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Development of an Innovative Solar Collector for Drying of Perishable Food Items in Rural Communities

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Abstract
The Federal University of Technology Ikot Abasi is blessed with abundant farmland and rivers, and the main source of livelihood of the inhabitants is through farming and fishing. However, most of the farm produce get spoiled because of lack of methods of preservation making many food items to be seasonal.Drying of fishes using firewood is not environmentally sustainable and promotes deforestation and greenhouse gases (GHGs). Therefore having an alternative, sustainable and cost-effective method of food preservation to mitigate the problem of postharvest deterioration becomes imperative. The design is novel since it is compact and composite type having a mixed mode features of both direct and indirect drying techniques. The dryer is composed of solar collector and a solar drying chamber containing rack of two wire mesh trays both being evenly spaced. Locally available materials chosen for production, chiefly comprising wood, glass, aluminium sheet, projection hanger, a compass, lagging material and wire mesh for the trays. The dryer is expected to attain the highest temperatures at 14:00 h, with cabinet temperature of 61.3℃, when the ambient temperature is 35℃.The load outlined be carried out in three replications. Two chipped samples of food items should be subjected to blanching at 100℃ and 70℃ respectively. Each sample should be subjected to drying using the equipment. Control experiment should also be set up by subjecting similarly treated samples to open-air sun drying. Under load, peak temperature and minimum relative humidity of 64.9℃ and 45.5% respectively is expected. The theoretical moisture content of 12% w/w is expected using the solar dryer from an initial moisture content of 64.0% w/w in 11 hours, while the open-air sun drying is expected to require 28 hours for complete drying.
Keywords: Dryer, food items, innovative, perishable, rural communities, solar.

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I. Introduction

Drying is basically a process of applying heat and mass transfer simultaneously and is one of the oldest means of preserving agricultural products [1]. Proper mastery and application of the techniques is crucial because of the sudden changes in the quality of dried goods which may eventually lead to spoilage if not adequately carried-out [2]. Researches have been carried out to determine the mechanisms of drying with the purpose of improving on the apparatus used for drying of agricultural products, and thus improving the quality of food nutrition, its hygiene and aesthetics. The drying rate of any food item depends on three important factors namely; the relative humidity of the surroundings air, the rate of air flow passing over the food and the composition of the food which will ultimately affect the rate at which moisture is lost [3].

Many agricultural products when harvested deteriorate rapidly, primarily due to physiological changes and mechanical damagesevidence during harvesting, transportation and handling. The very short storage life after harvest has been observed as a limitation to the cultivation of the crop [4]).Due to this, producers prefer to convert the tubers into more stable forms such as chips and flours so as to lengthened the shelf life[5],[6]. This is usually achieved by *cutting* the tubers into slices and drying them in the open sun or in an air-dryer.

An important method for achieving product stability for sweet potato is by drying. It has been found as the most efficient preservation method for most tropical crops [7]. In traditional practice, the farmers spread their crops mostly in the sun on mats, top of roofs, rocks or road sides. Although open sun drying requires little or no capital and little power input, it is however accompanied with many associated problems and short comings. A high percentage of the crops degrade quickly because of to the slow rate of drying process. Large quantity of crop spread for drying in the sun is normally contaminated by dirt, plant and animal remains.

Solar energy is growingly becoming an alternative source of energy dueto the high rate of depletion of the conventional energy source [8]. Solar energy has many advantages over other alternative sources of energy such as wind, hydro and shale because it is abundant, inexhaustible, and also renewable and non-polluting to the environmentin nature. Solar energy gives a higher air temperature and lower relative humidity, thus promoting drying rates, hence lower moisture content could be achieved in the dried produce compared to sun drying, resulting to higher quality of products and low risk of spoilage.

This value of moisture content obtained is very much higher than the one required for long time preservation. As a result, moisture content bacterial and fungal growth is very fast in the crops. Bacteria and enzymes are capable in spoiling the foodstuff and reducing the nutrient content in the food or product. Moisture content of crops to a certain level brings down the bacterial, enzymes, and yeasts and effect product [9]. Thus, it is necessary to reduce the moisture content in food stuff to enhance long preservation. Another method of drying is to remove the total moisture content from food. These dehydrated foods get again its original conditions after re-watering whenever there is need for use.

Applying solar drying technologies have verymany advantages than using fossil fuels for product drying. The most important advantage is pollution free method and reducing emission of carbon particles into the atmosphere. Solar drying technologies are broadly classified in to three modes: direct solar drying, indirect solar drying and mixed mode solar drying [10],[11],[12], [13], and [9]. Solar dryer are the devices used for product drying with due application of solar energy. Solar dryers are classified by the nature of air movement into the drying chamber. It is grouped into natural circulation and forced circulation [14], [15], [9].

Solar drying is different from sun drying by the use of equipment to receive the sun's radiation in order to obtain the radiated energy for drying applications. Sun drying is a common farming practiceand agricultural process in several countries, mostly where the outdoor temperature reaches $30°C$ or higher. However, weather conditions can hamper the use of sun drying because of spoilage due to rehydration during unexpected rainy days. Furthermore, any direct exposure to the sun during high temperature days might cause case hardening, a condition where a hard shell develops on the outside of the agricultural products, trapping moisture inside.

Traditional drying, which is most often done on the ground in the open air, is the most commonly method used in developing countries because of its simplicity and is the cheapest method of preserving foodstuffs. Some benefits of open air drying include: exposure of the food items to rain and dust; lack of controlled drying; exposure to direct sunlight which is not good for some foodstuffs; infestation by insects; attack by animals; etc.[16].

Thus, the use of solar dryer taps on the freely available sun energy while ensuring good product quality via judicious control of the radiated heat is desirable. Solar energy is a free form of energy, which has been available and used throughout the world to dry products. Solar dryers are commonly used to dry grains, fruits, meat, vegetables and fish. A typical solar dryer is better than the traditional open-air sun system in five differentways [17**]**.Most importantly,it is faster as materials can be dried in a shorter period of time.

Solar dryers shorten drying times in two ways. In the first instant, the translucent, or transparent, glazing over the collection area collects and traps heat inside the dryer, raising the temperature of the air. Secondly, the flexibility of enlarging the solar collection area allows for greater collection of the solar energy from the sun. Since materials can be dried more quickly, less spoilage is recorded immediately after harvest and therefore it is most efficient. This is especially good for products that require immediate drying such as freshly harvested grain with high moisture content. In this way, a larger percentage of products will be made available for human use. Furthermore, less of the harvest will be lost to wandering animals and insects since the products are in safely enclosed compartments.

It is very hygienic as the materials are dried in a controlled environment, and are less likely to be contaminated by pests, and can be stored with less likelihood of the growth of toxic fungi and associated infestation. Drying materials at optimum temperatures and in a shorter amount of time enables them to retain more of their nutritional value such as vitamin C, thus41making it healthier.An added bonus is that, the products will look better, which enhances their market value and hence provides better financial returns for the farmers. Using easy and freely available solar energy instead of conventional fuels to dry products, or by using a cheap supplementary supply of solar heat, therefore reducing conventional fuel demand can result in significant cost savings making it cheaper.

Due to the post-harvest losses, most perishable agricultural products need to be dried after harvest to prolong their shelf life. Also the stability of agricultural products by reducing their microbial contamination can be achieved by drying. Therefore, this research is to develop more efficient solar collector for drying of perishable food items in rural communities in order not to deteriorate their qualities.

This research is focused on to designa more efficient solar dryer for perishable food items that will elongate the shelf life of most of the seasonal agricultural products, increase the economy capital of most subsistence farmers in the rural communities.Sampling, experimentaland testing procedures are also presented.

II. Materials and Method

2.1Theoryof OperationoftheMachine

The solar dryer works on the principle of absorption of solar energy from the sun. It uses direct and indirect techniques. It has inlet and outlet air vents and also an additional collector that collects and concentrates sun rays to the glass materials, underneath an enclosure, where a tray is placed and the items for drying are placed. The absorbed is from the sun is used in drying the food items in the enclosure.

2.2 Design Criteria

The design criteria is to design a solar dryer with capability adjustment to different angles of inclination using a compass and also employing concentric lens to multiply the solar energy absorbed into the dryer for effective drying of perishable food items in the rural areas.

2.3 Design Analysis

2.3.1Design Considerations: The following considerations were considered in the design of the solar drying system:

i. Size of batch to be dried by the dryer.
ii. Harvesting period.
iii. Quantity of water to be removed from a given food item or product to bring it to safe storage level in a specific time.
iv. Daily hours of sunshine for the selection of the total drying time.
v. Design features of the dryer.
vi. Dryer dimensions.
vii. Wind speed to determine air vent dimension.
viii. Quantity of air required for drying.

2.3.2 Design Calculations

The design was based on the following considerations:

i. Design basis: Size of batch for samples: 5kg (with 65% initial moisture content-wet basis)
ii. Harvesting period: Products harvesting period vary from one to another
iii. Daily sunshine hours: Length of day for Ikot Abasi metropolis for drying time is 11.5hrs

The amount of moisture to be removed from the each product of the wet crop in order to bring the moisture content to safe value is given in Equation 1.

$$W_w = {W_g\,(M_i - M_f)}\Big/{100 - M_f} \qquad 1$$

where W_w is the amount of moisture to be removed (kg)**,**W_g is the initial mass of wet crop to be dried, $M_i$is the initial moisture content wet basis**,** $M_f$and is the desired final moisture content on dry basis.
The average drying rate of moistureis given in Equation 2.
.

$$W_{dr} = W_w\ /\ t_d \qquad 2$$

where$t_d$is the total drying time,W_{dr} is the average drying rate (kg/hr), W_w is the amount of moisture to be removed.

The quantity of air needed for drying is determined using the Equations 3 and 4.

$$W_w L = W_a C_a \rho_a\ (T_i - T_f) \qquad 3$$

From (3), $W_a = \quad W_w L/\ C_a \rho_a\ (T_f - T_i)$ 4

where $W\ _a$ is the quantity of air required, L is the specific heat of vaporization of water from samples, C_a is the specific heat capacity of air at constant pressure, ρ_a is the density of drying air (kg/m^3), T_i is the initial temperature of heated air is 32℃, T_f is the final temperature of drying air is 59℃ and the average climatic conditions in Ikot Abasi is be taken for ambient temperature of air (T_{am}) = 32℃, Augustine and Nnabuchi (2010).

The volume flow rate of Air V_a (m^3/hr.) is given in Equation 5.

$$Q_a = W_a / t_d \qquad 5$$

where Q_a is the mass flow rate, and W_a is the quantity of air required in m^3
The pressure drop in the dryer is calculated from Equation 6
P = 0.0038*T*G*H [8] 6
where, T is the change in temperature between ambient and hot air in the dryer (it is averagely a difference of about 15°C), g is the acceleration due to gravity -9.81m/s^2, H is the height of hot air.
The useful thermal energy by the collector is given in Equation 7:

$$Q_u = \left[C_P W_P (T_C - T_A) + L_V \left(MC_i W_P - MC_f (W_P - MC_i W_P)\right)\right] \qquad 7$$

where Q_u is the collector useful thermal energy gain, C_P is the specific heat capacity of product, T_c is the collector temperature, T_a is the ambient temperature, L_v is the latent heat of evaporation, MC_i is the initial moisture content, W_p is the weight of the product ; and MC_f is the final moisture content
The expression for area of collector is expressed in Equation 8.

$$Q/_A = Q_{ab} = (\tau\alpha I_0) \qquad 8$$

where, Q is the heat absorbed by solar collector, A is the area of solar collector, Q_{ab} is therate of heat absorption by solar collector, $\tau\alpha$ is the Transmittance – absorptivity index of collector and is equal to 0.83, I_0 is the incident solar radiation (360.4W/m^2)[18].

The design of components of the solar dryer are provided:
i. Collector Dimension
Configuration of free convective solar dryer have been worked out to be X, 0.733X and 1.5X for solar collector length, width and drying chamber length respectively [19].
Collector area = $0.558m^2$
Therefore, length of the collector = $0.915m$
Width of the collector = $0.610m^2$
ii. The dimensions of the Total Dryer are chosen as:
Length of the total dryer = horizontal length of the collector + 2(allowance)
Total length of the dryer = 915mm+ 2(0.236) = 915.472mm
For the Direct Dryer:
Length= 0.915m, breadth =0.610m, height = 0.610m
The area of the direct dryer $0.558m^2$
The volume of the direct dryer = $0.340m^3$
The direct dryer carries on top it an adjustable glass collector suspended using tightly fitted hinges.
For the Indirect Dryer:
Length = 0.458m, breadth = 0.610m, height = 0.915m
The area of the indirect dryer = $0.279m^2$
The volume of the indirect dryer = $0.256m^3$
For the Total Dryer:
Total area = $0.837m^2$
Total volume = $0.596m^3$
Drying Tray
Length of the tray = length of the drying chamber – allowance of 2 x thickness of the wood that will be used for the dying chamber
The thickness of the wood = $\frac{1}{2}$inch = 0.0127m
∴ Allowance = 2 x 0.0127m = 0.0254 m
Hence, the length of the tray = 0.915m– 0.0254 m = 0.8896m
iii. Inlet and Outlet Air Vent:
The inlet and outlet air vents are assumed thus:
For the Inlet Air Vent; Diameter = 500 mm = 0.5 m
For the Outlet Air Vent; Length = 0.13mWidth = 0.12m

iv. Dryer support

The dryer comes with four castor tyres

Features of the Solar Dryer

i. Solar Air Heater
ii. Mesh Trays
iii. Drying Chamber
iv. Glass Cover:
v. Dryer
vi. Dryer Handle/Door
vii. Compass (Angle Adjuster)
viii. Projection hanger

2.3.2Materials Selection Based on Design Analysis

The hygienic condition of the materials wasconsidered during design, thus the following materials were selected:

i. Wire mesh: These was introduced at both the inlet and outlet of the air vent to prevent foreign bodies such as dust, insect, rodents etc., from entering the dryer which might contaminate the product.
ii. Glass: This material was used for the solar collector cover. It helps to prevent rain from entering the dryer, and permit solar radiation into the system.
iii. Wood: This was selected because of its good insulating properties and it is cost effective. It was used for the housing of the entire system.
iv. Paint: Black and grey used for absorbability.
v. Aluminium sheet: 5mm thickness was painted black for absorbing solar radiation.
vi. Lagging material: Was used to lag the direct dryer's top, to prevent heat loss from the dryer. Foams of specific dimensions were considered.

2.3.3 Samples Preparation

The below procedures are outlined for the preparation of sample for drying:

i. Purchase of samples from the local market in Ikot Abasi.
ii. Weighing using a mechanical scale.
iii. Preparing the samples; by peeling the samples, etc.
iv. Cleaning and washing of the samples.
v. Slicing the samples to different reduced dimensions.
vi. Blanching at 70℃ and 100℃ of 5mimutes and 3minutes respectively. This was done to deactivate the enzymes, hence preventing the samples to deteriorate before being finally dried.
vii. Allowing the water to drain out.
viii. Placing the drain samples in the drying trays and putting them in the drying chamber.

2.3. 4Experimental Procedures

Samples from the cabinet and sun-drying should be weighed at three hour interval daily, between the hours of 7am and 6pm. The following parameters should be measured;

i. Moisture content at every three hour interval using oven method.
ii. Ambient temperature every three hours.
iii. Temperature of the dryer at every three hours interval.
iv. Outlet temperature of the dryer at every three hours interval.
v. Relative humidity at every one hour.

III. Results and Discussion

3.1 Results

The design drawings of the dryer are shown in Figures 1, 2 3 and 4.

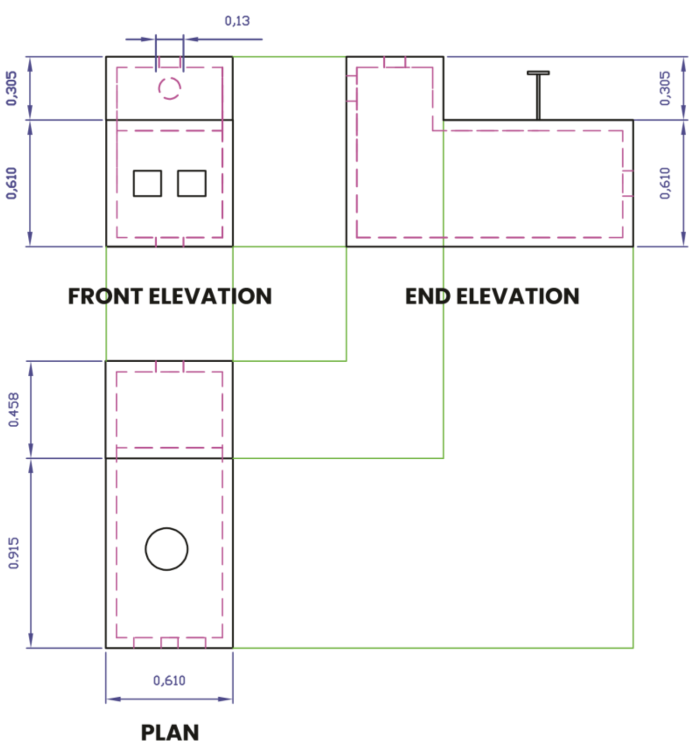

Figure 1: Orthographic Views

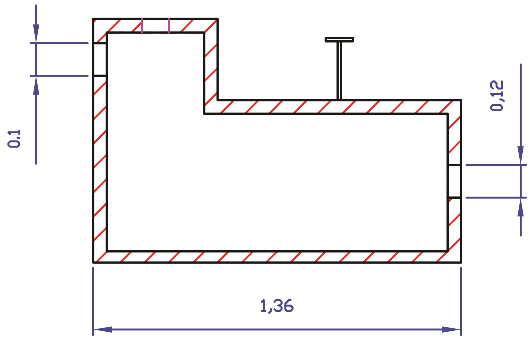

Figure 2: Sectional View

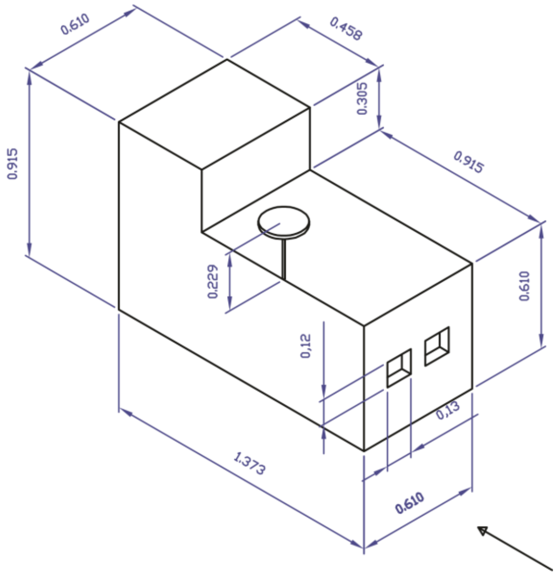

Figure 3: Isometric Projectio

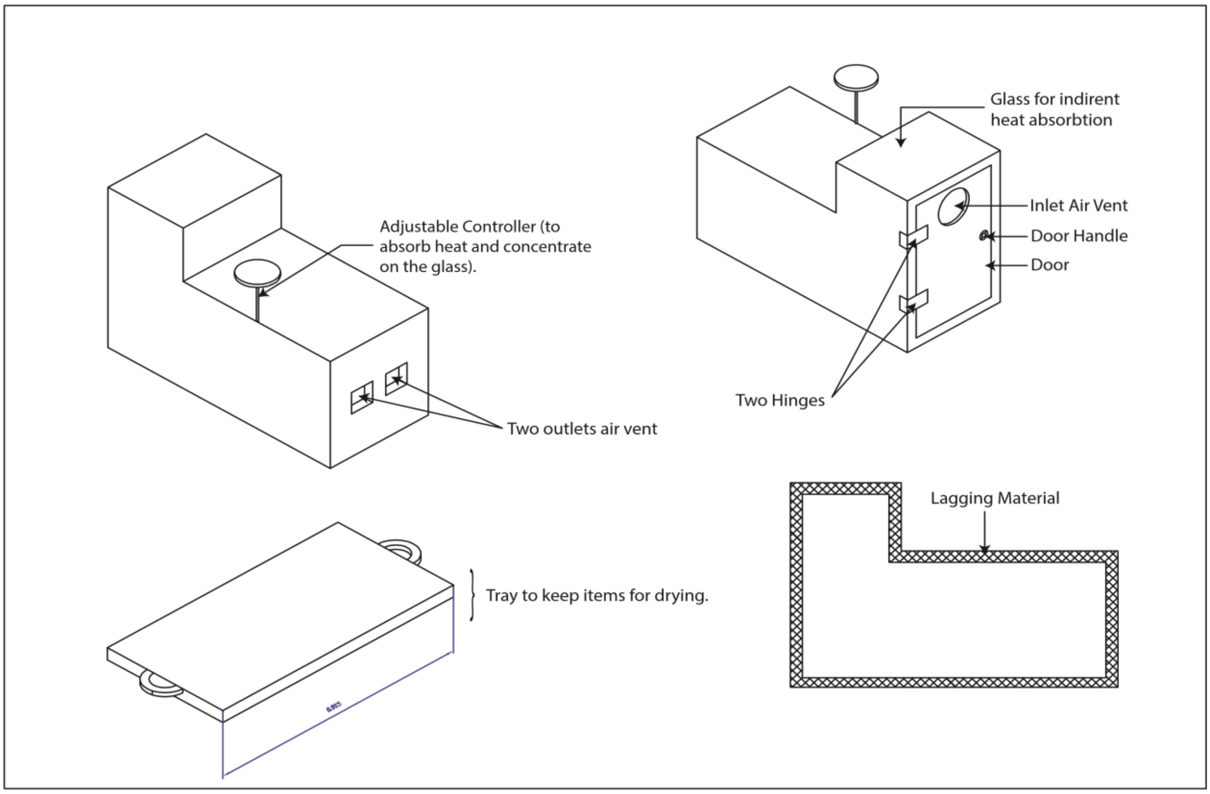

Figure 4: Detail View

3.2 Discussion

The dryer is design is unique with a collector which collects the sun rays and concentrates it on the direct dryer section. It has an adjustable mechanism that enables its angular orientation to be changed to collect the sun rays as the earth revolves around the sun. The dryer is compact and can be moved around with the castor wheels, thus increasing its versatility. The dryer is provided with an inlet air intake of 0.5m and two outlet vents of $0.25m^2$ area each. The indirect dryer gets the heat from the collector on its surface and passes it through the movement of air to the drying chamber. The combined effects of direct, indirect drying together with an additional collector and concentrators maximise the quantity of heat trapped to the enclosure for drying. Adequate lagging is provided to minimize heat loss to the surroundings.

IV. Conclusion

The design of the direct and indirect dryer with a collector and concentrator has been conceived, designed and produced as shown in this research. Its design features provides manoeuvrability with the castor wheels. The angular adjuster for sun ray collections is manual and most suitable for rural communities. It is simple, compact and easy to be used, giving additional advantage to its design for rural communities. The theoretical minimum and maximum designed temperatures are feasible. The dryer is expected to attain the highest temperatures at 14:00 h, with cabinet temperature of 61.3℃, when the ambient temperature is 35℃. Under load, peak temperature and minimum relative humidity of 64.9℃ and 45.5% respectively is expected. The theoretical moisture content of 12%w/w is expected using the solar dryer from an initial moisture content of 64.0% w/w in 11 hours, while the open-air sun drying is expected to require 28 hours for complete drying.

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