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Development and Performance Evaluation of Solar Dryer for Green Tea Leaves in Mambila Plateau

[1]Umar Nuhu Musa, [2]Ademola Bello Adisa, [3]Habou Dandakuta

[1] *PG student, Department of Mechanical/Production Engineering, Abubakar Tafawa Balewa University, Bauchi, Nigeria*

[2,3] *Professor, Department of Mechanical/Production Engineering, Abubakar Tafawa Balewa University, Bauchi, Nigeria*

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ABSTRACT:A proper drying process of agricultural produce is necessary not only to preserve and promote quality but also to minimize energy inputs. Tea production is not an exceptional in this aspect. Different methods are used in tea leaves processing that include Orthodox method, Crush Tear and Curl (CTC), open sun drying and solar drying. The motivation of this research work was to develop a solar dryer for green tea leaf drying in Mambila Plateau for local farmers. This is because the other methods are not favourable to them due to bad weather condition for open sun drying and high cost for the modern dryers. A Solar dryer of 5000 cm^2 collector area was developed with 70Watts backup heater incorporated to the dryer with controller to maintain the drying chamber temperature between 35^0C and 50^0C. Different tests were carried out in order to evaluate the dryer performance. No load test (i.e test without any material to be dried) was performed indicating temperature rise up to 45^0C in the chamber with maximum collector temperature of 61^0C at an ambient condition of 26^0C, relative humidity 59% and solar insolation of 539.20W/m^2 recorded without backup heater. The dryer performance was also evaluated using fixed tealeaves of 1.5 kg using three different test scenarios and moisture content and drying rate as performance evaluation parameters. The moisture content of the tea leaves was reduced from 82% (w.b) to 5.1% (w.b) without backup heater, 82% (w.b) to 5.4% (w.b) backup heater during sunset, and 82% (w.b) to 4.9% (w.b) backup heater throughout the day, the drying rates were found to be 17.1g/h, 23.14g/h and 36g/h, within 19 hrs without heater, 14 hours with heater in the night and 9 hours with heater throughout the day respectively. The total cost of the dryer was estimated to be N=61950.

KEYWORDS: Solar, Radiation, drying, Green-tea, Collector, Moisture

I. INTRODUCTION

Drying of agricultural produce is necessary not only to preserve and promote quality but also to minimize energy inputs. Tea is made from the young shoots and leaves of the plant Camellia sinensis (L) Kuntze [1]. It is a popular beverage produced from the young leaves of commercially cultivated tea plant and has become one of the important revenue sources for tea producing countries in the world [2]. Depending on the techniques used in the production and processing, tea can be divided into four basic types, namely green tea, black tea, oolong tea, and white tea [3]. Today, tea is grown over a wide range of a tropical and subtropical region in more than 50 countries throughout Asia and Africa [4]. Tea was introduced into Nigeria by de Bouley from west Cameroon in 1952 [5]. Tea production can contribute immensely to food security. The tea industry creates considerable economic benefits, employing a large labor force; for example, the Tea Board of India statistics show that at least one million laborers were employed in the tea industry in 2007 [6]. Green Tea is unoxidized tea, the application of heat (called fixing) soon after bringing the harvested leaves from the field sets green tea apart from other types. Green tea is a medicinal herb, it’s one of the most popular beverages consumed around the world which is of great interest due to its beneficial medicinal properties [7,8,9].

Traditional drying method is mainly used in manufactured of green tea by farmers in Mambila plateau, inconsistency of quality low process efficiency affects the end product. More attention has been paid to not only to the quantity but also the quality of tea, as the quality is an essential factor influencing the market value of tea [10].Currently, hot air drying is the most widely used method in the post-harvest technology of agricultural produce. Using this method, a more uniform, hygienic and attractive colored dried product can be obtained

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rapidly. However, it is an energy consuming operation, so more emphasis is given on using solar energy due to low cost and shortage of fossil fuels. Solar dryers have potential to produce high quality dried products and can help to avoid the problem of contamination. In comparison to natural open sun drying, solar dryers generate higher temperature, lower relative humidity, lower product moisture content and reduced spoilage during the drying process and thus preserving vital nutrients and also it takes less time and relatively inexpensive [11]. Solar dryers are classified depending upon the mode of air circulation, such as natural circulation and forced circulation dryers; or based on type of drying, like, direct solar drying, indirect solar drying and mixed mode solar drying. They are also classified depending upon the construction of the drying section [12].

Indirect solar drying is the new and more effective technique of product drying. In this type of drying, the products are not directly exposed to the sun but, the solar radiation is used to heat the air which then flows through the product to be dried. Thus, moisture from the product may be lost by convection and diffusion [13].

II. METHODOLOGY

2.1 Design Procedure

2.2.1 Drying temperature

[16]. indicated the optimal temperature for drying common agricultural products is between 35.5-55.5°C. It is noticed that increasing airflow increased drying efficiency even if air temperature dropped in the process. Hence, for this design an average drying temperature, T_f, of 45°C was considered.

2.2.2 Amount of moisture to be removed

The formula to calculate the total amount of moisture to be removed (M_w) is given by

$$M_w = \frac{W_w (M_i - M_f)}{1 - M_f} \qquad (1)$$

Where: M_w = amount of moisture removed
W_w = initial total weight;
M_i = initial moisture content on wet basis;
M_f = the final moisture content on wet basis;

$$M_w = \frac{1.5\text{kg} \times (0.82 - 0.06)}{1 - 0.06} = 1.213\text{kg}$$

2.1.3 Heat energy required to remove Water from the leave

The heat required to remove water from a produce was calculated using the formula provided by [17]. It considers drying as a two-stage process where the first one is raising the temperature of the wet material to a desired level at which the moisture will be removed. This is given by:

$$Q_1 = W_w \times Cps \times \Delta T \qquad (2)$$

Where: W_w= initial total weight
Cp = the specific heat capacity of the produce (in kJ/kg ^{o}C)
$\Delta T = T_f - T_a$, is temperature change (in ^{o}C).
The specific heat capacity (Cps) of tea leaves was determined using Eq. below [18].

$$Cps = 0.827 + 3.348\, M_d\,(wb)$$

M_d (wb) =Moisture content of tea leaves in decimal wet basis

The second stage is evaporating the moisture from the produce. As water starts to evaporate after the produce is warmed up to the drying temperature, heat required to evaporate it is given by:

$$Q_2 = Mw * L_m (3)$$

M_w = amount of moisture removed
$L_m = h_g - h_f$ is latent heat of vaporization. The values for h_g (enthalpy of water as a vapor) and h_f (enthalpy of water as a liquid) at the drying temperature of 45^{o}C were obtained from steam tables (Saturated water).

Total heat requirement: $Q_T = Q_1 + Q_2$ (4)

2.1.4 Sizing the Collector

The daily average insolation of Mambilla plateau is taken to be 20.20MJ/m^2/day.

Collector Area, $A_C = \frac{Q_T}{I_t \eta_d}$ (5)

2.2.5 Collector Tilt Angle

The flat plate solar collector should be tilted and oriented in such a way that it will receive maximum radiation. As a general rule, optimum angle of tilt is equal to the degree of latitude of the site [19]. For this design, the test location is Mambilla Plateau (latitude 7^{o}20′N and longitude 11^{o}43′E).

2.2 Performance Evaluation

2.3.1 Drying rate

Drying rate (DR) is the amount of evaporated moisture over time [20]. and is given as:

$$DR = \frac{M_i - M_d}{t} \qquad (6)$$

Where:
M_i= mass of sample before drying
M_d = mass of sample after drying
t = drying period

2.3.2 Moisture content

Moisture content (MC) of a material can be given either on the basis of total weight of the material to be dried or the amount of solid weight present in the

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material. The moisture content on wet basis is given by the following equation [21].

$$MC(w.b),\% = \frac{w-d}{w} \times 100 \quad (7)$$

Dry basis moisture content is given by [18].:

$$MC(d.b)gwater/gdrysolids = \frac{w-d}{d} \quad (8)$$

w = weight of wet material
d = weight of dry material

2.4 Testing

The experiment was performedusing fresh tea leaves samples obtained from the Mambilla highland of Taraba State, Nigeria, with initial moisture content of 82% (wet basis). The plucked tea leaves were fixed using steaming method in order to stop the activities of the enzyme that causes oxidation (fermentation). The fixed tea leaves samples were placed on trays in the drying chamber. Hot air from the solar collector was discharged into the drying chamber from the inlet duct. The parameters measured during the evaluation of solar dryer include weight of the material to be dried, ambient temperature, collector temperature; chamber temperature, humidity, wind speed as well as solar insolation. The drying air temperature was maintained between 35 to 50^{o}C when D.C heater with controller was used. The weight of the tea leaves was measured before putting it in the dryer. Once the drying process started the tea leaves being dried was taken out from the dryer every one hour for weight loss record. The no load test was performed to ascertain the temperature in the dryer without any material. The temperature variation at the collector, in drying chamber and ambient temperature values were recorded every one-hour interval. Three different test scenarios were carried out, Solar drying test Photothermal only, Solar Drying Test Photothermal, Photovoltaic (intermitted) and Solar Drying Test Photothermal, Photovoltaic (simultaneously) and moisture content and drying rate as performance evaluation parameters.

III. MODELING AND ANALYSIS

3.1 Material Selection

The following materials were selected and used for the construction of the solar dryer.

Glass of 5 mm thickness was used as glazing material for transparent cover. Glass is preferred to Polycarbonate due to its high transmittance, higher strength and does not deteriorate over time when exposed to UV radiation [14].

3.1.2 Absorber plate

Corrugated galvanized sheet of 2mm thicknesswas painted black to make it perfect absorber of heat. The selection of galvanized sheet will be based on properties it possesses such as high absorptance (0.80) and a low longwave emittance (0.28) and able to transfer the absorbed energy efficiently to the air within the collector [14]. This coupled with its low cost and availability makes it suitable candidate for efficient absorbers.

3.1.3Insulator

Polyurethane foam of 5cm thickness was used as insulator. Polyurethane foams use non-chlorofluorocarbon (CFC) gas for use as a blowing agent. This helps to decrease the amount of damage to the ozone layer.

3.1.4 Collector casing

The collector casing was made from plywood. Plywood is preferred to metal because it is a good insulator. The air inlet opening was covered with smaller size wire mesh. The dimensions of collector casing: Length = 1.0 m, Width = 0.5 m, Depth of air channel =6.0cm.

3.1.5 Drying Chamber

The drying chamber was made from plywood with Mahogany wood support. It consisted of three trays, for the produce to be dried. The trays were made from perforated stainless steel. Stainless steel was chosen to avoid rusting due to high initial moisture content of the produce. At the back of the drying chamber, a door was provided as a means for loading and uploading the material to be dried.
The dimensions of drying chamber: = length x width x height = 50cmx50cmx50cm.

3.1.6 Chimney

The recommended height of the chimney is between 2 and 6 m for corresponding pressure across the dryer between 0.8 and 2.5 Pa [15]. Taking this into consideration, 2 m height of chimney was fabricated. The fabricated chimney it's circular in shape so as to reduce drag on the exhaust air. It was incorporated with a rain cap in order to prevent rain from falling back into the drying chamber. The material selected for constructing the chimney was galvanized metal sheet due to the properties it possesses, good resistance to corrosion, high strength and easy machine.

3.1.7 Backup Heater

The backup heater used photovoltaic with battery as energy source. The D.C heater was used to heat the incoming moist air from the surrounding through the collector passage into the drying chamber during the night period as well as cloudy and rainy period. For this research, 70Watts D.C heater was equipped with controller in order to maintain the required temperature in the drying chamber.

3.2 Solar Dryer model

Figure 1(a) shows the conceptual model of the solar dryer, whereas, Figure 1(b) depicts the developed solar dryer.

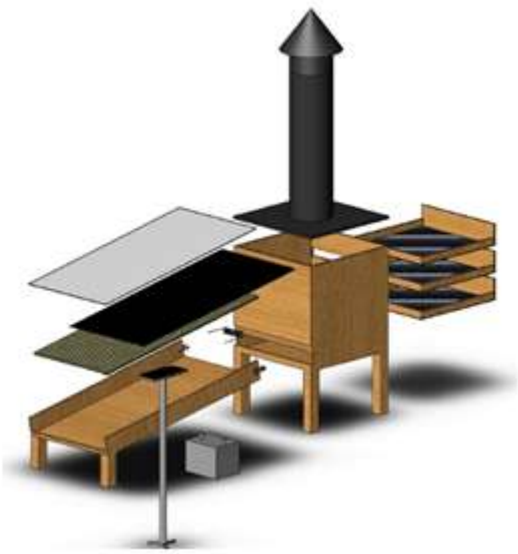

Figure 1 (a): 3D Solar dryer assembly exploded view

Figure 1 (b): Pictorial view of the constructed dryer under test condition.

IV. RESULTS AND DISCUSSION

After production of the solar dryer Figure 1, Tea leaves were dried during the test period. The results of different tests performed are presented below.

When sun was the only source of heat supply a maximum temperature of 61°C was attained by the collector at 13:00 hours.

The collector reached its peak temperature value when the ambient temperature was 26°C and the maximum average temperature rise on the drying chamber was 45°C.

4.1 No-Load test

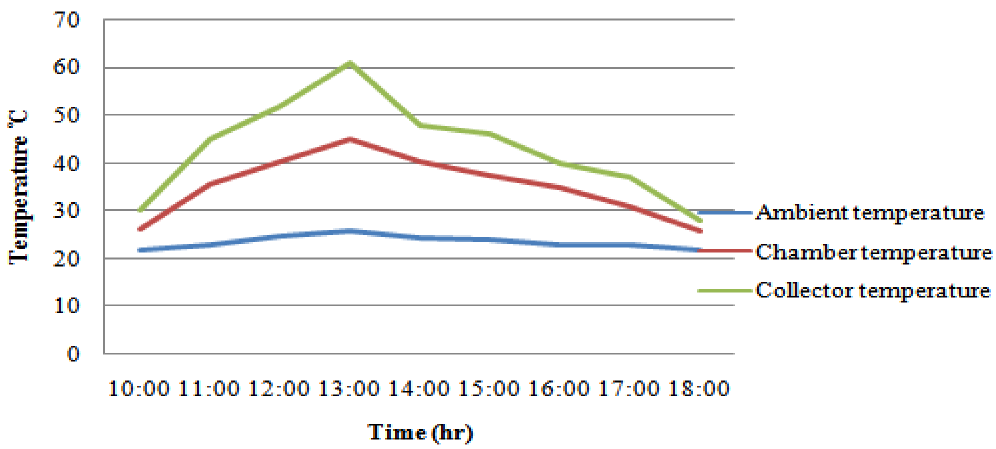

Figure 2: Temperature variation with time for a no-load test.

4.2 Solar drying test using Photothermal Only

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As the hot air rises in the drying chamber, it picks up moisture from the leaves on the trays. This results in reduction of weight or moisture loss of the tealeaves. The moisture content of Tealeaves was reduced from 82% (w.b) to 5.1% (w.b) within almost 19 sunshine hours.

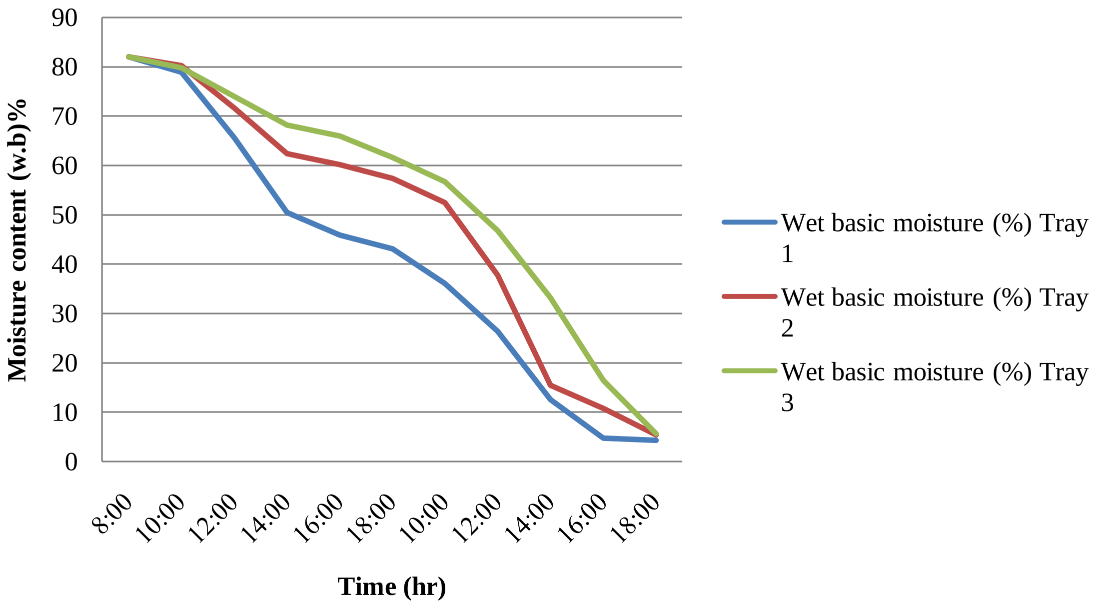

Figure 3: Variation of moisture content (wet basis) with time of Tea leaves

3.3 Solar Drying Test using Photothermal and Photovoltaic (intermitted)

When backup heater was used during off sunshine, the Moisture content of Tea leaves in the dryer for this test was reduced from 82% (w.b) to an average value of 5.4% (w.b) within almost 14 hours.

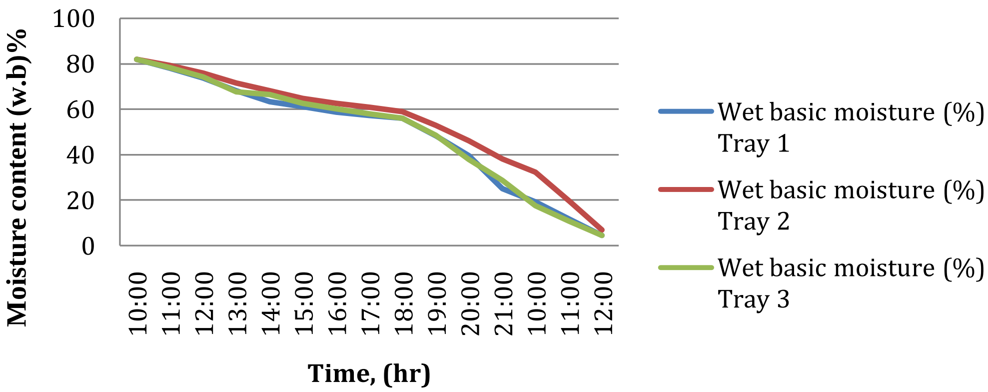

Figure 4: Variation of moisture content (wet basis) with time of Tea leaves using backup

Heater from 18:00hours to 21:00hours.

3.4 Solar Drying test using Photothermal and Photovoltaic (simultaneously)

Connecting the backup heater during the day time, by supplying heat from the 70W, 12V D.C heater provides a faster drying as compared to using solar energy only. It took nine (9) sunshine hours to reduce the moisture content of tea leaves from 82% (w.b) to 4.9% (w.b).

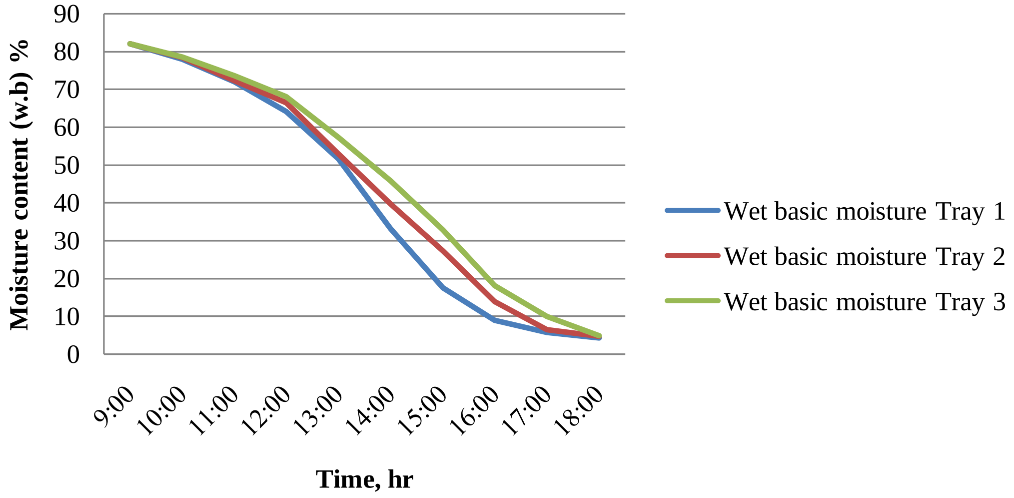

Figure 5: Variation of moisture content (w.b) with time of tea leaves using backup heater throughout the day

V. CONCLUSION

An indirect mode solar dryer with a backup heater was designed and produced with readily available materials in the market, having drying chamber of 125000 cm^3, 5000 cm^2 collector area, and backup battery of 8 hours. This dryer is easy to handle and operate. The backup battery was incorporated to make drying continues during the sunset hours as well as cloudy and rainy period. The performance of the solar dryer was carried out by considering no load and loaded dryer. Drying rate, moisture content removal and the average collector temperature were determined, with solar drying test using photothermal and photovoltaic (simultaneously) indicates a better performance.

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