International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Influence of operating parameters on the energy consumption of a hybrid solar dryer: Application to the drying of gombo (*Abelmoscus Esculentus*)

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Received 02 Sept 2023, Accepted 21 Sept 2023, Available online 27 Sept 2023, **Vol.13, No.5 (Sept/Oct 2023)**

Abstract

The present study aims to investigate the influence of temperature, drying air speed and product thickness on energy consumption during drying of okra slices. The experimental methodology consists of following the evolution over time of solar irradiation, of the temperature of the different elements of the collector, of the air at the inlet and outlet of the collector, of the electrical energy via a meter digital thus leading to the determination of energy consumption by equations found in the literature review. The results obtained are presented in the form of graphs and the analysis of the results revealed that the energy contribution provided by the solar collector increases from 1 to 9.8 kWh when the solar energy increases from 200 W/m² to 850 W/ m² and that this in electrical energy decreases from 6 to 1.3 kWh around 2 p.m. The energy consumption increases from 10.02 to 15.03 kWh when the air speed increases from 1 m/s to 2 m/s, an increase rate of 33.33%. In addition, increasing the air speed from 1 to 2 m/s increases the contribution of electrical energy from 54.89% to 60.80%, while that of solar energy decreases by 45.11% to 39.20%. It increases from 9.1 to 15.5 kWh when the thickness of the product increases from 10 to 20 mm; i.e. an increase rate of 58.71%. This increase in thickness from 10 to 20 mm increases the percentage of electrical energy contribution from 46.70% to 52.90%, on the other hand that of solar energy decreases from 53.30% to 47.10 %. Regarding the air temperature, the energy consumption increases from 7.82 to 14.95 kWh when the temperature increases from 40°C to 60°C, an increase of 47.69%. This increase in temperature from 40 to 60 °C increases the percentage of electrical energy input from 45.65% to 54.85%, while that of solar energy decreases from 54.35% to 45.15%.

Keywords: *Drying of okra slices, Solar collector etc.*

1. Introduction

Okra is one of the most consumed vegetable fruits in Africa, due to its availability, its nutritional qualities and its medicinal virtues. It is low in calories because 100g of material provides 36 kcal [1].It is used in breadmaking as a texturizing agent in medicine for the healing of internal stomach lesions. It is also appreciated for nutritional, technological and economic reasons. It contains 87 to 90% water, 7 to 8% carbohydrates, vitamins A, B, K and E as well as mineral salts [2].

However, its high water content makes its microbiological activity intense, resulting in losses of up to 40 to 50% of its production. During the harvest period, producers are faced with short-term overproduction and difficulty in extending the conservation of this commodity throughout the year in developing countries where conservation techniques are almost non-existent.

*Corresponding author's ORCID ID: 0009-0008-4682-6824
DOI: https://doi.org/10.14741/ijcet/v.13.5.4

Drying is the most widely used method of preserving agri-food products because it blocks microbial activity by reducing the water content.Although effective for preserving products, this technique requires a large quantity of energy which can reach significant values and causes the quality of the product to deteriorate when it is not controlled.The challenge is therefore to be able to remedy this problem while guaranteeing quality drying with reduced time and at lower cost.Solar drying represents a solution that satisfies value for money. It is more energy efficient, free, clean, inexhaustible and simple.

However, the intermittent nature of solar energy involves the use of additional energy from an energy source which allows drying during periods of low irradiation and at night. Although considered an effective solution, this drying system leads to excess energy consumption and an extension of drying time when it is not controlled. However, this high energy consumption has a significant impact on the quality of the dried product as well as the drying cost. This process also has low thermal efficiency, leading to high consumption of electrical energy. Numerous works have been carried out to optimize the drying operation Abdullah and Aydin[3], Sharma et Prasad[4], Talla and Jannot [5].They consist of rationalizing the energy consumption necessary to stabilize the product and safeguard the quality of the product. Dryer energy consumption is vital technical information applied for the optimal and cost-effective design and operation of drying systems [6]

However, little information is available on energy requirements during solar drying of okra. With this in mind, consideration of the problem of energy saving during drying must be carried out in order to minimize both energy consumption and the contribution in electrical energy. The objective of this work is to evaluate the influence of operating parameters on energy consumption during okra drying.

2. Materials and methods

2.1 Vegetable material

The plant material used is fresh okra (Abelmoscus Esculentus) purchased at the Total market in the city of Brazzaville.

Figure.1 : *Abelmoscus Esculentus* fruit

2.2 Material of laboratory

The laboratory equipment used consists of a hybrid solar dryer,a pressure balance and digital solarimeter (Figure.2)

Figure.2a Hybrid solar dryer

Figure.2b Scale with an accuracy of 0.01g

Figure.2c Digital solarimeter *PL-110SM*

2.3.1.Solar drying of okra

The experimental method consists of drying the product daily between 7 a.m. and 6 p.m. The tests were carried out at temperatures of 40°C, 50°C and 60°C, speeds of 1 m/s, 1.5 m/s, and 2 m/s and at slice thicknesses of 10 mm, 15 mm and 20 mm.

The follow-up of the mass loss of the product during the drying is ensured by mass measurements carried out at regular time intervals of 30 minutes using a precision balance to within 0.01 g.The end of the operation is marked by the stabilization of the mass of the product after three successive weighings.

2.3.2. Measured parameters

The drying temperature was set for each experiment (4 0°C, 50°C and 60°C) using a thermo regulator and the speed of the fan which is the speed of the drying air;

The experimental study on this dryer consists of measuring;

- The global solar radiation received on the collector plane using a solarimeter, the results of which are displayed digitally;
- Temperatures using thermo-hydrometers at the inlet and outlet of the collector and the ambient environment;

- The systematic loss of mass of the product to be dried using a balance with a precision of 0.01 g;
- Electrical energy consumption using an electrical meter with digital display in kWh.

2.3.3.Data analysis

2.3.3.1. Water content

The determination of the water content was carried out according to the equation:

X=((M_(0-M_s)))/M_0 (1)

X=Water content;
M_0: wet mass (g);
M_s:dry mass(g).

2.3.3.2. Energy consumption

Energy consumption leading to the stabilization of the product after three (03) successive weighings is estimated using the following relationship ([7].

CE=Igt+ER+EV (kWh) (2)

Igt: Total solar energy entering the collector (kWh) over a period of time, t:drying time (h);
ER: Energy consumed by electrical resistors (kWh);
EV: Energy consumed by the fan (kWh);
CE: Energy consumption (kWh).

3. Results and Discussion

3.1. Evolution of the temperature of the different elements of the sensor and solar irration as a function of time

Figure.3 shows the evolution of the different temperatures of the sensor elements as a function of time. These curves all have the same shape, increase between 7 a.m and 2 p.m and decrease after 2 p.m reach their optimum values of 58°C, 51°C, 46°C and 33°C respectively for the absorber, from air to the outlet of the sensor, of the window as well as that of the air at the inlet of the sensor. The high temperature of the absorber is due to the high absorption coefficient which makes it possible to absorb most of the solar radiation; that of the glass is low compared to the other components of the collector because of thermal losses to the outside and its low absorption coefficient.It is also observed that the temperature of the air at the outlet of the sensor reaches a maximum value of 56°C,this means that the sensor has allowed a rise in temperature of approximately 18°C, which constitutes an economic gain for the energy point of view for the drying of local products. These results are similar to those found by Kanouté et al.[8] Pascal et al.[9].These authors evaluated the thermal performance of a solar air collector and a solar water collector .

Figure.4 shows that the daily variation of the air temperature at the outlet of the solar collector is proportional to the global solar energy as well as to the air temperature at the inlet of the collector. We observe in this figure a maximum of the climatic parameters around 997 W/m2, 38°C and 56°C respectively for the global solar energy, the air temperature at the inlet and at the outlet of the sensor around 14 hours. These results are similar to those found by Fouakeu Nanfack et al.[10] and confirm that solar energy has a significant influence on the thermal performance of the solar collector. Indeed, the rise in the temperature of the air at the outlet of the collector is due to the increase in the temperature of the absorber which is a function of the solar.

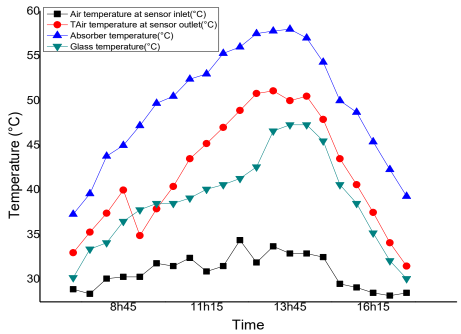

Figure.3: Evolution of the temperature of the various elements of the sensor

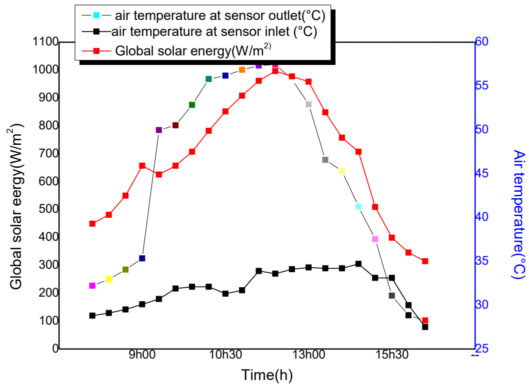

Figure.4: Evolution of the air temperature according to the global solar energy

3.2. Effect of air temperature outlet and global solar energy on energy consumption

The effect of solar energy received on the contribution of energy consumption is shown in Figure.5. This figure clearly shows that increasing solar energy increases the contribution of solar energy to heat the drying air and reduces the contribution of electrical energy. This increase in the rate of input of solar energy with solar radiation is due to the increase in the temperature of the air leaving the collector with solar energy. Indeed, it shows that the contribution of solar energy increases from 1 to 9.8 kWh when solar energy increases from 200 W/m2 to 850 W/m2 and that of electrical energy decreases from 6 to 1.3 kWh around 2 p.m. However, we note a strong contribution from electrical energy consumption (additional) around 8 a.m and around 6 p.m. This strong contribution is explained by the low temperatures recorded at the sensor output, which reduce the decrease in solar energy [11]. It therefore clearly appears that the use of electrical support is useful at the start and end of drying in order to compensate for the energy deficit around sunrise and sunset.

In Figure.6, we present the effect of the air temperature at the outlet of the sensor on the energy contribution of the different energies used. We note that the increase in the temperature of the air at the outlet of the sensor decreases the rate of contribution of electrical energy 5.1 to 1.5 kWh when the temperature goes from 36.5 °C to 47 ° C, on the other hand that of solar energy 4.5 to 10.1 kWh around 10 am.

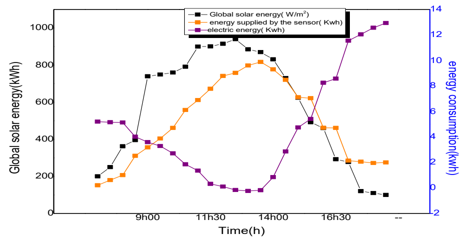

Figure.5: Influence of solar energy on the energy contribution (ECH/50 °C/15 mm/1.5 m/s)

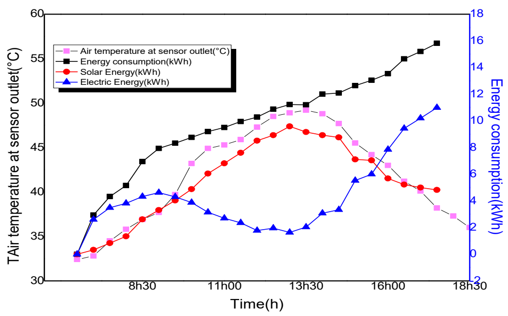

Figure.6: Effet de la température de l'air à la sortie du capteur sur la contribution ECH/60 °C/15 mm/1.5 m/s

3.3. Effect of air temperature and produit thickness on energy consumption

The effect of air temperature on energy consumption during drying is shown in Figure.7. The tests were conducted with an air speed of 1.5 m/S (m˙_air=0.0275 kg/s) and a product thickness of 15 mm. We see in this figure that the energy consumption increases with the air temperature. Indeed, the increase in air temperature from 40°C to 60°C increases the energy contribution from 7.82 to 14.95 kWh, an increase of 47.69%. In addition, this increase in temperature from 40 to 60°C increases the percentage contribution of electrical energy from 45.65% to 54.85%, on the other hand that of solar energy decreases by 54.35% at 45.15%. These results are similar to those found by [11]. This increase in consumption results from the increase in the thermal difference between the air temperatures at the inlet and at the outlet of the heating system. These results are similar to those found in the literature by Youssouf [12,],Kumar et al.[13], Akpinar[14] disagree with those found by Motevali et al.[15], Saeid Minaei et al.[16] Aviara et al.[17] for drying pomegranate;for drying pomegranate arils[18]. They concluded that temperature increases the rate of evaporation of internal moisture for increased diffusion of heat and moisture and evaporation is accomplished in a short time, thus reducing the amount of energy consumed which is a function of drying time.

Fig.8 represents the energy consumption over time at 50°C, at an air speed of 1.5 m/s (m˙_air=0.0275 kg/s) and at different thicknesses of the product. The analysis of the figure shows that the energy consumption is an increasing function of the thickness of the product. Indeed, it shows that energy consumption increases from 9.1 to 15.5 KWh when the thickness of the product increases from 10 to 20 mm; i.e a rate of increase of 58.71%. In addition, this increase in thickness from 10 to 20 mm increases the percentage of contribution of electrical energy from 46.70% to 52.90%, on the other hand that of solar energy decreases from 53.30% to 47.10% ncreases of the thickness of the product thus leading to an increase in drying time and therefore an increase in energy consumption. Similar trends were found by [19]. These authors reported that increasing the thickness of the product prolongs the time of drying and therefore the energy required for drying increases.

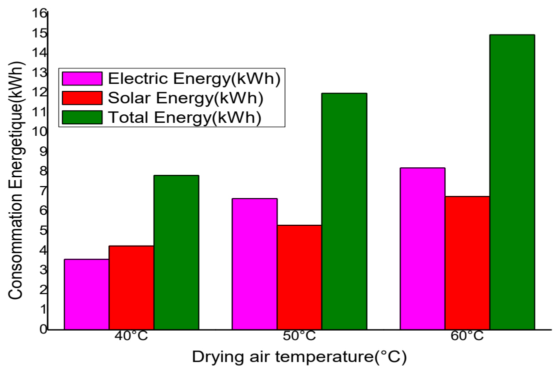

Figure 7: Effect of air temperature on energy consumption of Okra drying (Ep=15 mm,V=1.5 m/s)

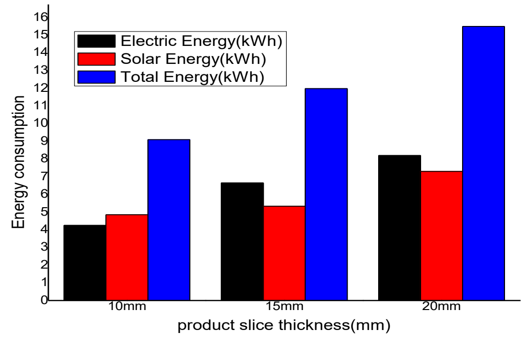

Figure 8: Effect of Product Thickness on Energy Consumption of Okra Drying (T=50 °C,V=1.5 m/s)

3.4. Effect of air speed and produit water on energy consumption

Figure.9 illustrates the effect of product moisture content on energy consumption during dryingof okra. In this figure, we see an increase in energy consumption when the water content of the product decreases. This increase in energy consumption can be explained by the high energy that must be provided to tear off the bound water.This same observation was made by Talla and Jannot[6].

Figure10 shows the effect of air speed on energy consumption during drying at a temperature of 50°C and a product thickness of 15 mm.It is found that increasing the air speed from 1 m/s to 2 m/s results in an increase in energy consumption from 10.02 to 15.03 kWh, a rate of 33.33% increasing the air speed from 1 to 2 m/s increases the contribution of electrical energy from 54.89% to 60.80%, on the other hand that of solar energy decreases by 45.11% to 39.20%.This increase in the percentage of electrical energy input is due to the fact that for high air speeds, the residence time of the air in the collector is reduced under the effect of a low air temperature at the sensor output. Similar trends to those found by and Kumar et al.[13],Abbaszadeh et al.[18] observed an increase in energy consumption as air velocity increased during drying at a fixed temperature. Therefore, for economic reasons, it is preferable to carry out the drying operation with low air speeds.

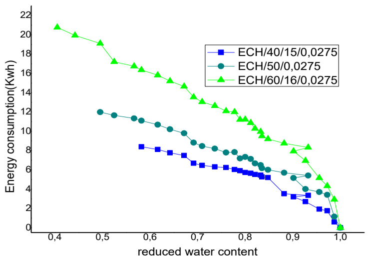

Figure 9: Evolution of energy consumption as a function of water content

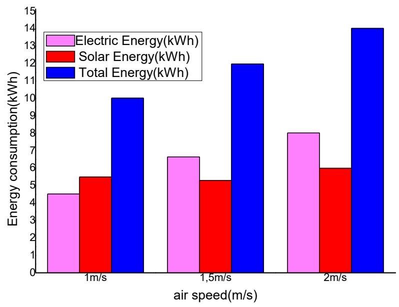

Figure 10: Evolution of energy consumption according to air speed (Ep=15 mm,T=50 °C)

The objective of this work is to assess the influence of parameters (air temperature, air speed and product thickness) on energy consumption during drying of okra.It is therefore a question of making a contribution to the thermal and energy study of a hybrid solar dryer in order to consider its optimization.The results obtained made it possible to affirm that the contribution of electrical energy during drying decreases with the increase in global solar energy and therefore with the temperature of the air at the outlet of the collector.The increase in these three parameters leads to an increase in energy consumption during drying. In addition, we noted a high-energy consumption towards the end of the drying operation; which could be due to the elimination of bound water within the product, which requires high energy. For energy saving reasons, it would therefore be desirable to work at low levels of these three parameters.

Acknowledgements

We thank all authors cited in this article for their technical and scientific contributions which helped improve this work. Then,we also thank the Center for Research and Technological Innovation 2i, for funding this article.

Conflict of interest

The authors declare no interest of any kind in this article.

Contributions by each author

J.W. Mayembo Mfoutou: He is the main designer of the article as this article is part of his doctoral thesis. He participated in the experimentation, data processing and writing of the article.

F.C.Bakeni Moukani: She also contributed to the writing and editing of this article.

J.M.Nzikou: He is responsible for the Process Engineering Laboratory and responsible for doctoral training, he supervises and coordinates all research activities of said laboratory in the search for financing, in the writing and publication of articles, doctoral theses, etc.

B.W.Loumouamou: He contributed to the correction and acquisition of financing;

B.D.Biyendolo Loupangou; K.E.Malela and S.Moussoyi Moundanga: They also participated in the correction, revision, editing, translation and formatting of this article.

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