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Solar Energy Storage in an Indirect Solar Dryer (ISD) with Stone for Drying in Continuous

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A B S T R A C T

Solar storage energy using black volcanic stone (pouzzolan) as the absorber in the solar collector of the Indirect Solar Dryer with oriented flux to dry in continuous is investigated. The collector using crushed pouzzolan as absorber is exposed in the sunshine. Daily and evening experiments were conducted with different loads and oriented air flux in the drying chamber. It is observed that on the day, the irradiance do not affect outlet temperature of collector and in the evening up to 14 hours after the absence of the sun, the temperature difference between the ambient and the collector output is above 7°C. This temperature may be sufficient to reduce or to stabilizise the water intake of the product in the absence of the sun. The model of the discharge equation show that the time constant is a function of the intrinsic characteristics of the thermo physic properties of material and different heat transfers put in place.

1. Introduction

Solar drying is one of the oldest methods of preserving food [1]. In rural areas, the traditional method of spreading the product in the sun does not always guarantee the quality of the dried product [2]. Indeed, work is being carried out to optimize the drying operation, in particular the rationalization of energy and the safeguarding of the quality of the dried product. Thus, the setting up of direct, indirect, mixed and hybrid solar dryers has revolutionized this sector [3–6]. . However, it is not always easy to exploit these techniques wherever they are needed because they require energy in proportions that depend on the moisture content, the drying system used, the temperature of drying and specific characteristics of the agricultural product concerned [7]. The indirect solar dryer seems, therefore, to be an adequate solution to this problem. It avoids the destructive action of heat on the product; but some parameters (temperature and relative humidity) of the drying chamber are still uncontrolled. Energy storage is the accumulating of as much energy as it is available for later retrieval in the most efficient manner [8]. Indeed the restitution time may be sufficient to reduce the return of water in the product in the absence of the sun. [9] used C_aCl_2-$6H_2O$ as PCM at melting temperature 23°C to establish the difference of 6-9°C between room temperature and that at the outlet of the sensor whereas [10] used Wax to establish the difference of 5°C for 24 hours. Studies by [11] on the equipment using the thermochemical properties of the PCM show that these materials are expensive and that the choice of the type of PCM is important.

2. Materials and Method

Indirect Solar Dryer with Oriented Airflow (ISDOA)

The ISDOA [6] is an equipment set up to optimize the drying of products by adjusting the air flow orientation in the drying chamber. It is constituted of three main parts namely: the chimney, the drying chamber and the absorber. The part we are interested in is the thermal sensor because it will be manufactured a storage box where the volcanic stone (pozzolana) will be spraindeded as a homogeneous bed.

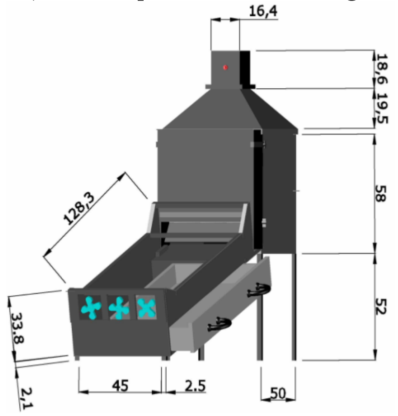

Figure 1. Indirect Solar Dryer with Oriented Airflow (ISDOA)

The thermal sensor (Figure 2) is constituted of a glass (transparent body), fans and an energy accumulator (volcanic stones) that works as absorber. When the coolant (air) passes through a gap between the absorber and the glass, its temperature increases because of the heat exchange created by the absorber that has received the energy of the sun under the greenhouse effect. It has an energy storage cabinet. Volcanic stones (black color) are rocks that are contained in a drawer (storage box).

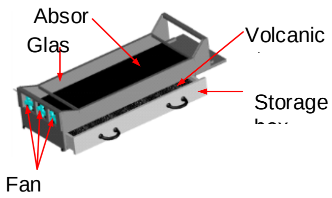

Figure2. Solar absorber plan

2.2. Estimated destocking duration of the stored energy

The thermal equations at the absorber considering the heat exchanges of Figure 3 are written:

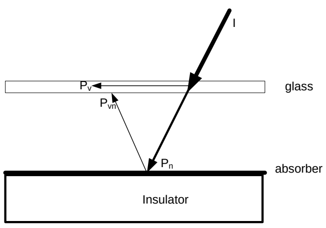

Figure 3. Partition of energy received by the absorber

$$P_v = \alpha_v I \quad (1)$$

$$P_n = \alpha_n \tau_v I \quad (2)$$

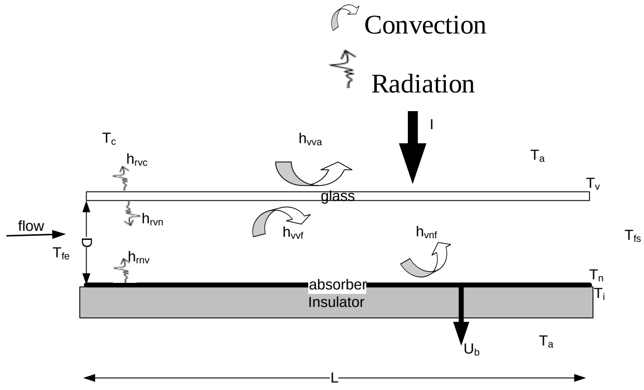

Figure 4. Heat transfers in the storage absorber in single-sided type

$$\frac{M_n c_n}{S_n}\frac{dT_n}{dt} = \frac{P_n}{S_n} + h_{rnv}(T_v - T_n) + h_{vnf}(T_f - T_n) + U_t(T_a - T_n) \quad (3)$$

$$\frac{M_n c_n}{S_n}\frac{dT_n}{dt} = h_{rnv}(T_v - T_n) + h_{vnf}(T_f - T_n) + U_t(T_a - T_n) \quad (4)$$

Storage Modeling

For a sunny day, the temperature and irradiance are recorded every 5 minutes and then stored in an acquisition unit (ALMEMO 2398). Three PT100 type sensors are placed on the absorber, at the sensor output and outside the thermal sensor, respectively. The absorber consists of black volcanic stone (pozzolana). It allows the storage of heat at the flat solar collector. This stone is crushed and spread in a non-compact bed in the storage box. The crushing granulometry of the stone is not uniform. The temperature and irradiance curves are plotted against time.

Drying shea nuts with energy storage

The almonds cut into strips of shea nuts were spread on the racks of the drying chamber in order to be dehydrated. A temperature sensor connected to the ALMEMO is installed on each rack to monitor the temperature evolution as a function of time.

3. Results & Discussion

3.1. Equation of empty energy storage

The integration of the equation with the term Pn informs about the load (equation 3) and that without this term approaches the discharge (equation 4).
The resolution of equation 3 gives

$$A = (h_{vvf} + h_{rnv} + U_t)S_n \qquad (5)$$

$$B = (h_{vvf}T_f + h_{rnv}T_v + U_tT_a)S_n + P_n \quad \text{and} \quad B' = B - P_n \qquad (6)$$

$$T_n(t) = \frac{B}{A}\left(1 - e^{\frac{-At}{M_nC_n}}\right) + T_a e^{\frac{-At}{M_nC_n}} \qquad (7)$$

The term $T_a\, e^{\frac{-At}{M_nC_n}}$ explains the behavior of the absorber when it exchanges little with the outside. If the exponential term tends to one then.

$$T_n(t) - T_a = \frac{B}{A}\left(1 - e^{\frac{-At}{M_nC_n}}\right) \qquad (8)$$

At the initial moment, the absorber heats and must discharge through the exchanges with its environment (glass, outside air and insulation). If B is low (no energy source), then the maximum temperature of T_n is $\frac{B}{A}$.

The resolution of equation 4 gives:

$$T_n(t) = \frac{B'}{A}\left(1 - e^{\frac{-At}{M_nC_n}}\right) + \frac{B}{A} e^{\frac{-At}{M_nC_n}} \qquad (9)$$

$$B' = B - P_n$$

$$T_n(t) = \frac{B'}{A} + \frac{P_n}{A} e^{\frac{-At}{M_nC_n}} \qquad (10)$$

This is the discharge equation.
The time constant, $\frac{M_nC_n}{A}$ is a function of the different exchanges and intrinsic characteristics of the material M_nC_n. The charge constant increases if the M_n and C_n parameters are large too. The M_nC_n product is 4486.2 W/°C for steel, 2987.4 W/°C for aluminum and 36950 W/°C for volcanic stone. They define time constant τ as a quantity called characteristic thermal storage time of volcanic stone. This corresponds to the time required for the absorber to accumulate 63% of its maximum thermal load at saturation.
This time constant τ is thus the discharge characteristic thermal time of absorber which is corresponding to the time required for the absorbing material to liberate 37% of its smallest thermal load.

3.2. Heat storage with unload dryer

Storage is done using black volcanic rock. The rise in temperature is slow; because, at the beginning, the absorber stores and saturates itself before starting to release but the duration of the saturation depends on the sunshine received. After this phase, the temperature of the absorber reaches its maximum (80.70 ° C) and no longer follows the irradiance. This is what the plateau represents on the two temperature curves (absorber and absorber output). The saturation of the material takes place after one hour of time for an irradiance higher than 800 W / m² then the temperature profile remained constant until fifteen (15) hours. It is found that the fall of the solar radiation does not influence the temperature until fifteen (15) hours. Here, this inertia lasted around three (3) hours in the day before the fall began (Figure 5). The similar results obtained by applying phase change materials (PCMs) to the absorber [12]. Temperature measurements during the discharge showed that, charged up to 82.2 ° C, the absorber has 3 hours to reach 73.3°C in the absence of sunshine. The temperature at the exit of the sensor in the absence of the sun from 16h is 55°C while the ambient temperature is 38 ° C

3.3. Curve of approximation of the storage at the exit of the sensor

The temperature curve output from the absorber of figure 5 can be divided into two parts, namely: a first which takes into account the sunlight (figure. 6); and the other which takes into account the absence of the sun (figure 7). By empirically adjusting the two parts of the sensor output temperature curve, the following rise and fall equations are respectively found with regression coefficient R = 0,996.

$$T_c = 32{,}35 + 29{,}3(1 - e^{-1{,}98t}) \qquad (11)$$

$$T_d = 32{,}61 + 231{,}79e^{-0{,}35t} \qquad (12)$$

The two equations (11) and (12) are similar to (8) and (10) respectively

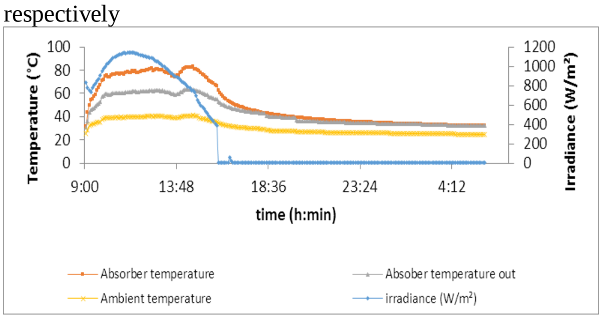

Figure 5. Temperature and irradiance profiles with energy storage

For a volcanic stone absorber, the time constant of 0.52 hours by equating equations (10) and (8) or (11) and (10).
Up to 14 hours after the absence of the sun, the temperature difference between the ambient and the sensor output is above 7°C (see Figure 5). This time may be sufficient to reduce the water intake of the product in the absence of the sun

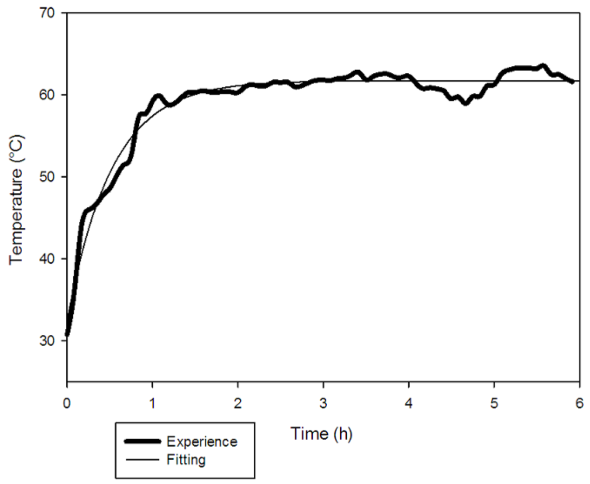

Figure 6. Temperature profile during the energy storage through the volcanic stone

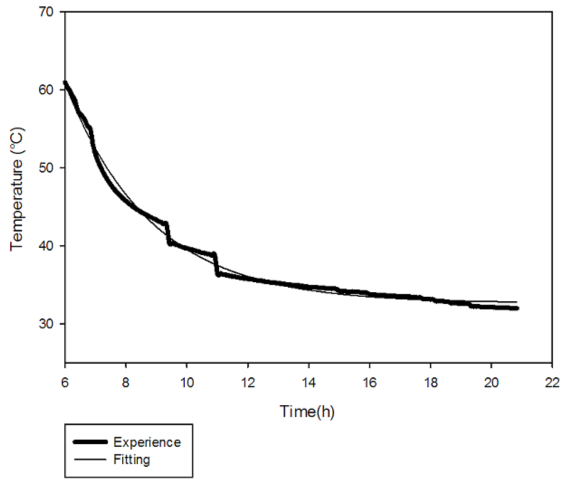

Figure 7. Temperature profile during discharge of the volcanic stone

3.4. Effect of storage on the drying of shea nuts in licking mode

During storage under load, the temperature varies little with irradiance. In Figure 8, a plateau is observed at the temperature profile while sunshine decreases. The material releases its accumulated energy to the chamber and the profile of the temperature at this time depends on the discharge dynamics of the volcanic stone. During the inertia of the system the temperature remained at 47°C for about 3.5 h on the trays for an average irradiance of 800 W / m². The temperature has always remained at 47°C on average from 13h 30 where the sun has dropped. This temperature is maintained until 16h. There is a difference of 3°C for about an hour in total absence of sunshine. The ambient temperature remained at 30.3°C.

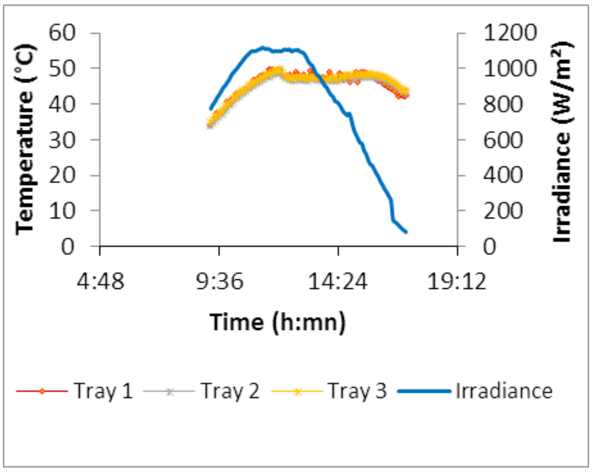

Figure 8. Temperature and irradiance profiles for drying nuts with storage in licking mode

3.5. Effect of drying shea nuts in cross mode.

In Figure 9, we also see that the fall of the irradiance does not directly affect the temperature on the racks because the volcanic stone quickly saturated. The temperature profile is that obtained by [13] when they used phase change materials (PCMs) to store energy. Despite fluctuations in irradiance, the temperature on tray 1 evolved from 35°C to 37°C through 46°C (maximum). In the absence of sunshine that can heat the absorber (value less than 800 W / m²), the temperature on the tray 1 is 44.55°C to 14h and 38°C to 17 h is a variation of 5°C after 3 hours of time. The average ambient temperature remained at 31°C.

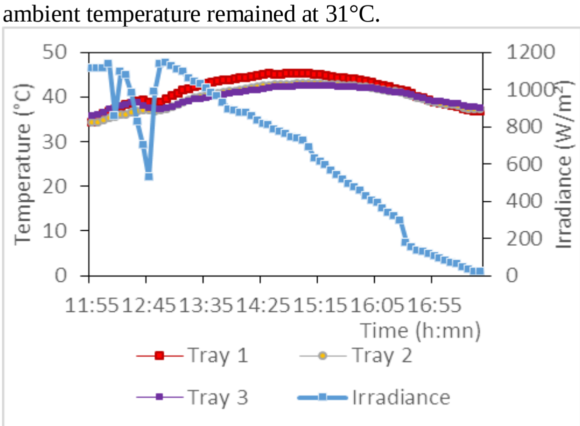

Figure 9. Temperature and irradiance profiles for drying nuts with cross storage

4. Conclusions

The heat storage keeps the temperature constant in the drying chamber and prevents the rehydration of sun-dried food in the absence of the energy source.

Up to 14 hours after the absence of the sun, the temperature difference between the ambient and the sensor output is above 7°C. This time may be sufficient to reduce the water intake of the product in the absence of the sun.

Acknowledgements

Nomenclature

M_n Masse de l'absorbeur (kg)

c_n Capacité calorifique massique de l'absorbeur (J/kg °C).

h_{rnv} Coefficient d'échange thermique par rayonnement absorbeur et vitre (W /m^2 °C)

h_{vnf} Coefficient d'échange thermique par convection absorbeur et air (W / m^2 °C)

U_t Coefficient de perte globale (W /m^2 °C)

T_v Température de la vitre (°C)

T_a Ambient temperature (°C)

T_f Température du fluide caloporteur (°C)

T_n Température de l'absorbeur (°C)

P_n Puissance reçue par l'absorbeur (W)

S_n Surface de l'absorbeur (m²)

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