



# A Comparison of Banana Fiber Thermal Insulation with Conventional Building Thermal Insulation

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## Authors' contributions

This work was carried out in collaboration between the both authors. Author KM designed the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript and managed literature searches. Author AAA managed submission reviewed the analyses of the study, literature searches, edited and formatted the document for submission. Both authors read and approved the final manuscript.

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## ABSTRACT

The use of conventional non-biodegradable building thermal insulation has resulted in environmental issues which prompted research to focus on the use of natural fibres in many regions. The thermal insulating properties of banana fibre was investigated and compared with conventional insulating materials to ascertain the use as building thermal insulation. Thermal conductivity measurements were conducted in accordance with ASTM C-518-04 on 38 mm thick slab-like banana fibre specimens. Experiments were conducted for the density range 20 kg/m<sup>3</sup> to 120 kg/m<sup>3</sup> in increments of 10 kg/m<sup>3</sup> and for mean test temperature range 20°C to 40°C in increments of 5°C. Results showed that banana fiber exhibited the characteristic behaviour associated with fibrous thermal insulation of decreasing thermal conductivity with increasing density to a minimum value and then increasing in thermal conductivity with further increase in density. Consistent with loose fill materials, there was a linear increase in thermal conductivity with increase in mean test temperature. An empirical equation developed to calculate the apparent thermal

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conductivity variation with density and temperature correlated within  $\pm 4.42\%$  of the experimental results. At  $25^{\circ}\text{C}$  the experimental results showed a minimum thermal conductivity of  $0.04110 \text{ W/m.K}$  at  $80 \text{ kg/m}^3$  and the empirical equation  $0.04150 \text{ W/m.K}$  at a density of  $73.4 \text{ kg/m}^3$ . The empirical and experimental minimum thermal conductivity was within  $0.96\%$ . The comparative thermal conductivity of banana fiber with conventional non-biodegradable insulation show the minimum thermal conductivity was higher than all the conventional insulation. The difference ranged from  $8.5\%$  (a  $\lambda$  difference of  $0.0035 \text{ W/m.K}$ ) for glass fiber to  $24.0\%$  (a  $\lambda$  difference of  $0.0099 \text{ W/m.K}$ ) for urethane foam. Although the banana fiber showed the highest thermal conductivity among the materials compared, its value was within the  $0.02 \text{ W/m.K}$  to  $0.06 \text{ W/m.K}$  range for use as building thermal insulation.

*Keywords: Banana fiber; thermal conductivity; building insulation; biodegradable insulation.*

## 1. INTRODUCTION

Building thermal insulation is the simplest, cheapest, most reliable and effective means of maintaining a comfortable indoor building environment. Insulation is a passive method of reducing the rate of heat flow across a building envelope which has a direct impact on the energy bill for maintaining thermal comfort which eventually leads to a decrease in greenhouse gas emissions and environmental pollution [1,2]. Over the decades research and development has mastered the art of building thermal insulation and continues to develop more innovative and sophisticated materials to meet the demands of modern society.

Some of the most effective and commonly used building thermal insulation are inorganic materials such as mineral wool, lightweight and cellular concretes, foam glass, fiberglass, plastic foams, Styrofoam and expanded perlite [3]. However, besides their long-term financial benefit the use of inorganic insulating materials may be harmful to human health and body and cause environmental pollution by the emission of toxic gasses and particles [4]. Also, the production of these materials is highly energy intensive [5]. In the recent past the growing number of rebuilding, renovating and restructuring of old buildings has produced an enormous amount of inorganic building thermal insulation waste. The non-biodegradability of these materials has resulted in environmental issues with the increasing volume of discarded insulation material for disposal [6,7]. The environmental concern has prompted research to focus on the use of natural fibers in developing new and innovative insulation techniques and materials to accommodate, facilitate and improve the thermal needs of society.

In tropical countries banana is one of the most common fruit grown and is among one of the

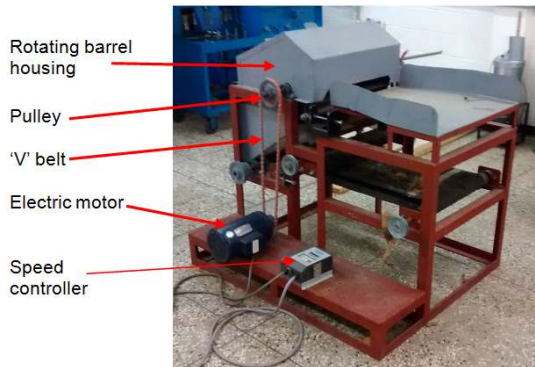
most eaten fruit in the world. After the banana bunch is removed from the plant, the banana tree and leaves are discarded. In some banana plantations the large number of trees incur extra cost to the farmer for disposal despite some parts of the tree being used in the plantations as organic fertilizer [8]. In the banana tree the long fibers represent approximately  $1.5\%$  by total mass of the plant [8,9].

The long banana fiber makes it an attractive alternative for use as building thermal insulation as the fibers can be easily woven into an insulation batt without the use of binders. However, use as thermal insulation and further research and investment will depend on the thermal insulating properties being within the range  $0.02 \text{ W/m.K}$  to  $0.06 \text{ W/m.K}$  [10]. If managed effectively, banana fibers can serve as a renewable biodegradable thermal insulation with a net reduction in  $\text{CO}_2$  emissions over the life cycle [10]. The commercial agricultural industries can provide a cheap, reliable and abundant supply of banana fibre as waste by-products. The main indicator of the quality of an insulating material is the effective thermal conductivity [11]. The effective thermal conductivity of a loose-fill fibrous material varies with bulk density and the optimum density at which minimum thermal conductivity is exhibited is required for best thermal and economical use of the material [12]. In this study the thermal insulating properties of banana fiber is investigated and compared with conventional insulating materials to ascertain the use as building thermal insulation.

## 2. SAMPLE PREPERATION

Presently there are no commercial means of extracting banana fibers as the demand is low and buyers of banana fiber are erratic. Usually experimental projects that use rotary type

machines are adapted to extract banana fibres [13,14]. An experimental slotted-barrel rotating machine in the Agricultural Engineering Laboratory at The University of the West Indies was used to extract the banana fibre (Fig. 1). The fiber extracting machine consisted of a pair of rollers. One was a smooth roller (squeezing roller) and the other was a grooved roller (scraper roller). The slices from the banana tree trunk were fed between the squeezing roller and the scraper roller following which the pulp was separated and fibers were exposed.



**Fig. 1. Slotted-barrel rotating machine used to extract the banana fibre**

Samples for processing in the machine were prepared by stripping the banana trunk in approximately 10 cm wide pieces as shown in Fig. 2. The innermost part of the banana trunk was not used as it contained softer fibres. During processing the soft material was removed and the long banana fiber strands exposed.



**Fig. 2. Strips from the banana tree trunk for processing**

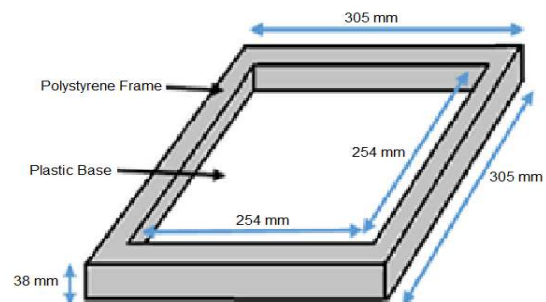
The fibers were then cut and allowed to air dry under laboratory conditions for five days. The dried fibers were then randomly arranged in a slab-like form as a thermal insulation batt. The minimum density at which the slab-like batt showed no settling was at  $20 \text{ kg.m}^3$ . This density

was used as the minimum test density for sample preparation. Fig. 3 shows a picture of the dried and sorted banana fiber.



**Fig. 3. Dried and sorted banana fiber**

Test specimens were prepared by randomly arranging the banana fibers horizontally to form an insulation batt in a square polystyrene frames of thickness 38 mm. The polystyrene frames were constructed from 25.4 mm strips with a thin plastic base to hold the fibres from falling through. The inner dimensions of the specimen holder was 254 mm x 254 mm. 38 mm thick test specimens were prepared at densities  $20 \text{ kg/m}^3$ ,  $30 \text{ kg/m}^3$ ,  $40 \text{ kg/m}^3$ ,  $50 \text{ kg/m}^3$ ,  $60 \text{ kg/m}^3$ ,  $70 \text{ kg/m}^3$ ,  $80 \text{ kg/m}^3$ ,  $90 \text{ kg/m}^3$ ,  $100 \text{ kg/m}^3$ ,  $110 \text{ kg/m}^3$  and  $120 \text{ kg/m}^3$ . The maximum test density was determined by the clamping force of the test apparatus and the mass of fibre at the respective density was calculated from the target density and the known specimen holder volume. Fig. 4 shows a schematic of the specimen holder.



**Fig. 4. Polystyrene specimen holder**

### 3. EXPERIMENTAL RESULTS

Thermal conductivity measurements were conducted with the LaserComp FOX 304 steady state thermal conductivity measurement apparatus. This equipment operated in accordance with ASTM C-518-04, Standard Test Method for Steady-State Thermal Transmission

Properties by Means of the Heat Flow Meter Apparatus [15]. The FOX 304 measures thermal conductivity under steady state one-dimensional test conditions with heat flow upwards. Two centrally located heat flux transducer, 102 mm X 102 mm, continuously monitored the heat flow across the specimen. The FOX 304 provided thermal conductivity measurements within the range 0.005 W/m.K to 0.35 W/m.K with  $\pm 0.2\%$  repeatability and  $\pm 0.5\%$  reproducibility. Fig. 5 is a picture of the experimental set-up.

The test apparatus was calibrated using NIST SRM 1450b, Standard Reference Material of the National Institute of Standards and Technology with a 20°C temperature difference between the plates and upward heat flow. The heat sink was provided by an independent chilled water system and a circulating pump. The test results for the 38 mm thick banana fiber specimens for the density range 20 kg/m<sup>3</sup> to 120 kg/m<sup>3</sup> and mean test temperature range 20°C to 40°C are shown on Table 1.

#### 4. ANALYSIS OF DATA

Results shown on Table 1 for the 38 mm thick loose-fill banana fiber specimens at the five respective mean test temperatures all indicated a decrease in thermal conductivity with increase in density to a minimum value and then increase in thermal conductivity with further increase in density [10,16,17,18,19]. This hooked-shape trend is associated with the behaviour of loose fill thermal insulation. Therefore, the thermal conductivity,  $\lambda$ , variation with density should conform to the general empirical correlation associated with this characteristic behaviour for

materials of this nature as given by equation (1) [10,20].

$$\lambda = a + b\rho + c/\rho \quad (1)$$

where  $\lambda$  is thermal conductivity in W/m.K,  $\rho$  is density in kg/m<sup>3</sup>, and a, b, c are numerical constants. The first term representative of the thermal conductivity of air, the second term represents solid conduction and the third term represents radiation contribution [21,22]. Using the Method Least Squares the banana fibre experimental data for the respective mean test temperature was fitted in the form of equation (1) and the constants determined. The resulting empirical correlation for each test condition as shown in equations (2) to (6).

At 20°C mean temperature;

$$\lambda = 0.01214 + (0.19741 \times 10^{-3})\rho + 1.0309/\rho \quad (2)$$

At 25°C mean temperature;

$$\lambda = 0.01264 + (0.19349 \times 10^{-3})\rho + 1.0642/\rho \quad (3)$$

At 30°C mean temperature;

$$\lambda = 0.01276 + (0.19893 \times 10^{-3})\rho + 1.1046/\rho \quad (4)$$

At 35 °C mean temperature;

$$\lambda = 0.01185 + (0.21480 \times 10^{-3})\rho + 1.1640/\rho \quad (5)$$

At 40°C mean temperature;

$$\lambda = 0.01163 + (0.22156 \times 10^{-3})\rho + 1.2094/\rho \quad (6)$$

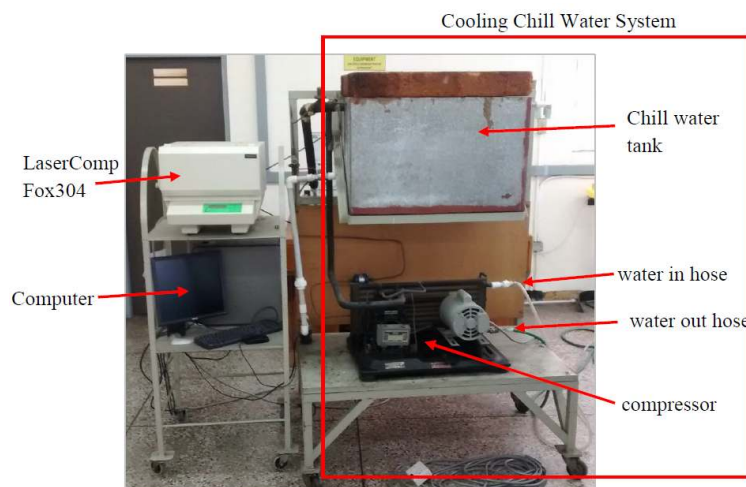


Fig. 5. Thermal conductivity apparatus experimental setup with the chilled water system

Another characterise associated with fibrous thermal insulation is a liner increase in thermal conductivity with mean test temperature which can be represented by a straight line equation of the form [23].

$$\omega(T) = d + e.T \tag{7}$$

where  $\omega(T)$  is an expression for the temperature dependence,  $d$  and  $e$  are numerical constants, and  $T$  is the mean test temperature.

Results on Table 1 indicated a linear increase in thermal conductivity with mean test temperature. Using the Method of Least Squares to incorporate the linear increase in thermal

conductivity with mean test temperature generated a general empirical correlation for determining  $\lambda$  in terms of temperature and specimen density for the banana fibre specimens as shown in equations (8).

$$\lambda = (0.01329 - 0.3616 \times 10^{-4} T) + (0.1635 \times 10^{-3} + 0.1392 \times 10^{-5} T)\rho + (0.8405 + 0.9137 \times 10^{-2} T)/\rho \tag{8}$$

The respective thermal conductivity value was calculated form the empirical correlations for the experimental conditions reported and the percentage difference between the theoretical and experimental  $\lambda$  determined. The results are shown on Table 2.

**Table 1. Banana fiber experimental thermal conductivity test results - 38 mm thick specimen**

Density (kg/m <sup>3</sup> )	Experimental determined thermal conductivity (W/m.K) ± 0.2%				
	20°C	25°C	30°C	35°C	40°C
20	0.06740	0.06934	0.07150	0.07380	0.07597
30	0.05251	0.05419	0.05594	0.05740	0.05926
40	0.04638	0.04770	0.04918	0.05070	0.05148
50	0.04290	0.04387	0.04501	0.04626	0.04655
60	0.04107	0.04197	0.04321	0.04454	0.04601
70	0.04063	0.04119	0.04196	0.04282	0.04408
80	0.04054	0.04110	0.04196	0.04281	0.04379
90	0.04093	0.04132	0.04260	0.04319	0.04427
100	0.04174	0.04176	0.04292	0.04395	0.04489
110	0.04268	0.04312	0.04409	0.04587	0.04621
120	0.04562	0.04629	0.04748	0.04924	0.05042

**Table 2. Percentage difference between the calculated thermal conductivity from equation (8) and the experimental results from Table 1 for 38 mm thick banana fibre specimen**

Density (kg/m <sup>3</sup> )	Calculated empirical correlation thermal conductivity (W/m.K) - equation (19) and % difference from experimental thermal conductivity – Table 2									
	20°C		25°C		30°C		35°C		40°C	
	$\lambda_{\text{empirical}}$ W/m.K	% Diff.	$\lambda_{\text{empirical}}$ W/m.K	% Diff.	$\lambda_{\text{empirical}}$ W/m.K	% Diff.	$\lambda_{\text{empirical}}$ W/m.K	% Diff.	$\lambda_{\text{empirical}}$ W/m.K	% Diff.
20	0.06756	0.23	0.06980	0.66	0.07204	0.76	0.07428	0.66	0.07653	0.73
30	0.05242	-0.18	0.05397	-0.41	0.05552	-0.76	0.05707	-0.58	0.05862	-1.08
40	0.04580	-1.25	0.04704	-1.38	0.04828	-1.83	0.04952	-2.33	0.05076	-1.40
50	0.04260	-0.70	0.04368	-0.44	0.04476	-0.56	0.04584	-0.91	0.04692	0.80
60	0.04110	0.07	0.04210	0.31	0.04310	-0.26	0.04409	-1.00	0.04509	-1.99
70	0.04058	-0.13	0.04154	0.84	0.04250	1.28	0.04345	1.48	0.04441	0.76
80	0.04066	0.30	0.04161	1.24	0.04256	1.42	0.04350	1.62	0.04445	1.51
90	0.04115	0.55	0.04211	1.91	0.04306	1.08	0.04401	1.91	0.04497	1.58
100	0.04193	0.46	0.04290	2.74	0.04388	2.23	0.04485	2.04	0.04582	2.07
110	0.04291	0.55	0.04391	1.84	0.04491	1.87	0.04591	0.10	0.04691	1.52
120	0.04405	-3.44	0.04509	-2.60	0.04612	-2.86	0.04716	-4.23	0.04819	-4.42

### 5. COMPARATIVE THERMAL CONDUCTIVITY

Conventionally used fibrous thermal insulations such as light weight foam, glass fiber, polystyrene and rock wool has established thermal characteristics that engineers use in design [15]. The apparent thermal conductivity for insulating materials are usually quoted as the thermal conductivity at the optimum density for a mean temperature value of 24°C [24,25]. The thermal conductivity variation with density at a mean test temperature of 24°C for glass fiber [20,26], air filled urethane foam [27], molded polystyrene and rock-wool [28] were compared

with the calculated thermal conductivity for banana fiber at 24°C mean test temperature from equation (8). From the published data the minimum thermal conductivity of glass fiber is 0.0378 W/m.K at a density of 165 kg/m<sup>3</sup>, the minimum thermal conductivity of air filled urethane foam is 0.0314 W/m.K at a density of 32 kg/m<sup>3</sup>, the minimum thermal conductivity of molded polystyrene is 0.0330 at a density of 40 kg/m<sup>3</sup>, and the minimum thermal conductivity of rock-wool is 0.0366 W/m.K at a density of 60 kg/m<sup>3</sup>. The comparative data at 24°C are shown graphically in Fig. 6 together with the plot of banana fiber experimental data at 25°C.

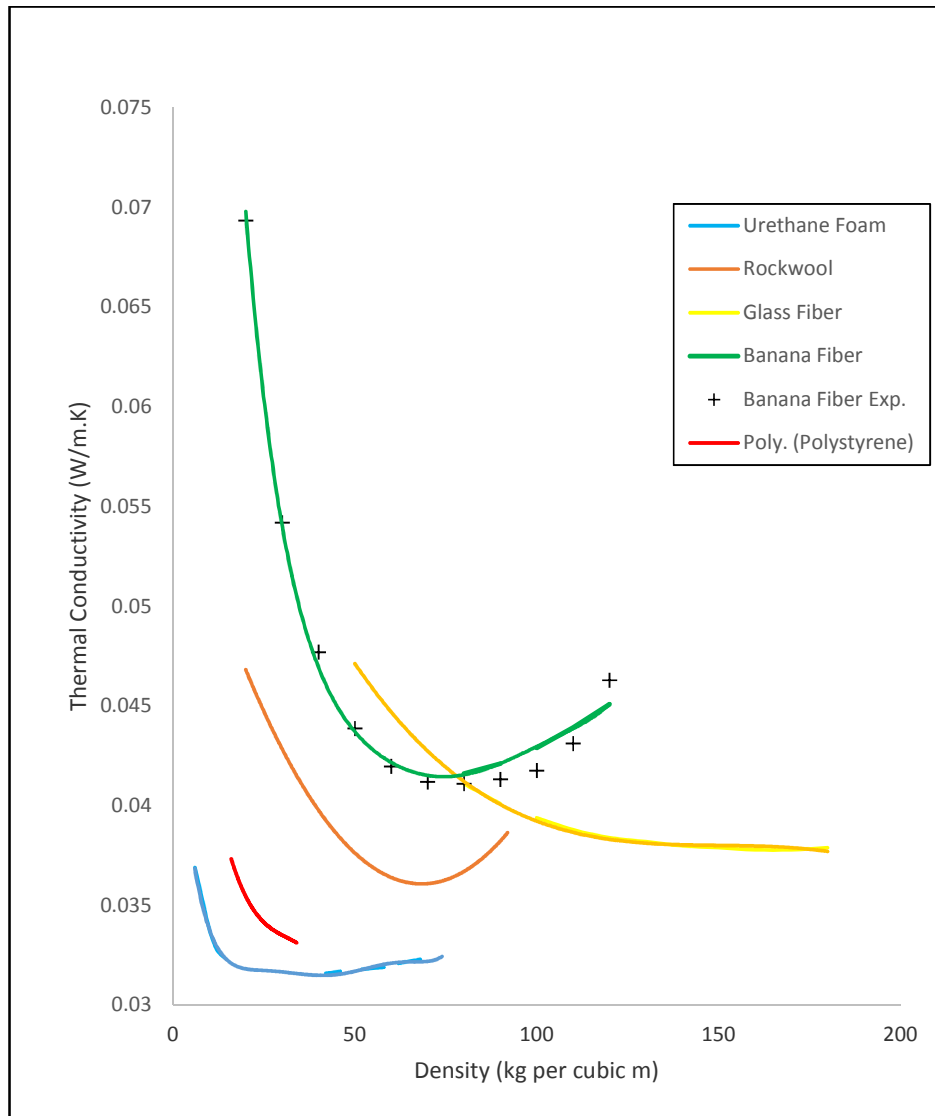


Fig. 6. Comparative apparent thermal conductivity variation with density at 24°C

## 6. DISCUSSION

The experimental results for banana fiber showed the characteristic behavior associated with loose-fill fibrous thermal insulation materials. As density increased from  $20 \text{ kg/m}^3$ , the apparent thermal conductivity decreased to a minimum value at  $80 \text{ kg/m}^3$  and then increased with further increase in density for all mean test temperatures. At each respective test density experimental results showed a linear increase in thermal conductivity with mean test temperature. The density and temperature dependent empirical correlation developed for the 38 mm thick specimen predicted the apparent thermal conductivity within  $\pm 4.42\%$  of the experimental values. At  $25^\circ\text{C}$  the experimental results for  $80 \text{ kg/m}^3$  showed the minimum thermal conductivity of  $0.04110 \text{ W/m.K}$ . At  $25^\circ\text{C}$  the calculated minimum thermal conductivity from equation (8) is  $0.04150 \text{ W/m.K}$  at a density of  $73.4 \text{ kg/m}^3$ . Therefore, at  $25^\circ\text{C}$  mean temperature, the empirical and experimental minimum thermal conductivity was within  $0.96\%$ .

For comparison with other materials, at  $24^\circ\text{C}$  mean temperature, the calculated minimum thermal conductivity of banana fiber is  $0.04130 \text{ W/m.K}$  at a density of  $73.36 \text{ kg/m}^3$ . The comparative thermal conductivity of banana fiber with conventional non-biodegradable insulation in Figure 6 all show the characteristic hook shape graph. The minimum thermal conductivity of banana fiber is higher than all the conventional insulation. The difference range from  $8.5\%$  (a  $\lambda$  difference of  $0.0035 \text{ W/m.K}$ ) for glass fiber to  $24.0\%$  (a  $\lambda$  difference of  $0.0099 \text{ W/m.K}$ ) for urethane foam. Although the banana fiber show the highest thermal conductivity among the materials compared, its value is within the  $0.02 \text{ W/m.K}$  to  $0.06 \text{ W/m.K}$  range for use as building thermal insulation. As a naturally occurring material, banana fibre has the advantage of being environmentally friendly (biodegradable), cheap and abundant supply of raw material and renewable. However, consideration has to be given to the flammability of the material. Also, for future work, susceptibility to insect attack and fungal growth over long time periods need to be investigated.

## 7. CONCLUSION

- Results showed that banana fiber exhibited the characteristic behaviour

associated with fibrous thermal insulation of decreasing thermal conductivity with increasing density to a minimum value and then increasing in thermal conductivity with further increase in density.

- Consistent with loose fill materials, there was a linear increase in thermal conductivity with increase in mean test temperature.
- Experimental results for banana fiber at a mean temperature of  $25^\circ\text{C}$  showed a minimum thermal conductivity of  $0.0411 \text{ W/m.K}$  at a density of  $80 \text{ kg/m}^3$ .
- The empirical correlation developed predicted the thermal conductivity within  $\pm 4.42\%$  of the experimental results.
- The empirically determined minimum thermal conductivity is  $0.04150 \text{ W/m.K}$  at a density of  $73.4 \text{ kg/m}^3$ .
- The thermal conductivity of banana fiber is within the  $0.02 \text{ W/m.K}$  to  $0.06 \text{ W/m.K}$  range for use as building thermal insulation.
- Banana fiber has the advantage of being environmentally friendly (biodegradable) and possibly lower processing cost.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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