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Article

Performance improvement of a forced convection solar dryer for agri-food products

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Abstract : This work presents the results of an experimental study on the spinach leaves drying in a solar-assisted forced convection dryer, developed and improved at the food science laboratory. The solar dryer was equipped with a flat air solar collector with an absorbent plate painted in matt black with a surface area of 2 m^2 exposed to solar radiation and a drying chamber with a volume of 0.5 m^3. It was developed to study the effect of the temperature of the drying air and the fraction of the exhaust air recycled (0, 50 up to 90%) on the total energy requirement of spinach drying as a function of time. In this dryer, the spinach leaves are dried from an initial moisture content of 93.23% (wet base) to a final moisture content of about 2% (wet base), with drying air velocity equal to 1 m/s. The spinach dries and reaches the final water content after 6 hours of drying, for air-recycled rate of 0%, and a low drying temperature of about 40°C. The drying rate has slightly increased in relation to the fraction of air-recycled, the drying time has been reduced from 3 to 4 hours for the fraction of air-recycled from 50 to 90% respectively with a significant gain in thermal energy; hence, the drying temperature is higher and stable in the drying chamber in the range of 55 to 65 °C (90% air is recycled).

Keywords : food drying; solar dryer; water content; drying; spinach; recycled air; solar energy.

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1. Introduction

Solar energy is an important alternative source of energy. It is relatively preferred to other sources because it is free, abundant, and inexhaustible and non-pollutant in nature compared with higher prices and shortage of fossil fuels. Solar energy is very abundant in Algeria, in particular in the south of this country.

As an alternative to open sun drying, the solar drying system is one of the most attractive and promising applications of solar energy systems. It is a renewable and environmentally friendly technology that is also economically viable is most developing countries.

Drying is one of an important post handling process of agricultural production. It can extend shelf life of harvested products, improves the quality and reduces post-harvest losses. Solar crop drying has been demonstrated, to be cost effective and could be an effective alternative to traditional and mechanical drying systems, especially in-locations with good sunshine during the harvest season [1]. However, considerable research has been done on drying but surprisingly limited research work on storage has been carried out. Annual loss of grain from harvesting to consumption is estimated to be 10 – 25%. The magnitude of these losses varies from country to country [2].

The purpose of this process is to remove moisture from a product to achieve the desired moisture content. The amount of heat supplied to the product by air heated with natural or artificial means causes the movement of moisture from inside the product to the surface

[2]. The air-drying temperature must be kept below the recommended values for the intended use of the product, as the excessive air-drying temperature can cause physical and chemical changes and deterioration of the product quality. To maintain of the product quality and avoid damaging its constituents, especially essential oils and vitamins that are sensitive to heat, it must be dried at a low temperature.

The problem of drying at low temperature is that it takes a lot of time. Many studies have led to a mastery of the solar drying process, and the design of dryers thus reducing drying times, improving the quality of dried products, and eliminating losses due to poor drying of products. These works were also carried out at the level of dryers per Ekechukwu *et al.* [3], Bala *et al.*[4], Jain *et al.*[5] and Koc *et al.*[6]; and at the level of the drying process per Talla *et al.*[7], Srivastava *et al.*[8], Togrul *et al.*[9], Doymaz *et al.*[10], Nguyen *et al.*[11], Kaya *et al.*[12] and Sharma *et al.*[13]. However, it is clear that the practice of drying has remained strongly traditional.

In this work, we are interested in improving the performance of an indirect forced convection solar dryer. To reduce the drying time and preserve the organoleptic quality of the products to be dried.

2. Materials and Methods

2.1. *Raw materiel*

Spinach is an herbaceous plant, vegetables grown for the consumption of their leaves, used first as a medicinal plant. It is very recognizable by its long green leaves, curly or flat depending on the variety [15]. The spinach used in this study of the *Spinacia oleracea* variety, were collected in the Batna's area in May 2015.

2.2. *Drying system*

The solar dryer (Figure 1) is used in this study. It designed and realized in the LESEI laboratory [14]. It consists of mainly a solar air heater, a centrifugal blower and drying chamber. Solar air heater with a surface area of 2 m^2, was used to preheat the air. It consists of a glass cover, a galvanized absorber (0.5 mm thick, painted matt black), glass wool insulation (50 mm thick) and a wooden outer cover box (15 mm thick). It was oriented due south and installed at an angle of 30° to the horizontal. Drying unit, a vertical chamber (0.5 m^3, inside) was provided for keeping the sample holding trays through which the hot air passed. Six drying trays were stacked evenly at a vertical spacing of 120 mm to each other in the drying chamber. A door (800 x 600 mm) was provided with locking arrangement on one side (front side) of the drying chamber for loading and unloading of trays. A centrifugal blower has operated with a single-phase electric motor at 2,800 rpm with a flow rate of 8,0 m^3/min, equipped with an air speed variator. An extractor blower placed at the top of the chamber to evacuate the air used to the outside.

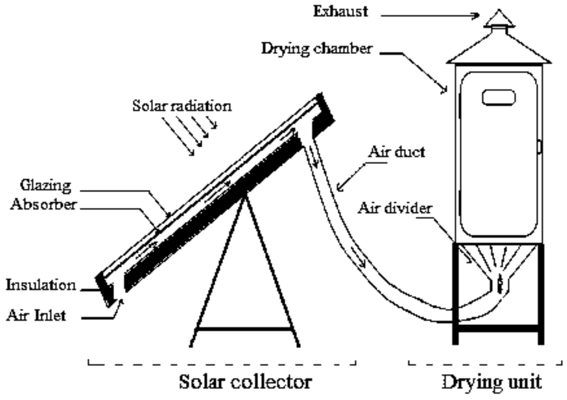

Figure 1. Prototype of Indirect solar drier with forced convection.

2.3. *Measurement instruments and equipment*

The measuring instruments used are a pyranometer to determine global sunlight received, thermostat with a thermocouple K type, to measure the temperature (accuracy ± 0.5 °C), thermo-hygrometers, placed inside the drying chamber to measure temperature and relative humidity (accuracy ± 1 °C for temperature, ± 3% for relative humidity), anemometer, to measure the airflow rate (accuracy ± 0.1 m/s) and a precision balance ± 0.1g, to determine the moisture loss of the products to be dried.

2.4. *Experimental methods*

The drying experiments, were carried out in a solar drier with forced convection for the periods (May – July 2015), under the climatic conditions of the Batna's city. Each experiment starts at 9 am to 5 pm. The spinach leaves to be dried of initial moisture content is approximately 93,23 %, drying occurs until a final moisture of 2 %; by taking the loss of moisture using a balance starting from an initial mass of 500 g/tray, each thirty minute. During this process, the air velocity setting in the drying chamber was fixed at 1 m/s. Air temperature (outside the dryer (ambient temperature), inside the dryer (the solar collector and the drying chamber)), solar radiation, relative humidity, solar radiation intensity and wind velocity were also measured each thirty minute. The solar dryer improvement was carried out by adding an exhaust air recycling system, connecting the drying chamber outlet with the solar collector inlet. Then, the influence of air recycling fractions evolution (0, 50 and 90%) on the drying kinetics and on the quality of the product to be dried. During the drying process, there is a double transfer: thermal and mass transfer. To illustrate these transfer movements, there are several characteristic curves called "drying curves"[16]. To know:

- The water content as a function of time: X = f (ts);
- The drying rate as a function of the water content: dX / dt = f (X).

3. Results and Discussion

3.1. Experimental conditions

Drying tests of spinach in the forced convection indirect solar dryer were carried out during the period of May - July 2015. **Figure 2** shows the variation of climatic conditions with time of day during the experimental drying. This period is characterized by sunny days. **Figure 2a** presents the change in global solar radiation for the day considered. It varied between 843 and 950 W/m², the intensity of solar radiation reached its maximum around noon hours. The variation in sunshine during drying implies a variation in the ambient air temperature of 23.0 and 31.9 °C. In addition, the relative humidity varied between 17.5 and 43.6% and the maximum wind velocity is 3.6 m/s are shown in **Figure 2b**.

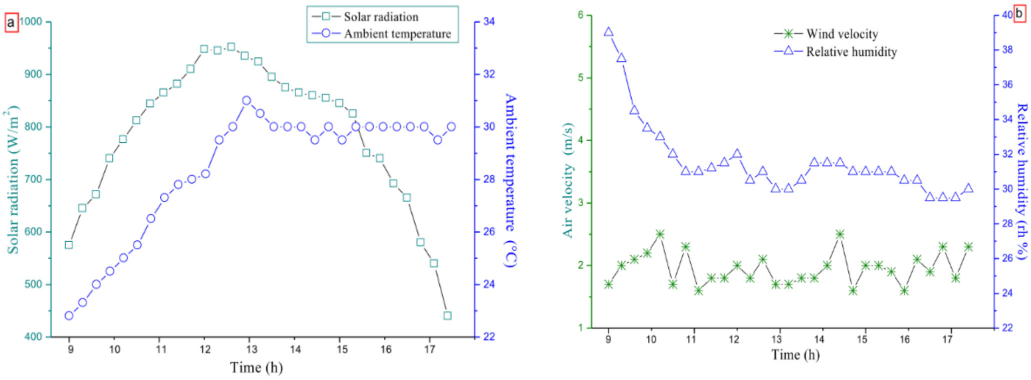

Figure 2. (a, b) Evolution of climatic conditions during the experiments drying.

3.2. Drying kinetics

The spinach leaves were dried to a final moisture content of 2% from 93.2% (wet basis) in 6 hours with an air-drying speed equal to 1 m/s. The drying curves of spinach are decreasing (Figure 3). They admit the same pace in the three experiments, but with a time gain of 3 to 4 hours of the drying time for the second and third experiments respectively, when increasing the fraction of recirculated air by 50 to 90%.
It is obviously observed from the Figure 3, that the moisture content is decreased faster at the initial stages of drying and thereafter became slower as drying proceeds.

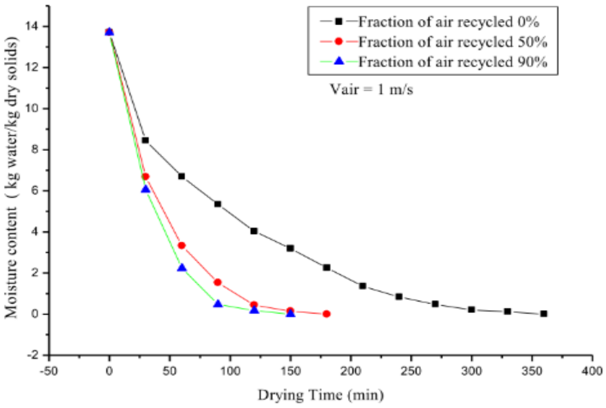

Figure 3. Variation of mean moisture content with drying time at different fractions of air recycled.

It is seen from the Figure 4 that the drying rate increased marginally with the increase in fraction of air recycled. These results agree with those of Bayoudh *et al.*[17], then of Sarsavadia [18].

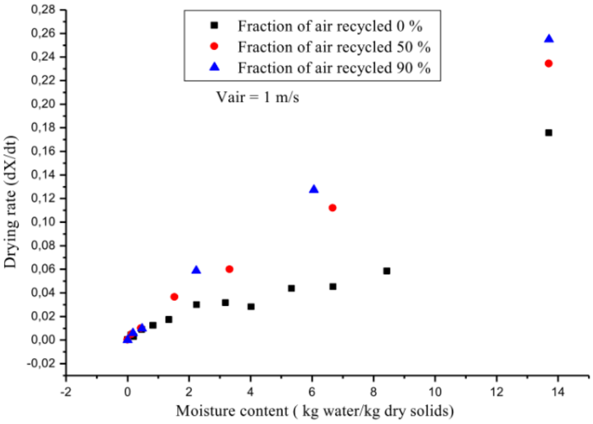

Figure 4. Drying rate at different fractions of air recycled.

There is a significant difference between the value of the ambient temperature and the temperature at the output of the solar collector (Figure 5), this temperature difference varies from 10 to 33.9 °C during the day of the experiment. Knowing that the ambient temperature is between 24 and 32 °C for the day considered. The difference is due to the influence of solar radiation on the absorber and to the greenhouse effect, which has results among the absorber and the glass cover, playing an important role in the heating of the air flowing through the air inside the solar collector.

The drying temperature is higher and stable in the drying chamber of the order of 55 to 65 °C, under the effect of recycle exhaust air (90% air recycled).

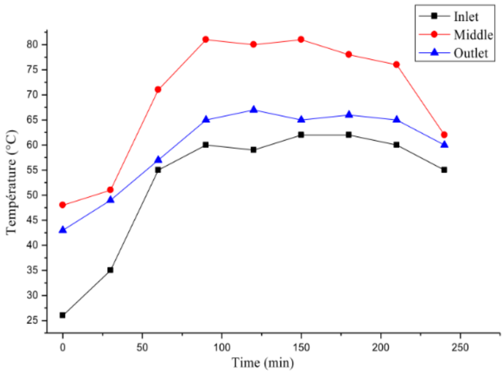

Figure 5. Evolution of the air temperature at the solar collector.

However, in the drying recirculation of exhaust air, it is more disturbed and variable of the order 26 to 43 °C (0% air recycled) are shown in Figure 6. This is the simultaneous action of reheating the exhaust air recycled, causing the temperature stability in the drying chamber, and then a significant decrease in drying time.

An essential factor in the drying process is the air relative humidity; the variation of the exhaust air relative humidity with drying time at different fractions of air recycled (up to 90%), is shown in **Figure 6**. It is seen from the figure that the relative humidity of the exhaust air is higher in the beginning of drying and decreased with drying time as drying proceeds and became constant in the final stage of drying. This is because the higher drying rate of the spinach leaves during initial stage of drying results in release of more moisture in the drying air. It is also observed from the figure that the relative humidity of the exhaust air increased, with the increase in fraction of air recycled. These results agree with those of Bayoudh *et al.*[17], then of Sarsavadia [18].

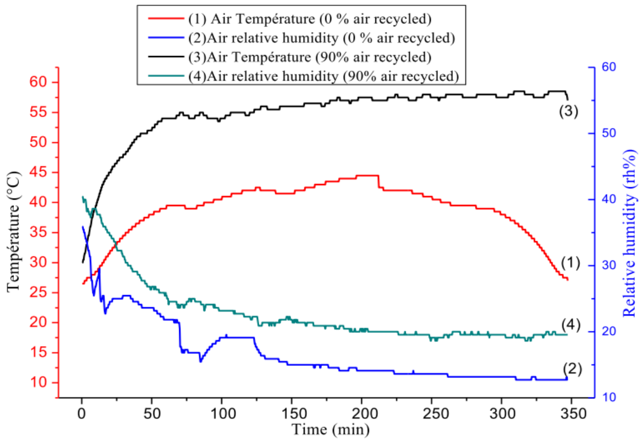

Figure 6. Evolution of temperature and relative humidity in the drying chamber.

4. Conclusions

The solar forced convection dryer operated well for spinach leaves dehydration for the controlled conditions of drying air temperature, relative humidity and drying air velocity. The dryer is also facilitated with exhaust air recycled. The spinach leaves were dried to a final moisture content of 2% from 93.23% (wet basis) in 6 hours with an air-drying speed equal to 1 m/s. The drying curves of spinach are decreasing. They admit the same pace in all experiments. The drying rate increased marginally (3 to 4 hours) with the increase in fraction of air recycled (50 to 90%). with a significant profit of thermal energy.

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