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Experimental performance of a solar greenhouse dryer for drying grape

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Abstract— **This work presents an experimental study of the drying kinetics of grape in a mixed mode solar greenhouse dryer. A solar dryer consisted of a solar air collector and greenhouse. The drier had a loading capacity of 80 kg of fresh grapes. The variation of the moisture content of the products studied and principal drying parameters are analysed. The grape with initial moisture content of 5.49 (g water/g dry matter) was dried to 0.22 (g water/g dry matter) in the greenhouse solar dryer within 50 h. The grape in the open-sun were dried to 0.23 (g water/g dry matter) within 67 h. The grape dries faster in the greenhouse solar dryer. In addition, the solar greenhouse dryer was protected from insects, rain and dusts. As a result the grape in the solar greenhouse dryer could be much higher than that for open air sun drying. The payback period of the dryer was found to be 0.86 years, much less than the estimated life of the system (20 years).**

Keywords— Sultana grapes, drying, open sun, solar greenhouse dryer

I. INTRODUCTION

Grapes are one of the most popular and palatable fruits in the world. It is an excellent source of vitamins C and potassium. Sultana, one of the variety grape in Tunisia.

Tunisia has between 2860 and 3200 hours of sunshine per year and receives a daily average solar energy of 4.8 $kWh \cdot m^{-2} \cdot day$ [1]. This energy is sufficient to meet all the energy demand for the drying of agricultural products. Most of these products are dried in a traditional way using sun drying. Open air, natural sun drying presents some problems making this operation not always suited to large scale production it does have some problems due to rain damage, insect and dust contamination.

If these products were dehydrated under shelter, it would provide appropriate hygienic conditions. Several solar dryers have been designed as alternative to traditional open sun drying. According to the past research Solar dryers were classified into three forms as direct solar dryers, indirect solar dryer and mixed mode [2, 3]. Solar drying systems were also categorized into two general groups: natural and forced convection solar dryers [4, 5].

Various of investigators have studied the experience of drying grapes in solar dryer such as Farhat et al. (2005) [6] to dry grapes in three different processes in, open sun drying, natural convection solar dryer and solar greenhouse drying and it was concluded that solar greenhouse drying is satisfactory and competitive to a natural convection solar drying process, N.S Rothore et al. (2010) [7] have studied grape in type solar tunnel dryer, Yaldiz et al. (2001) [8] investigated a thin layer solar drying of sultana grapes. They reported that the solar grape drying process occurred in the falling rate period. El-Sebaii et al.(2002) [9] found that the equilibrium moisture content for seedless grapes is reached after 60 and 72 h when the system is used with and without storage material, respectively. They found that the heat storage medium and chemical pretreatment have caused significant decreases of the drying time of the seedless grapes. Matteo et al. (2000) [10] reported that grape drying to produce raisins is a very slow process due to the peculiar structure of the grape peel, which is covered by a waxy layer.

The aim of the work is to study the drying of grape in a new mixed mode greenhouse dryer. A solar dryer consisting of a solar air collector and a chapel-shaped greenhouse, and under the open sun.

II. MATERIALS AND METHODS

A. *Sample preparation*

The grape bunches (sultana) were dipped in alkali solution (1% of NAOH) heated at 90°C for 3 second, the immersion is made two to three times successive, which reduces the drying time of grapes by improving the water permeability of the skin [11].

B.   Experimental set up

The Solar dryer is a new type of solar greenhouse dryer, recently built at the Research and technology center of Energy (CRTEn), has essentially two components the solar collector and solar greenhouse (figure 1):
The solar collector consists of absorber, insular and cover glass. The greenhouse used in the drying experiments was as follows: 4 meters long, 3.5 meters wide, 3 meters average height and 14.8 m^2 floor area. Its cover was plexiglass with 0,003 meters of thickness. To exhaust the moist air from the greenhouse, it was equipped with two centrifugal fans.

Finally, traditional sun drying experiments were carried out in the open air to be used later as reference.

Fig.1: Pictorial view of the solar greenhouse dryer

C. Instrumentation

Experiments were conducted in the months of September and October for forced convection in the solar greenhouse dryer and open sun.
The temperature, the incident solar radiation, the relative humidity and air velocity distributions were measured in the solar dryer and in open sun, during the experiments. Temperatures were continuously measured with K-type thermocouples. The air velocity was measured with an anemometer. The solar radiation incident on a horizontal surface was measured by a pyranometer in a range of 0-1000 w/m2. The relative humidity was measured by HM155A sensor. A top loading digital balance (RADWAG) of 200G weighing capacity, having at least count of 0, 0001 g was used to weigh the sample during drying. A data logger automatically recorded all experimental measurements. Drying experiment lasted for several days and data were captured every ten minutes using a CR5000 data logger (Campell scientific Inc).
At the end of each experiment of drying, sample is placed in an over drying at 120°C for 12h.

III. RESULTS AND DISCUSSION

During the 6 days of experiments, the solar radiation is shown in Fig. 2 for a typical day of September and October 2013. The Plexiglas cover transmitted about 85% of the incident solar radiation. The solar radiation on the horizontal surface outside is 795.2 W/m^2 and inside the greenhouse reached 675 W/m^2. The solar radiation energy is maximum at midday.

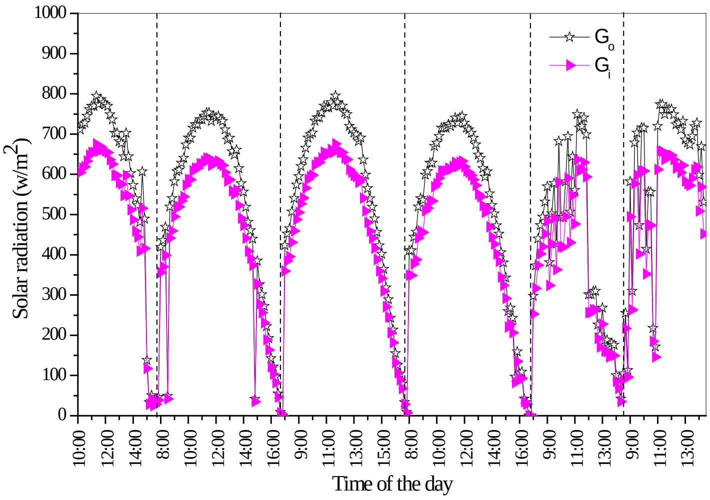

Fig.2. Variations of solar radiation with time of the day during drying of grape

Fig. 3 shows the variation curves of ambient air, outlet collector temperature and drying air temperature inside the greenhouse dryer. The temperature of ambient air ranged from 22.54°C to 35.75°C.
The drying air temperature record at the outlet of the solar collector and inside the greenhouse ranged from 28.08°C to 55.97°C and from 29.52°C to 55.94°C respectively.

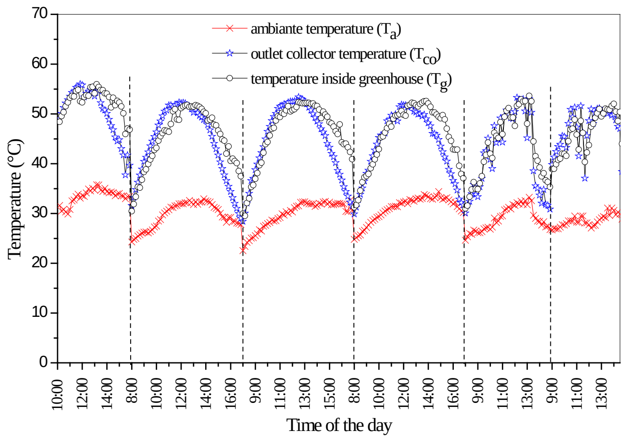

Fig.3. Variations of ambient temperature, outlet collector temperature and temperature inside the greenhouse solar dryer during drying of grape

The drying curves of grapes in the solar greenhouse dryer and an open sun drying process are presented in fig. 4. The initial moisture 54.9 (g water/g dry matter) was dried to 0.22 (g water/g dry matter) in eight days for the open sun drying, whereas the solar greenhouse dryer took only six days. The grape dries faster in the greenhouse solar dryer. The present system practically shortens the drying time of grape by two day.

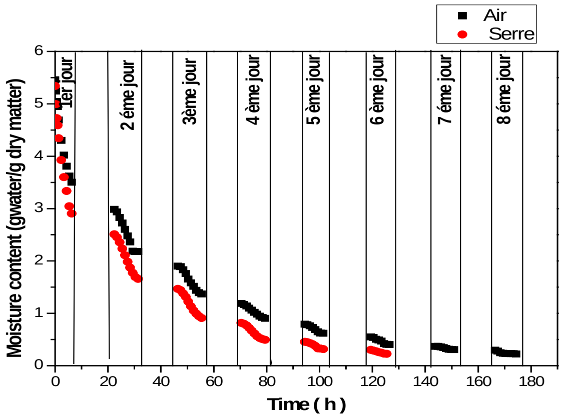

Fig.4. Variation of moisture content with drying time for grapes in solar tunnel and open sun drying process

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 grape in June –September. The costs and the main economic parameters based on the economic situation in Tunisia are shown in Table1. Approximately 500 kg of dry grape 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 (0,86 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	130 kg
Price of fresh grape	1 DT/kg
Price of dried grape	10 DT/kg
Life of dryer	20 years
Interest rate	8%
Inflation rate	5%

Note. 1US Dollar =1.17 DT

V. CONCLUSION

This study presents an experimental study of a new solar greenhouse dryer. The moisture content of Sultana grape was reduced to 18% (wet basis) in 76 h for open sun drying, whereas the greenhouse dryer took only 50 h. The new solar dryer shows better performance than drying in the open air. An economic evaluation was calculated using the criterion of payback period which is found very small 0,86 years compared to the life of the dryer 20 years.

NOMENCLATURE

T_a	ambient Temperature (°C)
T_G	temperature inside greenhouse (°C)
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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