Design And Development of an Active Indirect Solar Dryer for Cooking Banana

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Abstract- Food preservation techniques such as dehydration and drying are important. Although air drying with the sun's natural heat energy has a lot of advantages, it also has a number of disadvantages. As a result, the dryer, which generates heat using electricity, was born. However, using solar energy as a renewable source of heat for drying is becoming increasingly popular. Active mode (indirect) Solar dryers were conceived and built in Umudike, Nigeria, to dry fried bananas. To investigate if the air inlet area had an effect on the dryers' performance, the dryers were developed with a special focus on it. Square, rectangular, circular, and triangular air intake spaces were classified into five categories and four shapes. A total of 52 dryers were required for the experiment based on the mix of elements and degrees of experimentation employed in the Central Composite Rotatable Experimental Design. Fresh cooking banana samples were purchased from a local market, peeled, cleaned, and sliced to the required thickness for the drying experiment. Open sun drying was employed as a control. On each drying day between January and March, data was collected at a two-hour interval. The dryers reduced the moisture content of the products from 4.53 to 1.57 kg during 9 to 16 hours of drying, while moisture was reduced from 68.97 to 12.00 percent (wet basis). The dryers were able to save over 40% of the total drying time when compared to open-air drying. The efficiency of the dryers varied from 13.85 to 31.84 percent. The dryer's air input area was shown to have a significant impact on the product's drying efficiency.

Keywords: Solar dryers, Air inlet, Moisture content, Drying efficiency, Cooking banana.

I. INTRODUCTION

Sun thermal energy, in the form of solar radiation, can be used to dry a variety of items, including fruits, vegetables, agricultural grains, and wood. This method is especially beneficial in the world's "sunny belt," or areas where solar radiation intensity is high and sunshine lasts a long time. Because of a lack of alternative preservation methods, high postharvest losses of agricultural products are expected in underdeveloped countries. Solar energy drying, especially for medium to small volumes, is a cost-effective way for drying agricultural products. From domestic to small commercial sizes, it is still used to dry crops, agricultural products, and foodstuff, such as fruits, vegetables, fragrant herbs, wood, and so on, contributing significantly to the economy of local agricultural communities and farms. In various ways, a standard solar dryer exceeds a traditional open-air sun system, including speed, efficiency, hygiene, and cost.

1.1 Sun drying versus solar drying

Solar drying could be used instead of sun drying or traditional dehydration methods. Solar drying competes with a method that is strongly embedded in the way of life for most potential customers when it comes to sun drying. Sun drying is far from a flawless procedure, with issues such as potential produce contamination, variable drying times, rain damage, and so on. However, the following are some of the reasons given for the lack of success in solar drying adoption:

- Why Solar dryers have frequently proved too expensive or have been unavailable due to a lack of initial investment money or credit facilities.Solar dryers have frequently proved
- overly complicated, or local entrepreneurs and technicians have received inadequate training.
- Traditional drying processes have often necessitated too many modifications with solar dryers.
- Solar dryers aren't designed to last a long time.
- There is a lack of motivation to improve the product's quality. People are prepared to pay about the same price for discoloured or damaged meals, therefore there is little reason for manufacturers to invest more money in a dryer when the return is not significant.

When comparing solar drying to the conventional dehydration processes a new range of issues arises. These include:

- In terms of capacity, labour input, final product quality, overall drying costs, and reliability, solar dryers must perform similarly to conventional methods.
- To assure drying during the key periods when the weather is severe, a backup heating system should be built.

Advantages of solar drying can be summarized as follows:

- The pace of drying is accelerated by greater temperatures, air movement, and decreased humidity.
- Food is protected from dust, insects, birds, and animals by being encased in the dryer.
- The higher temperature deters insects, while the faster drying rate minimizes the risk of microbial spoiling;
- The faster drying rate also allows for a higher flow of food, resulting in a smaller drying area (approximately 1/3).
- Food does not need to be transported when it rains because the dryers are waterproof;
- Dryers may be built from locally available materials and are reasonably inexpensive;
- More complete drying allows for longer storage.

1.2 Types of solar dryers and its components

In general, solar dryers can be divided into two categories: passive solar-energy drying systems (also known as natural-circulation solar drying systems) and active solar-energy drying systems (most of which are commonly referred to as hybrid solar dryers), as shown in Fig.1.1. Air is heated and circulated naturally in a passive solar dryer by buoyancy force, wind pressure, or a combination of both. Solar energy and motorised fans/pump for air circulation are used in the active solar drier. As a result of their application, every active solar dryer is a forced convection dryer.

Direct-type solar dryers, indirect-type solar dryers, and hybrid solar dryers are three separate sub-classes of either active or passive solar drying systems. The key characteristics of typical designs for the various classes of solar-energy dryers are depicted in Fig. 1.2, which divides solar dryers into two categories based on the energy sources employed.

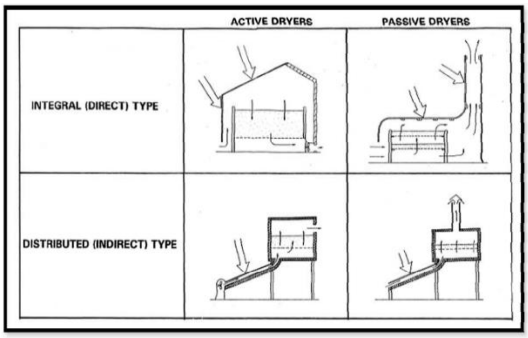

Fig 1.1 Types of Solar Dryer

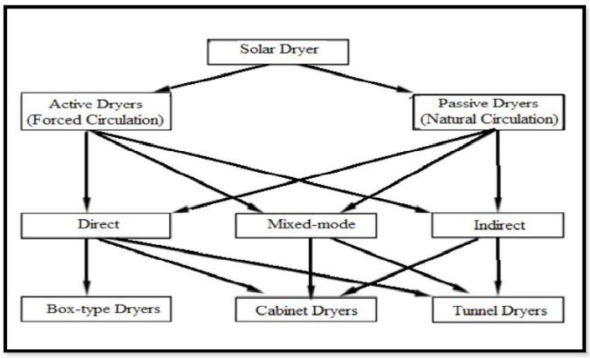

Fig 1.2 Different groups of solar dryers based on the energy sources used

1.3 Main Parts of Solar Dryers:

a) Drying space: to dry the food material

b) Collector: to collect the sun's radiation and heats up the air c) Air flow system
d) Auxiliary energy source (optional)
e) Heat storage unit (optional)
f) Measuring and control equipment (optional)
g) Ducts, pipes and other appliances

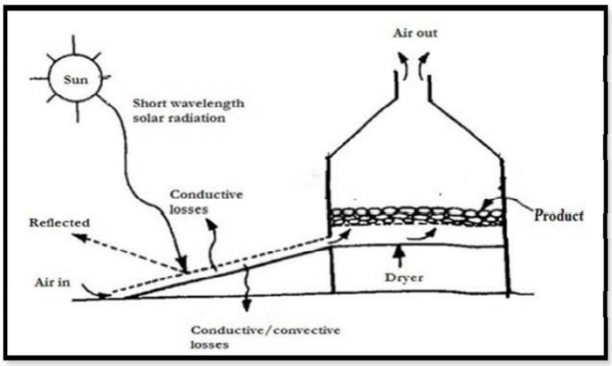

Fig 1.3 Working of Solar Drying System

II. LITERATURE REVIEW

The key characteristics of typical designs for the various classes of solar-energy dryers are depicted in Fig. 1.2, which divides solar dryers into two categories based on the energy source. Drying is the greatest locally available module for preserving meat, fish, and other agricultural commodities. Food products that have been dried can be stored for an extended period of time with little risk of spoilage. This is because food spoilage germs are unable to thrive and multiply in the absence of sufficient water and various enzymes that allow for undesired chemical and biological changes in food. The goal of drying food is to preserve it, extend its shelf life, and improve its quality. The key characteristics of typical designs for the various classes of solar-energy dryers are depicted in Fig. 1.2, which divides solar dryers into two categories based on the energy source. Drying is the greatest locally available module for preserving meat, fish, and other agricultural commodities. Food products that have been dried can be stored for an extended period of time with little risk of spoilage. This is because food spoilage germs are unable to thrive and multiply in the absence of sufficient water and various enzymes that allow for undesired chemical and biological changes in food. The goal of drying food is to preserve it, extend its shelf life, and improve its quality.

Solar energy can be used for a variety of things, including heating, drying, pumping water, and cooking, as well as producing electricity with solar cells. In South East Nigeria, solar drying has been recognized as a viable technique for drying staple crops [15]. It is economically priced, and local farmers may easily get it. High air temperatures and low relative humidity are produced by solar drying. In order to address concerns about the time it takes for cassava chips to dry using existing methods, Along and Jackson [6] designed an indirect forced convection solar dryer for Cassava. Solar dryers have been frequently utilized to dry crops, but the air input vent has received little attention. According to Alamu et al. [5] and Oguntola et al. [22], the air inlet area of a solar system is largely responsible for air flow into the system and temperature variation, which directly affects the amount of free water molecules removed from the cell and surface of the product during the initial stage of drying. The development of solar drying technologies that provide insight into air inlet spacing in order to achieve more efficient crop drying is required. Innovative innovations like these will pique farmers' curiosity and encourage them to use sun drying systems to dry their agricultural products.

Itodo et al. [20] suggested that if a study on the effect of air inlet area on dryer performance is considered while building an active solar dryer, the volumetric-air flow rate of a solar drying system can be increased. According to their findings, this will aid in the efficient comparison of forced convection and natural convection drying, as well as the recommendation of optimal drying technique for Nigerian rural farmers. Varun et al. [31] investigated the performance of an indirect mode solar dryer combined with a solar air heater and found that with an air inlet area of 0.018 m2 and dryer length and width of 1.3 and 0.6 m, respectively, the dryer gave a 17 percent performance efficiency. When they used the dryer, they were able to save 65 percent of the entire drying time.

Hedge et al. [18] developed a solar banana dryer. Sukhatme [27] recommends a 5 cm air gap for tropical regions, which they used in their investigation. When compared to open sun drying, the top and bottom flow efficiency was found to be 27.5 and 38.21 percent, respectively, saving more than 40% of the total drying time. Singh et al. [26] used a 0.042m2 air intake vent area in their design of an indirect type solar dryer. The dryer was said to have had a 35 percent total efficiency. When Seveda [25] designed a photovoltaic-powered forced convection solar dryer, he discovered that it could reduce the moisture content of chilli from 80.2 to 10% (w.b.) in 32 hours, compared to 56 hours when drying the same product in the open sun. Musembi et al. [21] showed a similar tendency, albeit with a lower efficiency of 17.89 percent when compared to the former. In the design and construction of dryers, Abdualahi et al. [1], Oguntola et al. [22], Eltawi et al. [16], Pape and Boda [24], and Ozumba et al. [23] employed 60, 25, 80, 49, and 60cm2, respectively. The discrepancies were attributed to variances in dryer sizes and sun dyer modes.

There is no research that links the performance of solar dryers to the size of the air inlet. Cooking banana was the product used in the dryer's performance testing. The result can be cooked, steamed, baked, or fried and eaten; mashed and baked with coconut cream and other confectionaries; mashed with other root crops, such as cassava, to make local cuisines; and dried and eaten as snacks [2], [3]. Cooking banana is often recommended as a good supplement for infants by pregnant and nursing mothers [10]. Cooking banana is a good dish for infants that some nursing mothers in Nigeria use to supplement breast feeding [4].

III. PROPOSED WORK

The principle of indirect solar drying which is generally known as conventional dryer. In this case, a separate unit termed as solar air heater is used for solar-energy collection for heating of entering air into this unit. The air heater is connected to a separate drying chamber where the crop is kept. The heated air is allowed to flow through wet crop. Here, the heat from moisture evaporation is provided by convective heat transfer between the hot air and the wet crop. The drying is basically by the difference in moisture concentration between the drying air and the air in the vicinity of crop surface. A better control over drying is achieved in indirect type of solar drying systems and the product obtained is good quality.

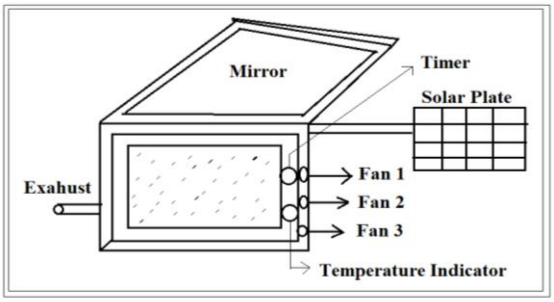

Fig 3.1: Working principle of in-direct solar drying system

The goal of a dryer is to provide more heat to the product than is available under ambient conditions, thereby increasing the vapour pressure of the moisture held within the crop and lowering the relative humidity of the drying air, increasing its moisture carrying capacity and ensuring a low equilibrium moisture content. Figure 3.1 depicts one example of a solar dryer. It was created to meet the specific needs of rice, but the concepts are applicable to a wide range of products and design types because the essential necessity to remove water is the same.

Natural convection circulates air through the dryer. As it travels through the collector, it heats up and then cools down as it absorbs moisture from the rice. The rice is warmed both by the air and by the sun directly. Warm air can keep more moisture than cold air, therefore the amount required is determined by the temperature to which it is heated in the collector, as well as the amount held (absolute humidity) when it entered. Table 1 depicts how air's moisture absorption capability is modified by its starting humidity and the temperature to which it is eventually heated.

Table 1: The drying process (air enters at 20 °C and leaves at 80% RH).

Initial relative humidity	**Moisture absorption capability (grams of water per m³ of air [g/m³])**		
	Not heated	Heated to 40 °C	Heated to 60 °C
40 %	4,3	9,2	16,3
60 %	1,4	8,2	15,6
80 %	0	7,1	14,9

The goal of most drying processes is to reduce the product's moisture content to a specific level. The weight as a percentage of total weight is used to calculate moisture content. The dryer does not have a set need for solar heat input. Because the incoming ambient air can use some of its inherent energy to evaporate the water, this is possible (becoming colder in the process). In fact, if the air is dry enough, no heat input is required. Nonetheless, additional heat is beneficial for two reasons. For starters, if the air is warmer, less of it is required. Second, the temperature of the rice grains may play a role, particularly in the final stages of drying, when moisture must be 'pulled' from the banana's centres to its surfaces. This temperature will be influenced by the ambient temperature, as well as the amount of direct solar radiation received by the rice.

3.1 Mechanism of drying

When heat is applied to the drying matter, it is dispersed throughout the occurrence, causing the water to be transferred to the food's surface and so removed from the surface. The total elimination of water is divided into two phases: a period of constant drying rate and a period of declining rate (Fig. 3.2).

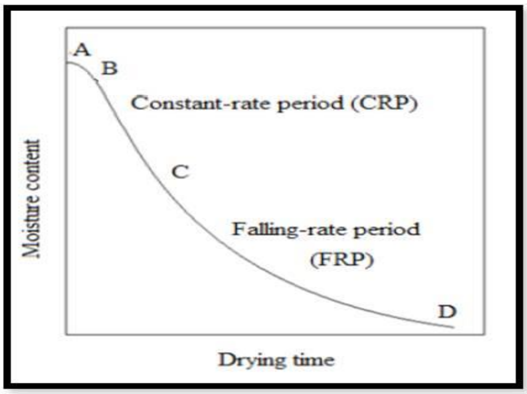

Fig. 3.2. Drying rate curve for a food product

1.2 Constant rate period

The rate of drying is controlled by the rate of heat delivered to the evaporating surface during the constant-rate period because moisture transport within the solid is fast enough to keep the surface saturated. Drying occurs when vapour from the saturated surface of the material diffuses into the environment over a stagnant air layer, and the temperature of the saturated surface remains constant because mass transfer balances heat transfer. The constant rate's size is determined by three factors:

i. The heat or mass transfer coefficient

ii. ii. The surface area exposed to the drying medium

iii. iii. The temperature or humidity difference between the gas stream and the solid's wet surface.

3.3 Falling rate period

When the constant rate period finishes, the falling-rate period begins at the critical moisture content. This is usually separated into two zones: I the unsaturated surface drying zone, and (ii) the zone where internal moisture transport is controlled. The entire evaporating surface cannot be maintained and saturated by moisture flow within the solid in the first zone. From the unsaturated portion, the drying rate drops, and so the rate for the overall surface lowers. In general, factors affecting moisture diffusion away from the evaporating surface and those impacting the rate of internal moisture movement influence the drying rate. As the drying process progresses, the evaporating surface becomes unsaturated. The evaporation point shifts into the solid, and the dry process begins the second falling-rate phase. The pace of internal moisture flow now determines the drying rate; external variables have less influence.

3.4 Solar drying for value addition to fruits and vegetables

Fruits and vegetables are perishable fresh agricultural product; fruit typically refers to the fleshy seed-associated structures of certain plants that are pleasant and edible in their raw state, such as apples, oranges, grapes, strawberries, juniper berries, and bananas. Vegetable refers to any edible plant or plant part that isn't a sweet fruit or seed. Raisins account for over half of all dried fruits sold on the international market, followed by dates, prunes, figs, apricots, peaches, apples, pears, and other fruits. Solar drying technique can be used to dry all of these items. Sour cherries, cherries, pineapples, and bananas are also dried in large quantities. Fruits can be dried whole, in halves, or in slices, or cut after they've dried. The residual moisture content varies from small (3–8%) to large (16–18%) amounts, according to the type of fruit [3.2]. Vegetables like cabbage, broccoli, peppers, herbs, onions, squash, tomatoes, asparagus, leafy vegetables, potatoes, peas, carrots & yams can be dried effectively using solar power as a source. Apart from fresh produce, quality processed products can also be get using solar drying like mango bars/rolls, guava bars/rolls, chikku bars/ rolls, mixed fruit bars/rolls, khatta-meetha bars/ rolls, papaya bars/rolls, apple bars/rolls, plum bars/ rolls, pineapple bars/rolls, strawberry bars/ rolls, apricot, grapes, banana, and fruit slices in case of fruits based products and potatoes, carrot, tomato, mushrooms, bitter gourd, onion etc., in the form of powders in case of vegetable based ones. The following flowchart shows the general steps involved in drying of fruits and vegetables:

Fig 3.3: Flow Chart of Proposed Working

1.5 Drying Efficiency

The efficiency of the drying operation is an important factor in the assessment and selection of the optimum dryer for a particular task. There are three groups of factors affecting drying efficiency: those related to the environment, in particular, ambient air conditions; those specific to the crop; those specific to the design and operation of the dryer.

There are several different ways of expressing the efficiency of drying, of which the sensible heat utilization efficiency (SHUE), the fuel efficiency, and the drying efficiency are the most useful.

The SHUE takes into account the sensible heat attributable to the condition of the ambientair and any heat added to the air by the fan as well as the heat supplied by combustion of thefuel. It is defined as:

$$\textbf{SHUE} = \frac{\text{Heat Utilized for Moisture Removal}}{\text{Total Sensible Heat in the Drying Air}}$$

The fuel efficiency is based only on the heat available from the fuel

$$\text{FUEL Efficiency} = \frac{\text{Heat Utilized for Moisture Removal}}{\text{Heat supplied from fule}}$$

It's easy to see how the fuel efficiency of the identical dryer at two different sites with drastically different ambient conditions would be drastically different. The heat supplied from the fuel may be less than half of the total sensible heat while drying at low temperatures, especially in arid areas, and the fuel efficiency may surpass 100%. The fuel economy cannot be used to compare the performance of dryers at different sites.

The drying efficiency, defined as:

$$\text{Drying Efficiency} = \frac{\text{Heat Utilized for Moisture Removal}}{\text{Heat Available for Moistrue Removal}}$$

Because it is a measurement of the degree of use of the sensible heat in the drying air, it is the term to use when evaluating dryer designs or comparing dryers. Foster (1973) compared the fuel and drying efficiency of various models of maize dryers. Continuous-flow dryers had a fuel efficiency of 38 percent and a drying efficiency of 51 percent, batch dryers 42 percent and 58 percent, dryeration 61 percent and 78 percent, and two-stage drying 60 percent and 79 percent, respectively, over a wide variety of conditions.

IV. RESULT AND DISCUSSION

Fig 5.4 Proposed Solar Cooker

Figure 5.4 represents the model of proposed system and the table below gives the details specification of fruit, where initial and final moisture contain, energy required, maximum temperature, storage, time and temperature required were taken into consideration.

V. CONCLUSION

Solar drying, being a low-cost food drying technology can be readily introduced in food processing sector for value addition to fruits and vegetables. It can be used to reduce spoilage, improve product quality and overall processing hygiene to significantly improve the agricultural returns for farmers. Solar tunnel drying is the cost effective and safe method of preserving the quality of fruits in terms of bioactive components and nutritional retention. At the same time, this can be used to promote the application of renewable energy sources as an income-generating option in the context of increased cost and shortage of non-renewable energy sources. The air inlet area of an active indirect mode solar dryer was examined as a function of performance of the dryer. The air input area of the dryer was shown to have a substantial impact on the dryer's performance. Increasing the amount of air in the late area improved the dryer's effectiveness, and vice versa. Because most studies based the air inlet area on assumptions, it is highly advised that the fluctuation in air in late area be taken into account when designing and developing solar drying systems. It is also recommended that the dryer's air inlet area be optimised in order to ensure that other features of the dryer are in good working order, ensuring that the dryer performs optimally in relation to the air inlet area. Further modifications should be made to investigate how the air output area of the dryer impacts the dryer's performance. A study of the blower's variation and optimization for best performance is also suggested.

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Table 5.1 Details Analysis of Banana Fruit

<table>
<tr><td>Initial Moisture Content:</td><td colspan="2">70-80 %</td></tr>
<tr><td>Final Moisture Content:</td><td colspan="2">7-15 %
2 % (powder)
8 % (flour)</td></tr>
<tr><td>Energy Required (MJ/kg):</td><td colspan="2">1.679</td></tr>
<tr><td>Maximum Temperature:</td><td colspan="2">70 °C</td></tr>
<tr><td>Storage</td><td colspan="2">Bundled and hung on racks in the warehouse.
Wrapped in leaves and tightly bound, vacuum sealed, dry circumstances; may be sulphated or fumigated (dried items) with methyl bromide or an antioxidant (chips)
Cellophane is used to wrap fruit bars.</td></tr>
<tr><td rowspan="2"></td><td>Low Temperature</td><td>High Temperature</td></tr>
<tr><td>1. Sun-drying
2. oven-drying
3. batch or in-bin drying afterosmotic dehydration for candied fruit
4. warehouse drying
5. spray or drum-drying (powder)</td><td>6. Tunnel or cabinet
7. osmotically (2000 ppm SO_2) usually followed by sun drying or air drying
8. sun and mechanical
9. forced air dehydrator for leather</td></tr>
<tr><td>Required drying time</td><td>1. several days (4-6)
2. several hours or days
3. several hours
4. several hours
5. 7-8 hours (flour)</td><td>6.
7. 2 hours followed by a dayof solar
8. 10 hours solar plus 16hours electric or steam power (fruit bars)
9. 3.5 hours</td></tr>
<tr><td>Required drying temperature</td><td>30-70 °C
60 °C (tunnel for powder)
75 °C inlet temperature and 45 °C outlet temp. (flour)</td><td>70 °C
45 °C</td></tr>
</table>