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Study on effectiveness of mixed mode solar greenhouse dryer for drying of red pepper

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***Abstract*— This paper presents an experimental analysis to investigate the performance of a novel mixed mode solar greenhouse dryer with forced convection which was used to dry red pepper. The drier consisted of a flat plate solar collector and a chapel-shaped greenhouse. The drying rate in the solar greenhouse dryer could be much higher than that for the open air sun drying. The present drying system practically shortens the drying time of red pepper and grape by 7 hours. The experimental drying curves show only the falling rate period. The payback period of the dryer was found to be 1.17 years, much less than the estimated life of the system (20 years).**

***Keywords*— greenhouse dryer, open sun drying, red pepper, economic evaluation.**

I. INTRODUCTION

Red pepper is an important ingredient in daily cuisine in Tunisia. Pepper is a good source of vitamins A and C, which are important antioxidants [1]. It is consumed both as fresh and dried products. Drying is a postharvest process which creates added value of red pepper [2]. The price of dried pepper always remains high even at the harvesting season.

Open sun drying, where the product is exposed directly to the sun allowing the solar radiation to be absorbed by the material, is one of the traditional techniques employed in Tunisia. The traditional (open sun) drying method requires little investment, but it has presented significant desaventages: it requires a large open space, long drying times, and the final products are of poor quality due to contamination by insects, birds and dusts.

Several solar-energy drying systems have been designed as alternatives to the traditional open-sun drying, especially in locations with good sunshine. These dryer systems can be classified in three forms as direct, indirect and mixed mode. Greenhouse dryer comes in the category of the direct solar drying and also sometimes mixed mode drying.

The applicability of greenhouses is limited because of high temperature during the warmer months of the year. When not in use for crop production the greenhouse can be used for drying the crop. A number of studies have been reported on greenhouse crop drying [3,4,5,6]. Anil Kumar et al. [7] have studied the effect of mass on convective mass transfer coefficient during open sun and greenhouse drying of onion flakes. Sethi et al. (2009) [8] studied the effects of inclined north wall reflection for improvement in greenhouse solar drying. The performance of a large-scale greenhouse type solar dryer for drying chilli was investigated by Kaewkiew [9].

The present study was undertaken to study and compare the thin layer drying characteristics of red pepper in the new solar greenhouse dryer and under open sun. The economics aspects of drying have been investigated in this study.

II. EXPERIMENTAL SETUP

A. Description of the solar greenhouse dryer system

The solar greenhouse forced convection drying system has been installed at the Research and Technology Centre of Energy (CRTEn) in Borj Cedria (North of Tunisia): Latitude 36°43' N and Longitude 10°25' E. It consists of two main parts namely: (1) a flat plate solar air collector, and (2) an experimental East–West oriented chapel-shaped greenhouse (Fig. 1).

The solar collector consists of insulator, absorber and cover glass. The length, the width and the total volume of the collector are 2 m, 1 m and 0.28 m^3, respectively. The 0.004 m thick transparent glass cover was placed 0.05 m apart the absorber. The 0.001 m thick corrugated absorber was placed 0.04 m apart the insulator. The 0.05 m thick polyurethane insulation, with heat conductivity 0.028 W/m K, is placed in the bottom of the collector to decrease thermal losses through the bottom. There are two air gaps between cover glass and the absorber and between absorber and insulator through which ambient air is sucked by a centrifugal fan from lower side of the collector to the greenhouse. The solar collector was oriented full south and inclined 37° to horizontal plane.

The experimental greenhouse occupy a floor area equal to 14.8 m^2, 3.7 m wide, 4 m long and 3 m high at the center. The greenhouse walls and roof are covered by plexiglass with

0.003 m of thickness. To exhaust the moist air from the greenhouse, it was equipped with two centrifugal fans.

Fig.1. Photograph of the solar greenhouse dryer.

B. Measurement equipment

The meteorological parameters as well as the mass and the product temperature are measured during the drying operation. Eight K-type thermocouples were fixed at different locations of the solar drier and in open sun to measure the temperature. The solar radiation incident on a horizontal surface was measured with a Kipp and Zonen pyranometer in a range of 0-1000W/m^2.Wind speed was measured by a 0–20 m/s range anemometer. The relative humidity of ambient air and drying air was periodically measured by a HMP155A sensor. All climatic and measured parameters are sample recorded every 10 min using a CR5000 data logger (Campbell Scientific Inc). The air speed at the ambient and inside of the dryer was manually recorded during the drying experiments. Product samples were weighed periodically using a digital balance (RADWAG, 200 g capacity).

III. RESULTS AND DISCUSSIONS

Drying experiments of red pepper in the open-sun and the greenhouse dryer were carried out in September in 2013. The hourly variation of solar radiation on horizontal surface during the experimentation is shown in Fig.2. The solar radiation on the horizontal surface outside the greenhouse dryer reached 808 W/m^2 (Fig.2). The Plexiglas cover transmitted about 85% of the incident solar radiation. The solar radiation energy is maximum at midday and minimum at evening.

Air relative humidity under the greenhouse, ambient air and drying air temperatures inside the greenhouse dryer are shown in Fig.3. The temperature of ambient air ranged from 21.25 to 35.71 °C. The drying air temperature recorded inside the greenhouse ranged from 29.21 to 49.88 °C. The relative humidity of the air under greenhouse ranged from 17.62 to 62.62 %.

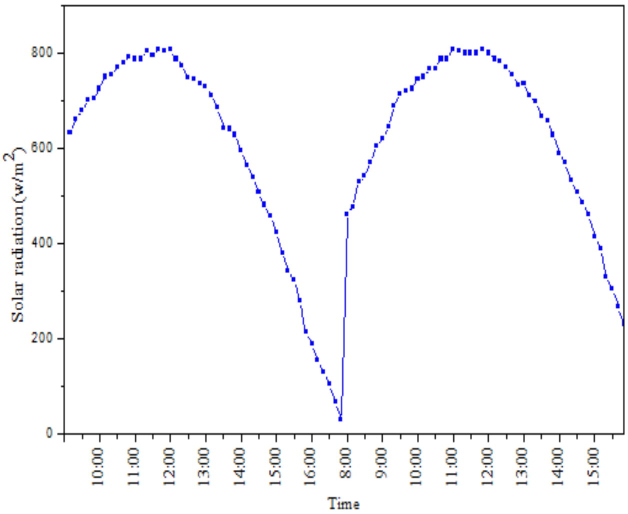

Fig.2. Variation of solar radiation with time of the day during drying of pepper.

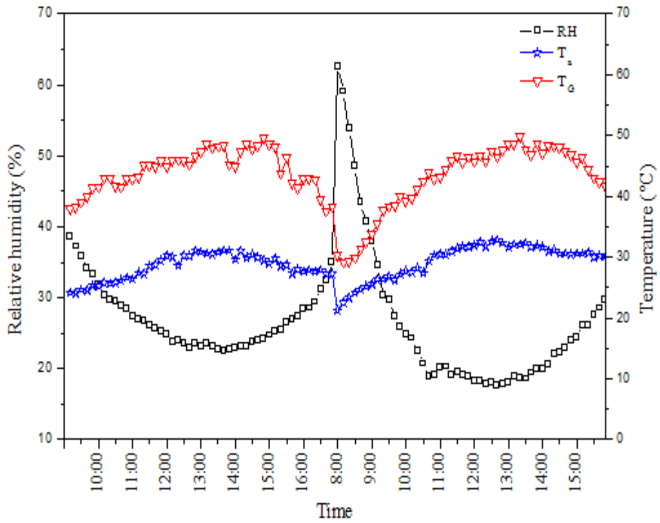

Fig.3. Relative humidity, ambient temperature and temperature inside greenhouse solar dryer during drying of pepper.

Comparison of the moisture contents (dry basis) of red pepper dried in the solar greenhouse dryer with open sun drying for a typical experimental run is shown in Fig.5. The interruptions of the lines in this figure represent the night periods of the drying operation. The red pepper with initial moisture content of 12.15 (g water/g dry matter) was dried to 0.17 (g water/g dry matter) in the greenhouse solar drying within 17 hours. The red pepper was dried to 0.19 (g water/g dry matter) in the open-sun drying within 24 hours. The pepper dries faster in the dryer. The present system practically shortens the drying time of red peppers by one day.

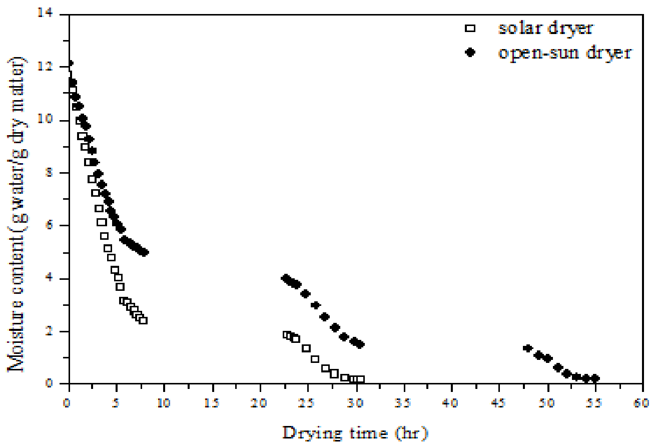

Fig.4. Drying kinetics of pepper slices.

VI. ECONOMIC EVALUATION

The greenhouse can be exploited in the warmer months of the year for drying agricultural products. From the economic evaluation the cost of greenhouse functioning as the dry cabinet is not included in the total cost of solar greenhouse dryer. It is assumed that each year the dryer is used to dry red pepper in June –September. The costs and the main economic parameters based on the economic situation in Tunisia are shown in Table1. Approximately 444 kg of dry red pepper is annually produced.

The annualized cost of a dryer (Ca) has been calculated as given by Eq. [10]:

$$C_a = C_{ac} + C_m - V_a + C_{re} \quad (1)$$

The annualized capital cost (C_{ac}) and annualized salvage value (V_a) are given by Eqs. (2) and (3), respectively.

$$C_{ac} = C_{cc} F_c \quad (2)$$

$$V_a = V F_s \quad (3)$$

Where the capital recovery factor (F_c), and the salvage fund factor (F_s) are defined by Eqs. (4) and (5), respectively.

$$F_c = \frac{d(1+d)^n}{(1+d)^n - 1} \quad (4)$$

$$F_s = \frac{d}{(1+d)^n - 1} \quad (5)$$

The cost of drying per kilogram of dried product is then calculated by:

$$C_s = \frac{C_a}{M_y} \quad (6)$$

Where the amount of dried product removed from the domestic solar dryer per year (M_y) is defined by Eq. (7)

$$M_y = \frac{M_d D}{D_b} \quad (7)$$

C_{re} is the annual electricity for fans.

$$C_{re} = R \times W \times C_e \quad (8)$$

R is the number of hours the fans are run each year, W is the rated power consumption of fans, and C_e is the unit charge for electricity.

The cost of fresh product per kilogram of dried product is calculated using Eq. (9).

$$C_{dp} = C_{fp} \frac{M_f}{M_d} \quad (9)$$

The cost of 1 kg of dried product (C_{ds}) for the domestic solar dryer is the summation of the cost of fresh product (C_{dp}) and the cost of drying (C_s) per kilogram of dried product.

$$C_{ds} = C_{dp} + C_s \quad (10)$$

The saving per kilogram of dried product (S_{kg}) in the base year due to use of the solar dryer is calculated using Eq. (11). The saving per batch (S_b) and the saving per day (S_d) in the base year are then calculated using Eqs. (12) and (13) respectively.

$$S_{kg} = C_b - C_{ds} \quad (11)$$

$$S_b = S_{kg} M_d \quad (12)$$

$$S_d = \frac{S_b}{D_b} \quad (13)$$

For the life of the system, the annual savings (S_j) for drying the typical product in the jth year are obtained using Eq. (14).

$$S_j = S_d D(1+i)^{j-1} \quad (14)$$

The payback period (N) is calculated from [10]:

$$N = \frac{\ln\left[1 - \frac{C_{cc}}{S_1}(d-i)\right]}{\ln\left(\frac{1+i}{1+d}\right)} \quad (15)$$

In our case the payback period is very small (1.17 years) compared to the life of the dryer (20 years).

TABLE 1. ECONOMIC EVALUATION OF SOLAR DRYER

Cost of dryer	2000 DT
Capacity of dryer	80 kg
Price of fresh pepper	0.5 DT/kg
Price of dried pepper	10 DT/kg
Life of dryer	20 years
Interest rate	8%
Inflation rate	5%

Note. 1US Dollar =1.17 DT

The open-sun drying is the cheapest method of conserving food stuffs, the dry products are of poor quality due to contamination by insects, birds, dusts, rain and also because of slow drying rate. Solar drying can be considered as an advancement of natural sun drying and it is a more efficient technique of utilizing solar energy. A reduction of losses, an improvement of quality of product and an investment cost are also important criteria dictating the adoption of the solar dryer.

V. CONCLUSION

The drying kinetics of pepper using solar greenhouse dryer is better than open sun drying. As the moisture content of the product decreased, the air temperature was more important to move the water from the interior to the surface for evaporation. The drying time to achieve moisture content below 16% (wet basis) for the product using solar dryer was reduced from 24 h to 17 h compared to open sun drying. An economic evaluation was calculated using the criterion of payback period which is found very small 1.17 years compared to the life of the dryer 20 years.

NOMENCLATURE

T_a ambient Temperature (°C)
T_G temperature inside greenhouse (°C)
RH relative humidity of the air (%)
C_a annualized cost of dryer (DT)
C_{ac} annual capital cost (DT)
C_b selling price of branded dried product (DT/kg)
C_{cc} capital cost of dryer (DT)
C_{dp} cost of fresh product per kg of dried product (DT/kg)
C_{ds} cost per kg of dried product for domestic solar dryer (DT/kg)
C_{fp} cost per kg of fresh product (DT/kg)
C_m annualized maintenance cost (DT)
C_{re} annual electricity cost for fans (DT)
C_s cost of drying per kg of dried product in dryer (DT/kg)
F_c capital recovery factor
F_s salvage fund factor
i rate of inflation
d rate of interest on long term investment
n life of solar dryer (year)
N Payback period (year)
S_b saving per batch for solar dryer (DT/kg)
S_d saving per day for domestic solar dryer in the jth year (DT)
Sj annual savings for domestic solar dryer in the jth year (DT)
S_1 saving during first year for solar dryer (DT)
S_{kg} savings per kg in comparison to branded product for solar dryer (DT/kg)
V salvage value (DT)
V_a annualized salvage value (DT)

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