Development of a Solar Furnace with High Insulating Properties Using Date Palm Waste

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***Abstract*—This paper reports the results of a study on thermo-physical properties of two varieties of local date palm wood, called petiole, namely Boufeggous and Hafsa from Tinghir oasis, southern Morocco. The goal is to use this natural material as insulation for a solar furnace to reduce heat loss. Experimental measurements of thermo-physical properties, according to the orientation of the fibers at ambient temperature and atmospheric pressure, have been conducted and analyzed. Furthermore, a scanning microscopy (SEM) analysis of the samples was investigated to characterize their microstructure. Preliminary results deducted from this study were compared with other insulation materials in literature in order to evaluate the interest of these kind of materials for solar cooking application.**

Keywords-Solar furnace; date palm; insulation and efficiency

I. INTRODUCTION

In many thermodynamic processes, the heat flow (gain or loss) can be optimized using special materials to insulate the system and, ultimately, save energy. In solar cooker applications, numerous materials with low thermal conductivity may be used for insulation. However, to ensure optimal insulation, we have to take into account the thermo-physical properties, environmental and economic impact, as well as availability and durability of the used material [1]. At present, there are a number of different insulating materials used for solar furnace manufactured from fiberglass, mineral wool (rock wool), cellulose or polystyrene (expanded) [2]. Although these materials have good physical properties, they are very expensive to acquire and they can be unsafe to human health and to the environment. For instance, the fiberglass could irritate the eyes, skin and the respiratory system. These disadvantages have necessitated research on natural, ecological and economic insulation materials such as flax, cotton, hemp, jute, sisal, kenaf, pineapple, ramie, bamboo, banana, palm etc. The performance of these materials is under study and their development is at an early stage [2][3]. Several authors have analyzed and characterized experimentally some of these natural materials, as described in the rest of this section.

Nguyen et al. [4] studied the thermal performance of hemp shives. They developed a multi-scale homogenization approach that takes into account the shape and orientation of pores and particles in order to predict the thermal performance of hemp as an insulation material. As results, they found that the thermal conductivity of hump increased linearly with increasing saturation degree, density and temperature. Tangjuank [1] presents the thermal properties of insulation material produced from pineapple leaves. As blinder, he used natural rubber latex. According to the results, the thermal conductivity obtained was close to the commercial insulator, with a value of 0.035W/m.K and with density of 210 Kg/m^3. This value ensures that pineapple fibrous material can replace the synthesis insulator.

Agoujdil et al. [5] have carried out an experimental investigation on the thermo-physical, chemical and dielectric properties of three varieties of date palm wood. According to the results, they noticed that date palm wood could be a good candidate as insulating material, in order to use it to reduce building heat loss. Oushabi et al. [2] analyzed a local date palm waste from Errachidia oasis in Morocco, in order to use it as a thermal insulation material in the vessel of refrigerator, cooler and food flask. Their results showed that this material had good thermal properties compared with other synthetic materials.

Djoudi et al. [6] have performed an experimental study and modeling of the effect of date palm fibers addition on thermal properties of plaster concrete. They reported that the thermal conductivity and density of this composite decrease as the fraction of fibers increases. The same results are found by Braiek et al. [7], who have analyzed the thermo physical properties of date palm/gypsum composite, in order to use it as insulating material in building.

The main goal of this paper is to evaluate the possibility of using the date palm wood waste (Phoenix Dactylifera), including petiole as an insulating material to reduce the heat loss in the solar box cooker. No study up to date has been conducted in terms of using the petiole of date palm as insulating material in solar furnace application. This paper is organized as following. Section 2 provides a description of different experimental measurements and samples preparation. The results are interpreted, discussed and compared with some conventional material described in literature in Section 3. We conclude the paper in Section 4.

 ISBN: 978-1-61208-588-3

II. MATERIAL AND METHODOLOGY

A. Experimental set up

1) Solar cooker description

In the experimental tests, a solar box cooker was used (Figure 1). It consists of the following main components: cover double glazed glass, three reflectors placed on the outer cover of the cooker, thermal insulator placed in the lateral part of the solar cooker and rocks bed for heat storage. The measured parameters are the ambient temperature, temperature of rocks and temperature inside the solar cooker. Type-k thermocouples were used for this purpose.

Figure 1. Solar furnace with three external reflectors.

The main problem this prototype faces is heat loss through the furnace walls as evidenced by thermographic analyses.

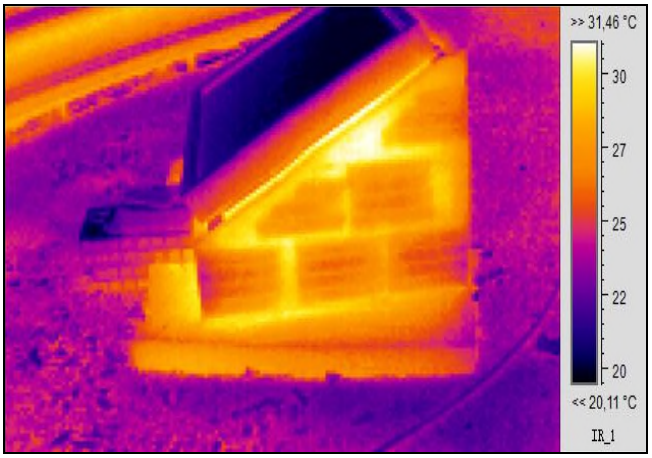


Figure 2. Infrared picture showing heat loss through the furnace walls.

Initially, we have tested glass wool as insulation material and we found out that the heat losses remain high, as we can conclude from Figure 2. Thus, we decided to go for date palm wood as insulation due to its availability, low economic and environmental impact.

B. Samples preparation

The natural materials used in this research are from two varieties of local date palm wood called petiole, namely Hafsa and Boufeggous, from Tinghir oasis, southern Morocco.

Two configurations of petiole (P), according to the orientation of fibers, were studied. Figure 3 shows these configurations.

Figure 3. Samples cut out from the petiole (a) petiole sample I longitudinal direction of fibers, (b) in transversal direction of fibers.

C. Thermal conductivity and diffusivity

All thermo-physical measurements of date palm samples at room temperature were determined using a Thermal Analyzer TPS 1500 (Figure 4). Transient plane source (TPS), or Hot-Disc method, is highly appreciated technique for measuring thermal properties of materials from a single measurement, with minimum sample preparation [8]. The results are displayed directly on the device screen.

Figure 4. Thermal properties test measurements.

D. *Morphological analysis*

Microscopic examinations of the samples were carried out using a TESCAN VEGA3 LM scanning electron microscope (SEM) in order to analyze the morphology of these samples.

III. RESULTS AND DISCUSSION

A. *Thermo-physical properties*

Thermal conductivity (k) is defined as the ability of a material to conduct heat. This parameter is tremendously important to evaluate an insulating material. The results of the thermal conductivity measurements at room temperature are provided in Table 1. The mean value of this parameter of the samples studied is about k = 0.076W/m.K at room temperature. This value is close to or lower compared to the thermal conductivity of other natural insulating materials, for example sisal (k = 0.070W/m.K), banana (k = 0.117 W/m.K), and hemp (0.115 W/m.K).

TABLE I. THERMAL CONDUCTIVITY OF PALM PETIOLE, SISAL, HEMP AND BANANA.

Sample	Thermal conductivity (W/m.K)	Reference
PLH (Hafsa petiole sample in longitudinal direction of fibers)	0.0736 ± 0.001	Present study
PTH (Hafsa petiole sample in transversal direction of fibers)	0.0670 ± 0.001	Present study
PTB (Boufeggous petiole sample in transversal direction of fibers)	0.0893 ± 0.001	Present study
Sisal	0.070	[9]
Hemp	0.115	[10]
Banana	0.117	[11]

For petiole of Hafsa variety, two types of measurements were performed according to the orientation of fibers. Figure 5 shows that orientation of fibers has a weak effect on thermal conductivity and diffusivity. Indeed, the number of fibers is much less in the longitudinal direction than in the transversal direction and, consequently, there should be more thermal resistance across the axis. Therefore, the orientation of the fiber should have a significant effect on the thermo-physical properties of this kind of natural materials. And yet, this behavior was not observed in this work neither in some other similar studies [12].

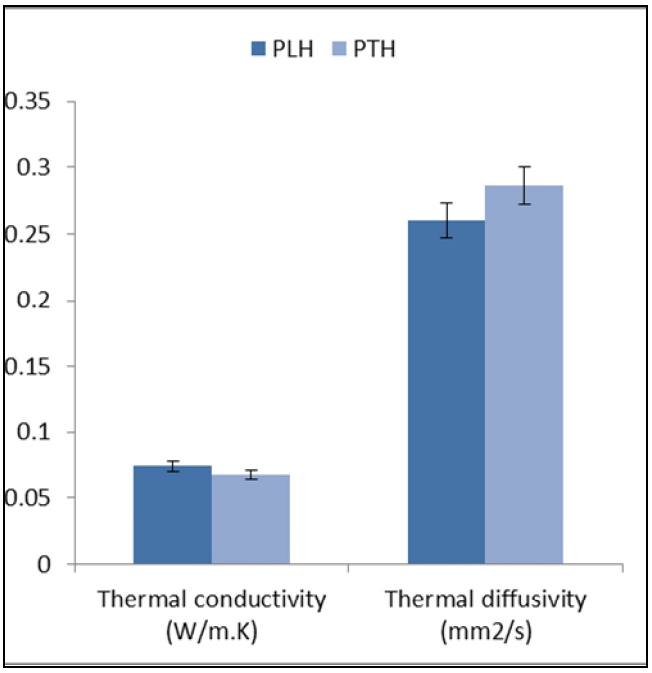
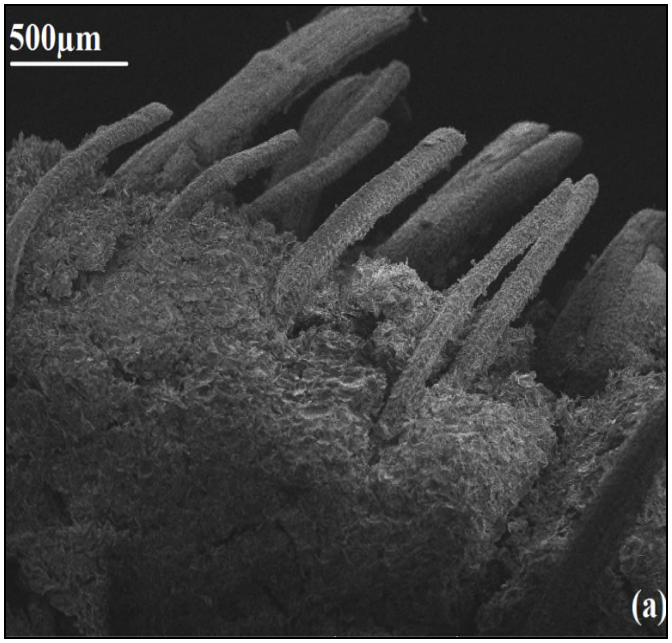


Figure 5. Thermal conductivity and diffusivity of Hafsa petiole samples measured at atmospheric pressure.

B. *Structure and morphology*

Figure 6 presents SEM images of a typical sample of Hafsa petiole in transversal direction of fibers. Observing these microstructures, it can be seen that the sample contains cylindrical fibers with irregular and rough surface containing many impurities. Likewise, the morphology of petiole fibers of date palms is similar to those of coir fiber [13] [14].



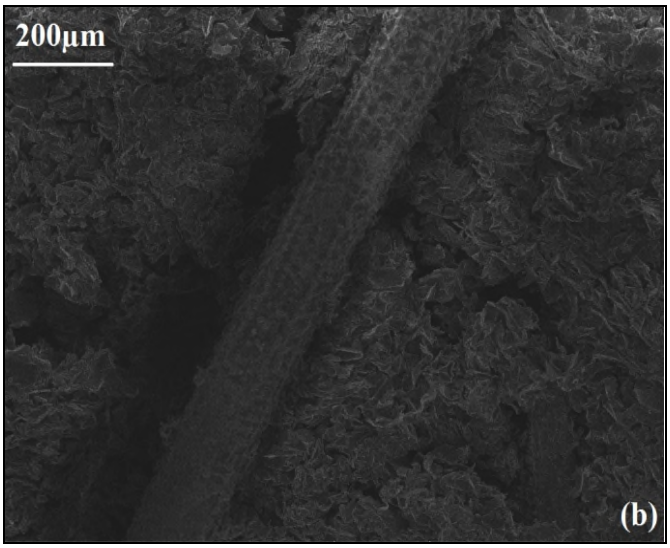


Figure 6. SEM images of Hafsa petiole sample in transversal direction of fibers (PTH). 500µm (a) and 200µm (b).

This kind of natural fiber has a cylindrical and irregular form with many filaments and cells.

IV. CONCLUSION

This study presents the results of experimental measurements and tests conducted on two varieties of date palm material, from Tinghir oasis, south in Morocco. The aim of this research was to evaluate some thermo-physical properties and investigate the possibility to use this local material in building solar furnace insulation.

The findings from this study reveal low thermal conductivity compared to other conventional materials used in this field.

In perspective, for more accurate results and recommendations, other tests will be carried out. The insulation efficiency will also be tested by manufacturing thermal insulation based on these candidate materials and using it as an insulating material in the solar furnace.

ACKNOWLEDGMENTS

This study was supported by The Moroccan Ministry of Higher Education and Research in the framework of (PPR/2015/31) project.

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 ISBN: 978-1-61208-588-3