MATEC Web of Conferences **13**, 02016 (2014)
DOI: 10.1051/matecconf/20141302016

Comparison Study of Thermal Insulation Characteristics from Oil Palm Fibre

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Abstract. In this study, investigation was conducted to study the use of solid biomass from palm oil mill as insulation material. The experimental study concentrates on using oil palm fiber to determine the unidirectional thermal conductivity, *k*. The experiment was conducted at different temperature ranges and packing density. The values of *k* obtained were found to be 0.2 W/m.K to 0.069 W/m.K for a packing density between 66 kg/m^3 to 110 kg/m^3, and at a temperature between 40ºC to 70ºC. Comparisons were made with others common insulating materials, and it was found that the experimental *k* values for oil palm waste insulation was lower by between 4 to 56 times for rockwool and between 7 to 57 times for glass fiber at low temperatures. The value *k* of oil palm fiber however showed an increase at higher temperatures and was lower at lower packing densities. Although not being able to match the *k* values of common insulators at higher temperatures, other factors such as cost and environmental benefits of using waste material should be taken into consideration and hence encouraging its use as at least a supplement to existing insulation materials

1 Introduction

The palm oil industry in Malaysia has grown rapidly over the past 20 years. In December 2012, Malaysia had 5.08 million hectares of oil palm plantation which produced 18.79 million ton of crude palm oil (CPO) and contributes 39 % of the world's total palm oil production and 44 % of world exports [1]. However, the huge amount of CPO production generates massive biomass residue which created a major disposal problem [2]. The fundamental principles of waste management are to minimize and to recycle the waste, and recover the energy as much as possible.

The waste from palm oil mill industry generally can be classified as empty fruit bunches (EFB), palm shell, mesocarp fibre and palm oil mill effluent (POME), where CPO and palm kernel oil constitute only 10% of the product while the remaining 90% are solid and liquid waste. Although the possibilities of utilization as fuel is by far, greater than fertilizers or feedstock, other options of reusing oil palm waste should not be ruled out. The basis behind this development work is to the study the possibilities of using oil palm waste as insulation material. Hence there is a need to determine its thermal conductivity under certain environmental conditions.

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Thermal insulation consisting of a single material, a mixture of materials, or a composite structure chosen has the objective of reducing heat flow. Its effectiveness is evaluated on the basis of thermal conductivity and depends on the physical and chemical structure of the insulation material. Thermal insulation material can be divided into three main categories: Fibrous, Cellular and Flake/Granule [3]. The fibrous type insulation has been commonly used in industrial processes especially as piping and furnace insulation. Research on physical and mechanical properties of palm oil wastes have been carried out [4], and palm oil wastes which contain air gaps in their micro structure have been reported to be poor conductors [5]. Since oil palm waste which mainly consists of fibers and shell have common physical properties as the material used in fibrous insulation, the development work would be focused toward this category of insulation.

Thermal conductivity, k is a measure of the flow of thermal energy through a unit thickness of a material under a given temperature gradient. Ramli et al [5], used Fourier's Law in determining the thermal conductivity of palm oil fibre. The relationship of variables under steady state conditions had been proven through Fourier's Law to follow:

$$Q = -kA\frac{dT}{dx} \tag{1}$$

Where : Q = heat transferred (W), A = cross sectional area (m^2), k = thermal conductivity (W/m.K), dT = temperature difference (K), dx = sample thickness (m)

The modes of heat transfer involved in fibrous insulators include Solid Fiber Conduction, Convection, Radiation and Still Air Conductivity. The trends of changes in conductivity for the above heat transfer components are observed to vary as packing density increases in fibrous installations. The convection mode decreases most significantly due to impediments of convective currents while radiation gradually decreases due to scattering and reemissions at higher densities. Solid conduction on the other increases with densities due to better fiber contact. The still air component on the other hand remains almost constant as fibrous insulation consists of mainly an air medium, therefore not responsive to changes in density. An optimum packing density would need therefore need to be established before an insulation material used in an application. The published values of thermal conductivity for some selected fibrous and non fibrous insulation material is shown in the following Table 1.

Table 1. Thermal conductivity of selected insulation material

Material	k (W/m.K)	Density (kg/m^3)
Rock Wool	0.016-0.026	9.6-32
Glass Fiber	0.036	64-140
Polystyrene	0.03	29-56

2 Methodology

The material used in the experiment was oil palm fibre collected from nearby palm oil mill. The raw material was 100% air dried before it was placed in the thermal conductivity test apparatus. The test apparatus was first calibrated within common insulating materials, and all test procedures were carried out in accordance to ISO 1180 [6]. Tests of thermal conductivities were carried out at different set points and different densities. Other mineral fibrous insulation material were also tested for its thermal conductivity for comparison purpose.

Based on Manohar [7], the oil palm fiber of waste material were place in a 254 mm × 254 mm × 51 mm wooden container for thermal conductivity measurement. Once the top cover of the equipment was secured in place, data was recorded at different temperature set points. The packing density of the insulating material was increased by adding more test material and repeating the earlier procedures.

Since the volume of the specimen is fixed, the density of the specimen is changed by adding or removing fibres from the specimen. In this way, the thermal conductivity of oil palm fibre at different densities can be determined.

Readings were observed to have been taken at long time intervals, due to the transient nature of heat transfer in fibrous materials, and the readings would have to be within a stable +/- 1ºC range before they could be accepted [8]. Calculations were carried out with the use of the following equation (2), based on Fourier's Law and the use of calibration constants.

$$k = \frac{l[(C1+(C2\times T_m))+(C3+(C4\times T_m))(HFM)+(C5+(C6\times T_m))(HFM^2)]}{dT} \tag{2}$$

Where : l = thickness (m), C = calibration constant, T_m = mean temperature of the hot and cold sinks, dT = temperature difference of the hot and HFM = heat flow (mV).

3 Results and Discussions

The results obtained indicate the performance of dry oil palm waste material as thermal insulators at specified temperature set points. As observed from the experimental data, the thermal conductivity values were greatly reduced after drying took place, hence the focus on testing dry samples. Different packing densities were also used to study its effect on the insulators performance. Table 2 shows the thermal conductivity results under different testing conditions and Figure 1 clearly illustrates the varying thermal conductivity values for the different packing densities and temperature set points.

Table 2. Thermal Conductivity at different densities and temperatures

Density ρ (kg/m³)	Temperature *T* (ºC)	*k* (W/m.K)
66	40	0.02
	60	0.09
	70	0.10
88	40	0.03
	60	0.07
	70	0.09
110	40	0.01
	60	0.09
	70	0.10

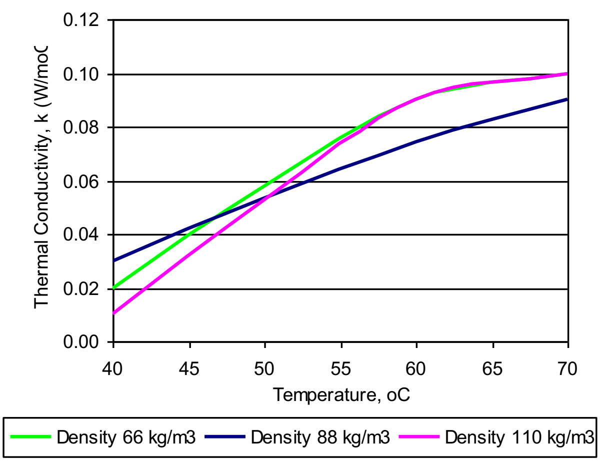

Figure 1. Thermal conductivity values for the different packing density

The following Figures 2-5 illustrate the comparison of other common fibrous and non fibrous insulating materials with the oil palm waste insulators. The packing densities were varied from 66 kg/m^3 (sample 1,2,3), 88 kg/m^3 (sample 4,5,6) and 110 kg/m^3 (sample 7,8,9) and the temperature set points were at 40 °C, 60 °C and 70 °C respectively.

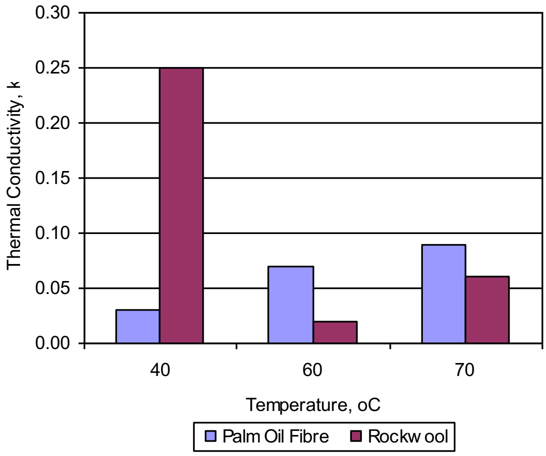

Figure 2. *k* values of palm oil fibre and rockwool at different temperatures

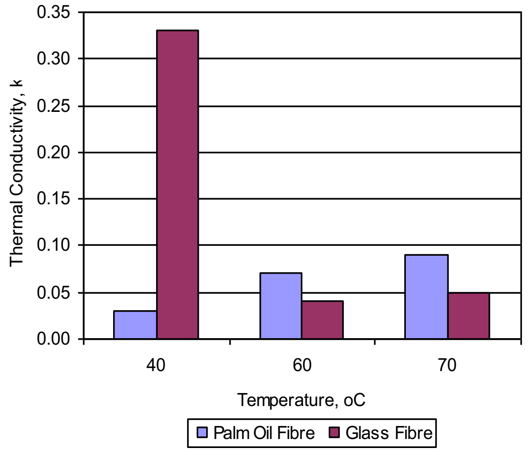

Figure 3. *k* values of palm oil fibre and glass fibre at different temperatures

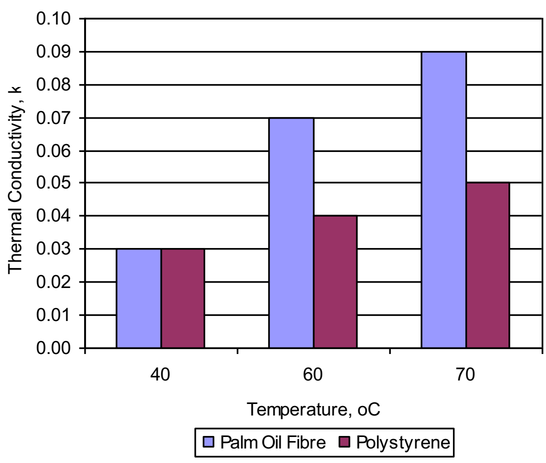

Figure 4. *k* values of palm oil fibre and polystyrene at different temperatures

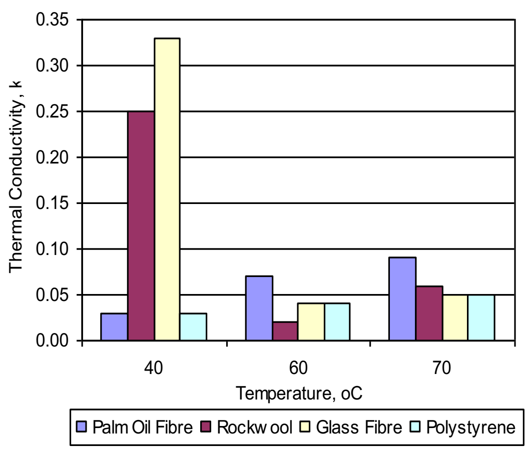

Figure 5. Comparison of *k* values of different materials

4 Conclusions

The study was successful in identifying the optimum operating temperature of below 40°C for oil palm fiber insulation through the tests conducted. Through comparison with the commonly used fibrous and non fibrous insulators, the value of thermal conductivity k from oil palm waste was found to be between 5 to 60 times lower at the optimum operating temperature, and therefore the density range between 66 kg/m^3 to 110 kg/m^3 was acceptable to be used as thermal insulators.

The study also suggest that other fiborous biomass waste should be investigated for its thermal properties and used together with oil palm waste for possibly improved insulation performance. Mechanical properties could also be improved by adding on the other waste fibres of various lengths to the existing samples. Both mechanical and thermal improvements would contribute towards better overall performance and possible commercialization of the insulators.

Acknowledgement

The authors would like to express sincere appreciation for the assistance of technical staffs in energy group for their co- operation and assistance; thanks for the kind help. Financial support for this project from the Department of Mechanical Engineering, Universiti Teknologi PETRONAS is gratefully acknowledged.

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