilitate air circulation within the drying chamber, a metal tray measuring 68 × 67 cm was chosen as the dryer tray.

4. Two Exhaust fans of 12V each is used to remove the air from the drying chamber and also to remove moisture from the product before drying.

5. For efficient drying during rainy season and in the two (2) PTC heaters were used.

6. For the system to work at optimum capacity during the night two (2) 12V batteries were selected.

3.3 Design Calculations

1. Solar collector inclination angle:

According to Onigbogi et al., (2012), the angle of tilt (β) of the solar collector is determined using equation (1) for maximum performance of the solar dryer

The angle of tilt (β) of the solar collector is given by the formula below:

$\beta = 10^0 + latitude\ \theta$ ……………… (1)

Where; θ is the angle of latitude. To get the accurate angle of inclination for the solar collector, the geographical location where the solar drier is going to be used was considered.

This study is carried out in Ilaro, Ogun State and the latitude was found to be 6.8953645^0N (Oluwagbayide & Oloruntade, 2021).

Therefore, the collector inclination angle is equal to 10° + 6.8953645^0N = 16.8953645^0

2. Total power consumption of the system:

$$Total\ power\ of\ PTC\ heating\ element\ = 2 \times 60W = 120W$$
$$Total\ power\ of\ DC\ fan\ = 2 \times 5W = 10W$$
$$Total\ power\ of\ other\ components\ used = 2W$$

$Total\ power\ of\ consumed\ (P_1 + P_2 + P_3) = 132W$ ……………… (2)

3. Battery capacity:

Two batteries of 12V, 7.5Ah connected in parallel are used in this system.

$Total\ capacity\ \ of\ battery = Total\ battery\ voltage\ in\ parallel \times total\ battery\ Ah\ in\ parallel$ …………… (3)

$$Total\ capacity\ \ of\ battery = 12 \times 15Ah = 180Wh$$

4. Current drawn in the system:

$I = \frac{P}{V}$ ……………… (4)

$$I = \frac{132}{12} = 11A$$

5. Battery runtime:

This is given as; $\frac{Battery\ capacity}{Current\ drawn\ in\ the\ system}$ ……………… (5)

$$= \frac{40}{11} \approx 4\ hours$$

6. Charging time:

A 50W solar panel was used for this design and it provides power at 12V.

$solar\ panel\ charging\ current = \frac{Solar\ panel\ power}{Soar\ panel\ voltage}$ ……………… (6)

$$solar\ panel\ charging\ current = \frac{50}{12} = 4.17A$$

Therefore, the time taken to fully charge a 15Ah battery is given by;

$Charging\ time\ = \frac{Battery\ capacity}{Charging\ current}$ ……………… (7)

$$= \frac{15}{4.17} \approx 3.6\ hours$$

3.4 Operational Procedure

The dehydration process involves the removal of moisture from the products placed inside the heating chamber using heat, in the presence of a controlled air flow. The solar dryer is first placed directly in the sun facing in order to get the maximum solar energy required for the drying process. The sun ray enters the dryer through the transparent glass and then to the solar collector where it is converted into heat energy. The temperature inside the chamber is increased due to the heat energy. The inlet DC fan blows air which mixed with the hot air to reduce the moisture contents of the drying products gradually.

The heated moist air goes up and is blown out of the chamber using the outlet DC fan air placed at one end of the drier. In the absence of sun, the dryer can still be used to dry produce using a heating element placed inside the chamber and powered by two (2) 12V batteries which can run effectively for four (4) hours. The drying process is controlled using a sensor placed inside the chamber and a microcontroller for real time monitoring of the drying process. The results are displayed on the LCD screen placed at one side of the dryer. A few of the variables that affects the efficiency of a solar dryer are the air's relative humidity, the materials' moisture content, their thickness and their quantity. Seasons, the time of the day and exposure duration all affect the level of solar radiation produced.

4. Result and Discussion

The solar dryer was tested under sunlight and based on the results obtained under test conditions, it was observed that the average temperature of the heated air in the solar dryer becomes higher than the ambient temperature over time. The solar dryer was tested with cut potato and maize seed samples. The results obtained are shown in Table 1 – Table 3 and from the table it was seen that the temperature increased with time especially during 12p.m and 2p.m and then gradually declined as the time increases while humidity decreased consistently as the temperature increases, showcasing the inverse relationship between the two parameters. The highest temperature of 60.20 ºC was obtained in Day 1. It was observed that large quantity of moisture content was removed from the two products (maize seed and sliced potatoe) dried during these three days period. The variations in temperature and humidity reductions across the three (3) days as shown in Figures 2 –Figure 4 could be attributed to factors such as solar intensity, ambient humidity, and the moisture content of the dried products. The maximum cut-off temperature of 65ºC which is the highest temperature required for drying of agricultural produce was not reached due to the temperature of the locality.

Table 1: Results of Solar Dryer for Day One (1)

Time	11a.m	12p.m	1p.m	2p.m	3p.m	4p.m
Temp(ºC)	32.70	51.90	56.60	60.20	60.00	58.10
Humidity (%)	60.50	34.00	31.90	31.50	31.40	31.40

Table 2: Results of Solar Dryer for Day Two (2)

Time	11a.m	12p.m	1p.m	2p.m	3p.m	4p.m
Temp(ºC)	30.90	52.50	54.10	50.20	49.50	45.30
Humidity(%)	61.80	34.10	32.50	31.60	31.30	31.25

Table 3: Results of Solar Dryer for Day Three (3)

Time	11a.m	12p.m	1p.m	2p.m	3p.m	4p.m
Temp(ºC)	30.70	51.10	54.80	54.70	51.30	50.20
Humidity(%)	76.60	33.90	32.50	32.30	32.10	32.05

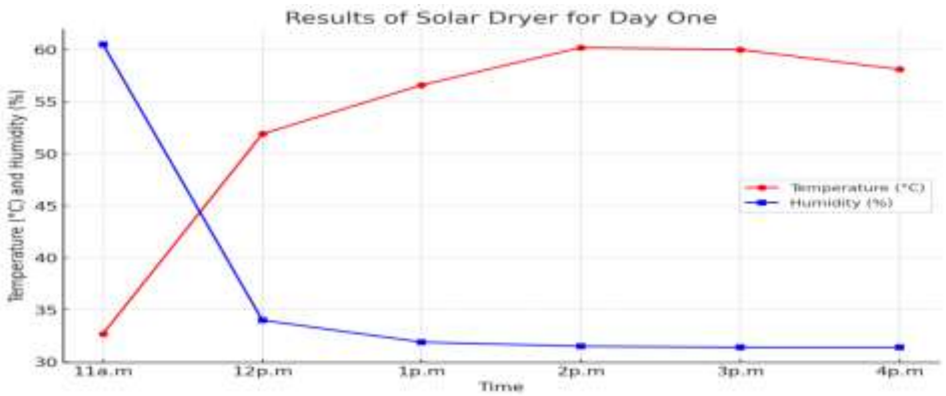

Figure 2: Graph of Temperature and Humidity against Drying Time for Day 1

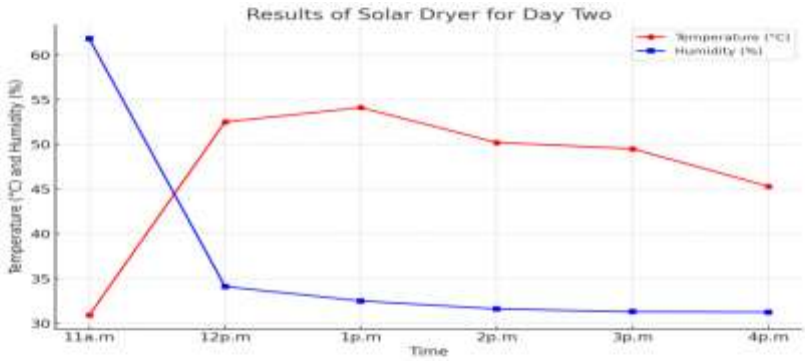

Figure 3: Graph of Temperature and Humidity against Drying Time for Day 2

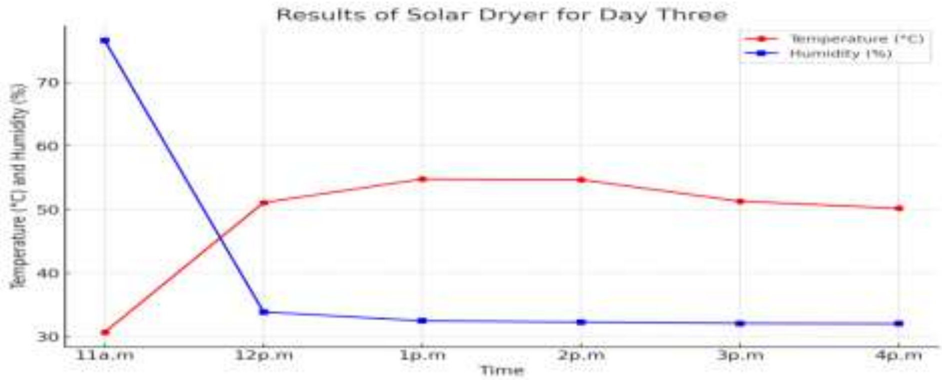

Figure 4: Graph of Temperature and Humidity against Drying Time for Day 3

5. Conclusion

A solar dryer was successfully designed and fabricated and from the results obtained from the test carried out, this solar dryer is capable of raising the ambient air temperature to a considerably high value for drying of agricultural produce with a gradual decreased in the percentage moisture content throughout the test period. Also, lesser attention was required for the drying products when compared to those dried in the open sun. This dryer is very easy to operate and can easily be replicated elsewhere in the world. With the results obtained with the sliced potatoe and maize seeds, this solar dryer can also be used to dry other types of crops.

References

Aduewa, T. ., Fatounde, S. ., & Aderotoye, A. . (2023). A Comprehensive Review of the Hybrid Solar Dryers. Asian Journal of Advances in Agricultural Research, 18(3), 21–33. https://doi.org/10.9734/AJAAR/2022/v18i330224

Alamu, O. J., Nwaokocha, C. N., & Adunola, O. (2010a). Design and Construction of a Domestic Passive Solar Food Dryer. Leonardo Journal of Sciences, 16, 71–82.

Alamu, O. J., Nwaokocha, C. N., & Adunola, O. (2010b). Design and Construction of a Domestic Passive Solar Food Dryer. Leonardo Journal of Sciences, 16, 71–82. http://ljs.academicdirect.org/A16/071_082.htm

Dare-Adeniran O.I, & Areola, R. . . (2022). Design and Construction of a Solar Dryer for Preservation of Agricultural Products in Ile-Oluji , Ondo State Nigeria . International Journal of Innovative Science, Engineering & Technology -IJISET, 09(04).

Elwakeel, A. E., Eutyche, D., Wapet, M., Mahmoud, W. A. E., Abdallah, S. E., Mahmoud, M. M., Ahmed, S., & Mehdi, E. (2023). Design and Implementation of a PV-Integrated Solar Dryer Based on Internet of Things and Date Fruit Quality Monitoring and Control. International Journal of Energy Research, 2023. https://doi.org/10.1155/2023/7425045

Gatea, A. A. (2018). Design and construction of a solar drying system , a cylindrical section and analysis of the performance of the thermal drying system. International Scholars Journals, 6(6), 1–9.

Gupta, P. M., Das, A. S., Barai, R. C., Pusadkar, S. C., & Pawar, V. G. (2017). Design and Construction of Solar Dryer for Drying Agricultural. International Research Journal of Engineering and Technology (IRJET), 04(03), 1946–1951.

HERA, G. (2022). Solar Drying. Energypedia. https://energypedia.info/index.php?title=Solar_Drying&oldid=386857

Islam, M. K., Karim, M. S., Begum, N. N., & Uddin, K. Z. (2018). Fabrication and Performance Study of a Direct Type Solar Dryer. International Journal of Scientific & Engineering Research, 9(2).

Maundu, N. M., Kiptoo, K. S., Eliud, K., Kindole, D., & Nakajo, Y. (2017). Air-flow Distribution Study and Performance Analysis of a Natural Convection Solar Dryer. 5(1), 12–22. https://doi.org/10.12691/ajer-5-1-2

Ogundana, O. ., Juneid, Y. ., Olaifa, O. ., & Owa, T. . (2022). Design , construction and evaluation of solar dryer. International Journal of Modern Science and Technology, 7(1–2), 1–5.

Okonkwo, H., & Ertekin, C. (2022). Review on Solar Drying in Nigeria. Turkish Journal of Agricultural Engineering Research, 3(2), 397–429. https://doi.org/10.46592/turkager.1060019

Oluwagbayide, S. D., & Oloruntade, A. J. (2021). Evaluation of Sprinkler Irrigation Evaporation Losses in Ilaro , Ogun State , South Western Nigeria Evaluation of Sprinkler Irrigation Evaporation Losses in Ilaro , Ogun. June. https://doi.org/10.46592/turkager.2021.v02i01.004

Onigbogi, I. O., Sobowale, S. S., & Ezekoma, O. S. (2012). Design, Construction and Evaluation of a Small Scale Solar Dryer. Journal of Engineering and Applied Science, 4(June), 8–21. https://doi.org/10.13140/RG.2.1.3370.2886

Oria, C. ., & Palconit, E. . (2022). Performance Investigation of an Inflatable Solar Dryer with Steel-Can Solar Air Heater for Drying Coffee and Corn. Engineering, Technology & Applied Science Research, 12(3), 8707–8711.

Rizalman, M. K., Moung, E. G., Dargham, J. A., Jamain, Z., Yaakub, M., & Farzamnia, A. (2023). A review of solar drying technology for agricultural produce. 30(3), 1407–1419. https://doi.org/10.11591/ijeecs.v30.i3.pp1407-1419

Salisu, S., Alexander, A., & Seyefa, O. I. (2020). Design and Construction of a Solar Dryer for Drying of Maize Seeds. International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS), IX(V), 66–72.

Seveda, M., & Jhajharia, D. (2012). Design and performance evaluation of solar dryer for drying of large cardamom (Amomum subulatum). Journal of Renewable and Sustainable Energy, 4(063129). https://doi.org/10.1063/1.4769199

Shikhare, T. ., Bhange, Y. ., & Vibhute, A. . . (2018). Review of Temperature Conditioning for Solar Dryer. International Research Journal of Engineering and Technology (IRJET), 05(04), 5–7.

Soumendra, B., Abhijeet, S., Aditya, V. S., Ashutosh, C. ., & Lavi, G. (2015). Design of Temperature Controlled Solar. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 4(11), 8731–8740. https://doi.org/10.15662/IJAREEIE.2015.0411028