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Thermal Properties of Palm Fronds (Krino) for Utilizing as a Thermal Insulation Material

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ABSTRACT

Insulation materials are of great importance for conserving stored energy and maintaining temperatures in cooling or heating processes. The cost of insulation materials is a large part of the initial, maintenance and repair costs. Glass-wool insulation namely exchanges in a short time due to its absorption of moisture resulting in decreasing the insulation value. Disposal of glass-wool insulation material constitutes an environmental problem due to its difficultly of degradation. The palm leaves are considered as a great field residues annually produce in Egypt and the Arab countries when each palm produces more than 25 kg per year and the number of palm trees in Egypt is more than 17 million palms. These field residues are rich in cellulose, sugars and many other important elements that can be used in different industries or extraction of important natural materials, which provide return an economic benefits instead of burning them. To achieve the goal of this research, four cylindrical metallic tanks made of black iron sheet, each one having gross dimensions of 50 cm long, 30 cm in dimeter, and 1 mm thick. Three tanks were thermal insulated using krino as an insulation material, with three different densities of insulation (50, 60, and 70 kg/m^3) and 5 cm thick. The fourth tank was insulated using 5 cm thick of glass wool. The most important results of the thermal conductivity test of krino revealed that the thermal conductivity of the krino depends on its density and temperature. The best density was 50 kg/m^3. The values of thermal conductivity of the three different densities was ranged between 0.0954 and 0.190 W/m K)

INTRODUCTION

The surface fibers of date palms are one of the most widespread environmental wastes in the Middle East. The thermal composition and microscopic structures of date palm fibers show that they can be used as new insulation materials for different applications. Corn starch is used to bind the fiber, which makes the insulation material quite natural. Ali and Alabdulkarem (2017) measured the thermal conductivity of the date palm for four different densities, the results showed that the minimum and maximum values are, respectively, 0.0475 and 0.0697 W/m K. The thermal weight analysis indicated that, the fiber degradation and degradation starts at 232 m, where the sample lost approximately 8.5% of its original mass only. Differential analysis is performed for the scan and showed that the heat transfer transition starts from 243 to 382°C with a peak at 369°C. The proposed natural materials are comparable to traditional insulating materials with many advantages without danger to humans. Natural fibers are very promising and have great potential as environmentally friendly raw materials, especially for thermal insulation (Rashed *et al*., 2006). In addition, the natural fibers are biodegradable and have a low impact on the environment. Natural fiber compounds are generally superior to fiberglass compounds from an environmental point of view for a number of reasons, including: less environmental impact than glass fiber production, high fiber content for similar performance, durability of end-of-life natural fibers, energy generation and carbon recovery credits (Joshi *et al*., 2004). The insulation market is competitive in terms of performance and cost. Natural insulation materials are now a niche market. It should be noted that cannabis is currently used as a natural insulator. Pervaiz and Sain (2003) identified the potential for storage and carbon dioxide emissions as well as their comparison with fiberglass compounds. Their results showed that, the average thermal conductivity was 0.083 W/m K for each neck and bundle of palms. A detailed review of the construction of insulation materials based on natural or recycled materials such as sugarcane, corn, cotton stalks, palms, fiber of palm, oil and others (Asdrubali *et al*., 2015). Experimental characterization and water absorption of treated and untreated natural fiber compounds were studied by Sgriccia *et al*. (2008). The results showed that, the natural fiber compounds absorbed more water than the glass fiber compounds. A review article on pretreatment of natural fibers and their applications as a catalyst in polymeric compounds has been published by Kalia *et al*. (2009). The synthesis and thermal decomposition of hemp fibers treated chemically showed that the main degradation of the fiber occurred at a temperature between 250°C and 375°C (Kabir, 2012). Access to an alkali-treated was reported by Mahato *et al*. (2013), they used scanners for differential scanning and infrared. Coconut fiber and sugar cane have been developed as biodegradable fibrous insulation (Manohar *et al*., 2006). The results showed that the thermal conductivity at 70 kg/m^3 of sugarcane and coconut fibers are 0.05094 W/m at 24°C and 0.04884 W/m at 21.8°C, respectively. Some insulating materials pose a hazard to humans in the event of a fire (Liang and Ho, 2007). Therefore, it is not recommended to use organic foam materials to construct walls as insulation. Recently, a new insulating material derived from fruit fibers has been reported in the protera calotropis plant using a corn starch solution as a binder (Ali and Zeitoun, 2012). The results showed that the average thermal conductivity at 130.47 kg/m^3 is 0.045 W/m °C, which is close to the ASTM standard. The new insulating materials developed can also absorb sounds. Protea procera (dirty apple) has been patented as an insulating material (Ali, 2013). Recently, The formal and thermal properties as well as the sound absorption properties of protona prolera (proalla proalla proallera callropis) have been studied and reported as a promising new natural insulating material by Ali (2012) and Ali (2016).. Thermal conductivity measurements of palm oil fiber, coconut and sugarcane have been examined as insulation materials for buildings by (Manohar, 2012). The obtained results showed that, the measured thermal conductivity is within the range normally used to insulate thermal buildings according to FAO (FAOSTAT, 2012). The Arab Republic of Egypt is the largest producer of dates with a capacity of 1.7 million metric tons per year. Palm trees produce a large amount of waste with many applications, such as the production of composite materials and activated carbon from pulp and fiber (MMS El Morsy, 1980; Barreveld, 1993; Khiari *et al.*, 2010). Palm trees produce large quantities of palm leaves. Each palm tree annually produces about 20 kg of dry leaves as waste. The burning of paper waste is a common practice in some places, resulting in environmental pollution (McKendry, 2002). The use of date palms, rather than burning them, is very important for the environment and also has economic benefits. In addition, there are 11 million tons of agricultural wastes per year in Saudi Arabia. Most of the waste belongs to palms, which, if not used properly, can cause environmental problems. This waste is a renewable resource that can have significant economic benefits (Nassour, *et al*., 2008; Saidik, *et al*., 2010). Dates palm trees and date stones (El May, at at., 2012), were potential use and investigated these materials to restore energy with emission factors declining to form trace gases and particulate matter in the exhaust that have the most significant impact on the environment. The insulating materials of dried palm leaves, which have been crushed, have been developed in small pieces (Al-Juruf, *et al*., 1988). In their study, the chemical, physical and mechanical properties of palm fibers were studied and reported. Physical and chemical properties of palm trees (necks and beams) are namely verified (Agoudjil *et al*., 2011). Their results showed that the average thermal conductivity was 0.083 W/m °C per neck and range of palm. A detailed study was reported on the construction of insulation products based on natural or recycled materials such as reeds, cattails, corn cobs, cottonwood, palm, durian, fiber and other palm oil (Asdrubali, *et al*., 2015). The main objective of this study is to study the possibility of using palm trees in the form of date palm leaves (krino) which extracted from leaves as new insulation material, which are wasted in large quantities and did not investigated in the literature. In addition, morphology and thermal analysis is also performed on palm leaves.

M ATERIALS AND METHODS

Materials

Experiments were carried out in Biogas laboratory-tractor and machinery testing center (TMTC) Sabhia, Alexandria governorate, during August 2018. To achieve the objective of this research work, four cylindrical metallic tanks made of black iron sheet, each one having gross dimensions of 50 cm long, 30 cm in dimeter, and 1 mm thick as shown in Fig. (1). Three tanks were thermal insulated using krino as an insulation material, with three different densities of insulation (50, 60, and 70 kg/m^3) and 5 cm thick. The fourth tank was insulated using 5 cm thick of glass wool with thermal conductivity of 0.078 W/m K. Each tank was equipped with three sensors of thermocouple type K for measuring the temperature and connected to the data logger of 16 channels as shown in Fig. (1). The four tanks were filled with 70% of the tank volume using hot water at an average temperature of 85°C.

Fig. 1. Three tanks insulated using krino material and the fourth tank insulated by glass wool

Thermal conductivity measurement

The thermal conductivity of the different thickness and density of krino, and glass wool was determined from the proportionality between heat flow and the potential temperature difference (Fourier's Law) as illustrated in Fig. (2). The heat energy balance on the water tanks is described by the equation of steady-state conduction as follows (Holman, 2010):

$$q_{cond.} = q_{conv.} + q_{rad.} \qquad (1)$$

$$q_{cond.} = A_o\, U_o\, dT_{overall} \qquad \text{Watt} \qquad (2)$$

$$A_o = 2\left(\frac{\pi\, d_o^2}{4}\right) + \pi\, d_o\, L_o = \frac{\pi\, d_o}{2}\,(d_o + 2L_o),\ \text{m}^2 \qquad (3)$$

$$U_o = \frac{1}{A_o \sum R_{th}}, \qquad \text{W/m}^2\,\text{K} \qquad (4)$$

$$\sum R_{th} = \frac{1}{h_i\, A_i} + \frac{\ln(r_o/r_i)}{2\,\pi\, k_c\, L_c} + \frac{\ln(r_s/r_o)}{2\,\pi\, k_s\, L_s} + \frac{1}{h_o\, A_o}, \quad \text{K/W} \qquad (5)$$

$$A_i = 2\left(\frac{\pi\, d_i^2}{4}\right) + \pi\, d_i\, L_i = \frac{5}{2}\,\pi\, d_i^2,\ \text{m}^2 \qquad (6)$$

$$dT_{overall} = (T_i - T_a), \qquad \text{K} \qquad (7)$$

$$q_{conv.} = h_o\, A_o\, (T_o - T_a), \qquad \text{Watt} \qquad (7)$$

$$q_{rad.} = A_o\, \varepsilon\, \sigma\left(T_o^4 - T_a^4\right), \qquad \text{Watt} \qquad (8)$$

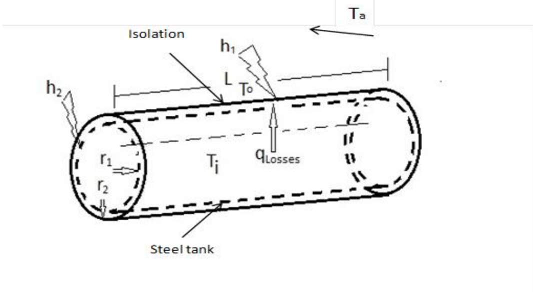

Fig. 2. Diagram of heat energy and temperature distribution on the tank

Where, d_i and d_o, are the inner and outer diameters of the water tanks, respectively, Ai and A_o, respectively, are the inside and outside surface areas, U_o is the overall heat transfer coefficient, R_{th}, is the thermal resistance, k_c, thermal conductivity of tank material, k_s, thermal conductivity of insulation material, L, is the length of tank, h_i, is the convection heat transfer coefficient between the water and the inner surface of the tank, h_o, is the convection heat transfer coefficient between the outer surface of the insulation material and the ambient air, T_i and T_a, respectively, are the water temperature in the tank and the ambient air temperature, T_o, is the outer surface temperature of insulation material, ε, is the emissivity factor of outer surface of insulation material which equal 0.04 (Bartl and Baranek, 2004; Holman, 2010) and , σ, is the Stefan–Boltzmann constant, 5.67 x 10^{-8} W/m^2 K^4. The heat transfer coefficient, h, can be determined from the following equations (Holman, 2010):

$$h = N_u \frac{k}{L_e}, \quad W/m^2\,K \qquad (9)$$

Where:- L_e = Effective length $= r_i$

For laminar flow regime ($G_r\ P_r$) ranges from 10^4 to 10^9

$$N_u = 0.53\,(G_r\ P_r)^{0.25} \qquad (10)$$

For Turbulent flow regime ($G_r\ P_r$) ranges from $>10^9$ to 10^{12}

$$N_u = 0.13\,(G_r\ P_r)^{1/3} \qquad (11)$$

$$G_r = \frac{g\ \beta\ L_e^3\,(T_o - T_a)}{\mu^2} \qquad (12)$$

Where, **N_u, is the Nusselt number, k, thermal conductivity of air, l_e, is the effective length of the tank (characteristics dimension), G_r, is the Grashof number, P_r, is the Prandtl number, g, is the gravitational force, β, is the extensibility coefficient, and, μ, is the viscosity of fluid. The physical properties of water and air at atmospheric pressure are listed in Table (1). Table (2) listed the input values and coefficients that used in the calculation of model. These physical properties can be determined at film temperature, T_f, which varied from time to time according to the outer surface temperature of insulation material (T_o) and the ambient air temperature (T_a) as follows:**

$$T_f = \frac{T_o + T_a}{2}, \quad K \qquad (13)$$

$$\beta = \frac{1}{T_f}, \quad K^{-1} \qquad (14)$$

Table 1. Some physical properties of water and air at atmospheric pressure

Water						Air			
T K	ρ kg/m^3	C_p J/kg K	μ m^2/s $x10^{-7}$	K W/m K	P_r	T K	μ m^2/s $x10^{-5}$	K W/m K	P_r
303	997.6	4180.1	8.320	0.6125	5.68	300	1.568	0.02624	0.708
313	994.6	4178.4	6.580	0.6280	4.34	325	1.828	0.02814	0.703
323	990.1	4181.4	5.680	0.6395	3.68	350	2.076	0.03003	0.697
333	985.5	4184.3	4.780	0.6510	3.02	375	2.333	0.03184	0.693
343	979.8	4190.4	4.21	0.6595	2.62	400	2.590	0.03365	0.689
353	974.1	4196.4	3.640	0.6680	2.22	425	2.738	0.03536	0.686
363	967.4	4206.3	3.290	0.6740	1.98	450	2.886	0.03707	0.683
373	960.6	4216.1	2.940	0.6800	1.74	475	3.338	0.03873	0.682
383	953.0	4233.1	2.710	0.6825	1.60	500	3.790	0.04038	0.680

(Eckert and Drake, 1972)

Table 2. Input values and coefficients used in the model

Sample	The Value
r_i	0.15
r_o	0.151
r_s	201
L_i	1.00
L_s	1.051
k	73.00 W/m K (Holman,2010)

RESULTS AND DISCUSSION

The obtained data from the experimental work were collected and analyzed through the process of heat energy loss and lower temperatures for the four treatments and the results were as follows:

The change in temperature with time for the four treatments and the lower temperature which reach to a quasi-equilibrium with the ambient temperature was plotted in Fig. (3). The surface temperatures for the four treatments (krino with 50, 60, and 70 kg/m^3) reached to the ambient air temperature within 23, 21, and 15 hours, respectively, while the surface temperature of fiber glass reached to the ambient air temperature within 35 hours. The ambient air temperature during the experimental work was ranged between 27.5 – 37°C. The thermal conductivity (k) for the four different samples is shown in Fig. (4). It reveals that the lowest value of thermal conductivity was achieved from the lowest density sample (50 kg/m^3). In addition, the thermal conductivity was linearly increased with temperature especially in the lowest density sample. The maximum change in thermal conductivity with temperature was 67.5, 52, 54.7 and 40.5% for the four different samples (glass wool, krino with 50, 60, and 70 kg/m^3), respectively

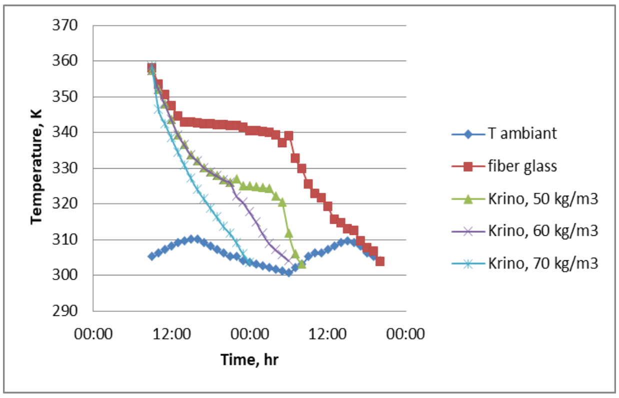

Fig. 3. Change in surface temperature versus time

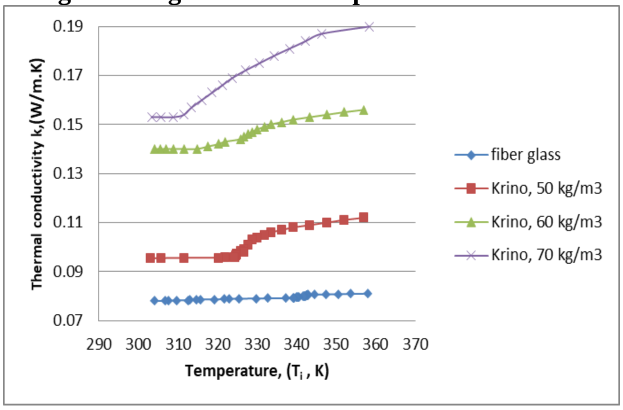

Fig. 4. Thermal conductivity (k) at different temperature

The changes in thermal conductivity with different densities are revealed in Fig. (5) and in Table (3). It evidently clarified that at constant density, thermal conductivity increases with increasing the temperature. Similar behavior of the thermal conductivity change with the temperature and density of the insulation materials made of wood (Suleiman *et al.*, 1999), made of rice straw (Wei *et al.*, 2015), and made from the fibers and Krino of date palm trees surface (Ali and Alabdulkarem, 2017).

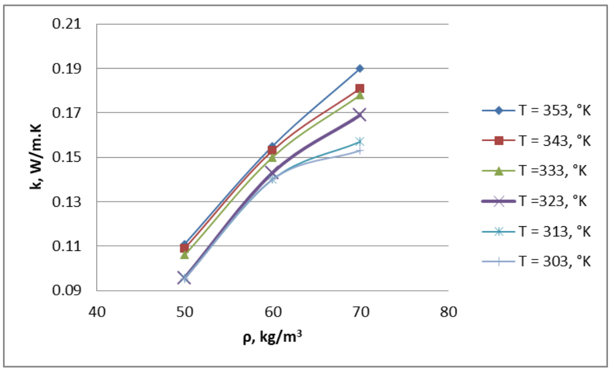

Fig. 5. Thermal conductivity (k) at different density.

Table 3. Thermal conductivity (k) at different density and different temperature

Sample	K (W/m K) at T = 303,K	K (W/m K) at T = 313, K	K (W/m K) at T = 323, K	K (W/m K) at T = 333, K	K (W/m K) at T = 343, K	K (W/m K) at T = 353, K
Krino 0.7	0.153	0.157	0.169	0.178	0.181	0.19
Krino 0.6	0.14	0.14	0.143	0.15	0.153	0.155
Krino 0.5	0.0954	0.0956	0.0958	0.106	0.109	0.111

The linear equations and the coefficient of determination for the four different samples are listed in Table (4). The values of thermal conductivity were functioned to calculate the heat transfer coefficient with the temperature change of stored liquid (water) for the four treatments.

Table 4. The linear l equations of thermal conductivity coefficient and the coefficient of determination for the four different treatments

Sample	Linearl equations	R^2
Glass wool	k = 0.000005 T + 0.076	0.8961
Krino 50	k =0.0004 T + 0.0788	0.8115
Krino 60	k = 0.0004 T + 0.1268	0.9481
Krino 70	k = 0.0008 T + 0.1263	0.9679

CONCLUSION

Thermal conductivity tests and thermal properties analysis are executed for some specimens made of date palm trees leaves (krino). The thermal conductivity test shows that the thermal conductivity coefficient of the krino insulation material for the three different densities is ranged between 0.0954 and 0.190 W/m-K. The date palm trees leaves (krino) are applicable to use as a thermal insulation for cylindrical tanks instead of the glass wool. The experimental work was conducted under the laboratory air conditions, so further experimental work must be carried out under different weather conditions to study the effect of different ambient air temperature, relatively humidity, intensity of solar radiation and air speed blowing over the water tanks.

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الخواص الحرارية لسعف النخيل (كرينو) لإستغلالها كمادة عزل حراري

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تعتبر المواد العازلة ذات أهمية كبيرة للحفاظ على الطاقة المخزنة والحفاظ على درجات الحرارة في التبريد أو التسخين ، كما تمثل تكلفة المواد العازلة جزء كبير من تكاليف الصيانة والاصلاح حيث يجب استبدال العزل (الصوف الزجاجي) كل مدة زمنية من الاستخدام حيث تمتص الرطوبة فتنخفض قيمة العزل لها وتصبح غير ذو فائدة كما يتم تغيرها عندما تبتل بالماء فتنعدم فائدتها، مما يزيد من تكاليف الصيانة ، كما يعتبر التخلص منها مشكلة بيئية كبيرة وخصوصا الالياف الزجاجية يعتبر تحللها صعب وتمثل مشكل بيئية كبيرة. أما الألياف الطبيعية كمادة خام صديقة للبيئة في معظم الاستخدامات ومنها العزل الحراري فهي سهلة التحلل البيئي مما يشجع على استخدامها في صناعات كثيرة، وتعتبر المتبقيات الزراعية كمواد سهلة التحلل كلها صديقة للبيئة في حالة استخدامها في صناعات تحويلية، وعلى العكس عدم استخدام المتبقيات الزراعية في صناعات تحويلية يمثل مشكلة بيئية كبيرة حيث يتم التخلص من معظمها بالحرق المباشر مما يسبب مشكلة بيئية وتلوث بيئي كبير. وتعتبر متبقيات النخيل من المتبقيات المهمة والكبيرة وخصوصا في مصر والدول العربية حيث تنتج النخلة الواحده أكثر من 25 كجم سنويا وعدد النخيل في مصر أكثر من 17 مليون نخلة، واصبحت هذه المتبقيات تمثل مشكلة بيئية كبيرة وملوثة للبيئة بعد انخفاض الصناعات اليدوية التي كانت قائمة على هذه المتبقيات، وهذه المتبقيات غنية بالسليلوز و السكريات وعناصر مهمة كثيرة يمكن الاستفادة منها بالصناعات التحويلية أو استخلاص مواد طبيعية مهمة مما يعيد على المزارعين بفوائد إقتصادية كبيرة بدلا من حرقها كما أن تصنيعها سوف يخلص المجتمع من مشكلة تلوث بيئي. الكرينو يعتبر أحد متبقيات جريد وخوص النخيل ويستخدم في تنجيد الأثاث المنزلي ، ومع ظهور الأسفنج وسهولة استخدامة في الأثاث المنزلي قل استخدام الكرينو كثير مما جعلة يمثل مشكلة بيئية كبيرة ، ويعتبر الكرينو من متبقيات النخيل التي تحتوي على نسبة كبيرة تزيد عن 70 % من السليلوز مما يتيح الفرصة في استخدامها في مجالات كثيرة مثل العزل الحراري و التبريد التبخيري. اجريت التجارب في معمل الغاز الحيوي - محطة اختبارات الجرار والآلات الصباحية- الإسكندرية ، خلال شهر أغسطس عام 2018. لتحقيق هدف هذا البحث، تم تصنيع أربع خزانات من صاج الأسود ، سمك 1 مم و قطرها 30 سم وطولها 50 سم ، ومغلقة من كلا الجانبين ، وهناك مدخل ومخرج للمياه في وسط الجانبين. تم عزل ثلاث خزانات باستخدام الكرينو ، بثلاث كثافات مختلفة من العزل (50 ، 60 ، 70 كجم / م 3) وسمك 5 سم ، وتم عزل الخزان الرابع بواسطة الصوف الزجاجي بسمك 5 سم. من أهم نتائج اختبار الموصلية الحرارية أن معامل التوصيل الحراري للكرينو يعتمد على الكثافة ودرجة الحرارة وكانت أفضل كثافة هى 50 كجم / م^3 ، وكانت القيم الدنيا والقصوى لمعامل التوصيل الحراري للمعاملات الثلاثة 0.190 – 0.0954 (W/m.K).