International Journal of Materials Science and Applications
2024, Vol. 13, No. 3, pp. 31-40
https://doi.org/10.11648/j.ijmsa.20241303.11

Research Article

Thermal Insulation of "akassa" Hot Preservation Baskets Using Cow Dung Coatings

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Abstract

The use of eco-materials for thermal insulation is becoming more and more recommended compared with synthetic materials. They have the advantage of being biodegradable and sometimes less expensive. To this end, the use of packaging with the function of hot preservatives but made from local and biodegradable materials is a very interesting alternative to synthetic enclosures. This work involved formulating eco-materials made from cow dung coatings and a mixture of cow dung coatings with a framework of fibres extracted from the stalks of oil palm leaves. In addition, to monitor the temperature rise in the various eco-materials manufactured and characterise them using the hot ribbon method to determine their effusivity and thermal conductivity. The pair of materials exposed to heating showed a gradual rise in temperature within the materials when the resistor was energised. A slightly faster rise was observed in the first fifty minutes. The results obtained indicate that the cow dung has a higher effusivity (E = 517.32 $J.m^{-2}.\ ℃^{-1}.\ s^{-1/2}$) than its composite (E = 501.20 $J.m^{-2}.\ ℃^{-1}.\ s^{-1/2}$). The thermal conductivity values obtained indicate that the cow dung has a higher thermal conductivity (λ'=0.19 $W.m^{-1}.K^{-1}$) than that of the composite structure (λ=0.15 $W.m^{-1}.K^{-1}$). From the above, the presence of the fibre frame has the effect of reducing thermal conductivity because it absorbs more energy. The materials produced therefore have proven insulating properties, which are improved when the framework is made from fibres extracted from the stalks of oil palm leaves. Using oil palm fibres in combination with cow dung as eco-materials for thermal insulation is an excellent alternative to synthetic insulation.

Keywords

Eco-materials, Insulation, Environment, Thermophysical Properties

1. Introduction

Protecting the environment and achieving the Sustainable Development Goals (SDGs) will certainly require some major decisions and orientations, and particularly a change of behaviour in the choice of basic materials. The design or choice of most of our household equipment and services, buildings, etc., in terms of what might be termed "eco-behaviour" or

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Received: 25 March 2024; **Accepted:** 22 April 2024; **Published:** 10 May 2024

"eco-friendly behaviour". It will be much more a question of using materials that are more affordable, renewable, biodegradable, and ecologically acceptable. Biocomposites are generally developed from renewable and sustainable sources, including plant-based sources [1], animal-based sources, and mineral-based sources. Fibres such as jute and coir, agricultural residues such as straw, stalks and husks, biomass such as bamboo and perennial grasses have been widely used to develop biocomposites and biobased products [2-5]. Using these resources to manufacture biocomposites adds significant value and maximises the use of natural resources.

For example, in many European Union countries, there are standards covering the materials and procedures for correctly achieving the objectives, as well as the tests to be carried out to prove the quality of the results in relation to the regulations in force [6]. While some regulations are informative, others are mandatory, setting limits for insulation, reverberation time and vibration. Energy savings must also be considered, considering directives aimed at achieving buildings with envelopes that limit energy demands to achieve correct thermal comfort.

The study of how to make the most of renewable and biodegradable resources, and of their energy efficiency to reduce the use of non-renewable resources, are the options that need to be considered. In this way, the desire for current guidelines is to give preference to materials that offer broader usage properties (adaptive, economical, durable, recyclable materials), with health guarantees (non-toxic materials) and better possibilities as insulators for thermal comfort and food preservation.

Animal excrement has been used by all civilisations since ancient times. Such is the case with cow dung. It was used as fuel very early on, and the practice was widespread in many regions. In the 6th century BC, it was also used for heating. Apart from relative differences of opinion about its smell and the possible influence of its fumes on humans, there is unanimous agreement about the way in which it burns, and it was well appreciated: it was called "cow dung". In many countries, dung has remained a basic building material, used to build walls, fill cracks, and waterproof roofs. In addition to these many other uses, cow dung is also used as an organic fertiliser and in some traditional medicine recipes.

Akassa" is also sold in southern Benin, especially in rural areas, in baskets made from vegetable fibres, mainly extracted from oil palm leaves. Some people use cow dung on these baskets. This ancient practice provides packaging capable of keeping the product hot for varying lengths of time. Unfortunately, the thermo-physical properties of this type of woven composite are still unknown, which hampers their development. For hot food preservation, modern enclosures commonly known as "iceboxes" are made from synthetic materials. In a context of modernism where the use of these 'coolers' is taking on ever greater proportions, there is unfortunately the problem of the probable risk of harmful interaction between them and the food being preserved, on the one hand, and the long-term management of their waste, on the other.

The aim of this work is to study the thermal insulation quality of baskets coated with cow dung. The baskets were coated with cow dung, the rate of temperature rise was monitored and their thermal properties, such as thermal conductivity and effusivity, were determined.

Thermal conductivity is the most important property, and generally the only one considered, of thermal insulation material, responsible for heat flow and temperature distribution under steady-state heat transfer conditions [7].

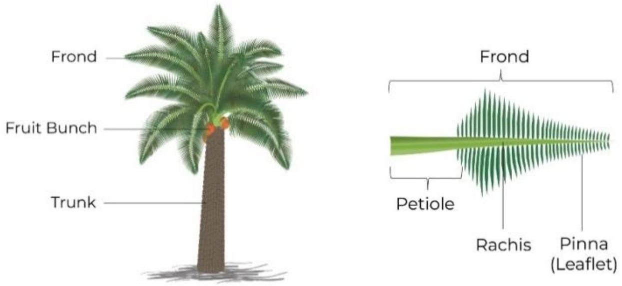
2. Materials and Methods

2.1. Materials

The material consists mainly of cow dung, starch and various palm organs used to make the baskets (Figures 1, 2 and 3). The leaves are 6 to 9 metres long and can have more than 300 leaflets. This is the part used to make the baskets. The oil palm is essentially a potential source of fibre.

(a) Palmeraie

(b) Palm nut diets



(c) Different parts of the oil palm.

Figure 1. *Morphology and description of oil palm.*

Figure 2. Cow dung.

Figure 3. Starch.

2.2. Methods

2.2.1. Techniques for Realising Test Specimens

The test specimens were made using a mould designed for this purpose (Figure 4.) according to the dimensions shown in Figure 5. The fibre skeleton of the oil palm leaf rachis cut from a basket (Figure 6) was placed in the mould, which was then filled on each side with a mixture of cow dung mixed with starch as a binder in a proportion of approximately 10% by mass to obtain the composite test specimen.

The homogeneous test specimen comprises the following elements: cow dung mixed with starch as a binder in a proportion of approximately 10% by mass. After demoulding, the test pieces are sun-dried for approximately five (05) days.

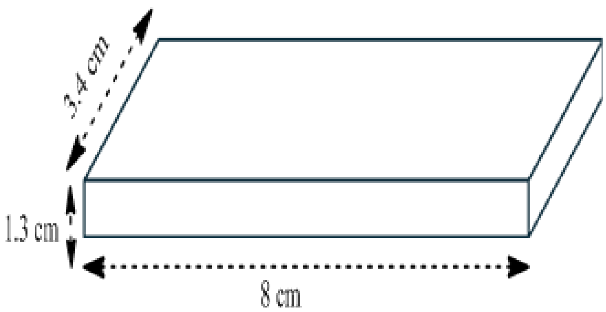


Figure 4. Dimension of test specimens.

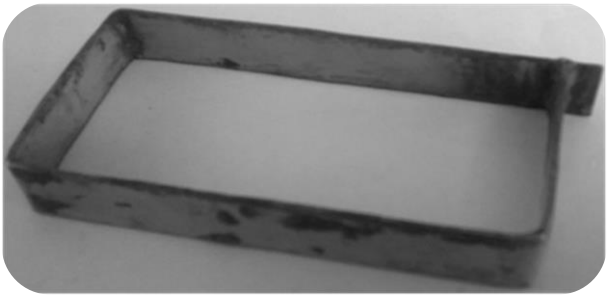


Figure 5. Mould to produce test specimens.

Figure 6. Basket cut to realise the framework for the composite sample.

2.2.2. Description of the Experimental System

The experimental set-up is built around a data acquisition central, to which a heating resistor + thermocouple probe assembly is connected. This equipment is controlled by a desktop microcomputer. The device consists of: samples of raw material (1), heating resistor + thermocouple inserted between two samples of material (2), polystyrene (3 and, 5) and, mass (4) (Figure 7).

An electronic balance is used at the start of the operation to ensure that the acceptable mass difference (0.5g) between the samples is respected. The set-up is based on the principle of simultaneous measurement of thermal conductivity and effusivity with the symmetrical 2D "hot ribbon".

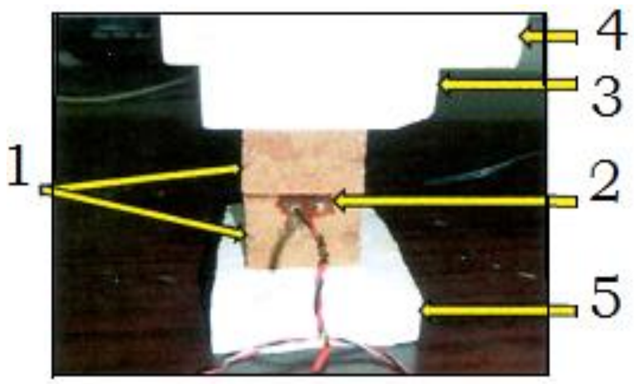


Figure 7. Example of assembly for a hot tape measure [8].

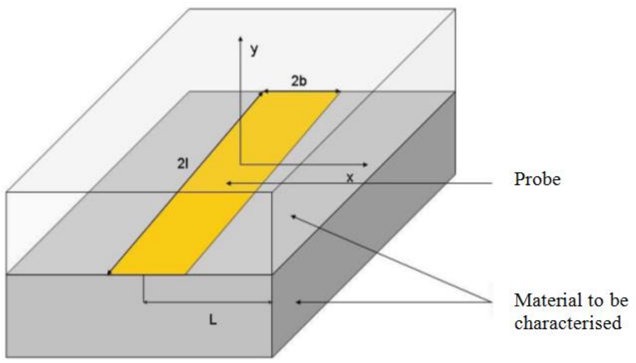


Figure 8. Principle of the hot-tape method.

Table 1. Characteristics of the ribbon.

R	L	l	U
43.4 Ohms	5cm	1,5cm	6.3 V

2.2.3. Physicothermal Characteristics

(i). Hot-Tape Method

Principe

The principle is based on the consideration of short time hot plane type behaviour at the centre of the probe and long-time hot wire type behaviour when the flux becomes assimilable to a radia flux (Figure 5). The ribbon will therefore take the same form as the hot plane, only its dimensions will differ.

The method has been put into practice by setting up a data acquisition and processing chain.

This is the symmetrical model using a pair of samples of the same type. It offers advantages in terms of implementation, as it allows measurements to be taken under variable conditions for sufficiently short periods of time for it to be assumed that the water content of the pairs of samples has remained constant.

Experimental protocol

The heating resistor and thermocouple are inserted between the two samples of material. The assembly is protected on either side by an insulator (polystyrene) and then stabilised or immobilised with a mass. When the resistor is energised, the computer displays the behaviour of the pair of materials when heated. The data acquisition chain made it possible to follow the evolution of the temperature as a function of time every second (dt=1second).

These data were used in an Excel spreadsheet to calculate the effusivity at short times (0 and 50s) and the thermal conductivity at long times (100 and 150s).

(ii). Calculating Effusivity and Thermal Conductivity

Determination of effusivity

The effusivity (E) is determined by plotting the function $\Delta\theta = f(\sqrt{t})$. It is determined based on the first fifty (50) successive measurements. The set of data considered is obtained using the best linear regression. The slope β of this curve is used to calculate the effusivity E, using relationship (1).

$$\beta = \frac{2\varphi_0}{ES\sqrt{\pi}} \tag{1}$$

Table 2. Parameter values for effusivity E calculation.

U (Volts)	R (Ohms)	L (cm)	l (cm)	$S = L \times l$ (m^2)	$\varphi_0 = \frac{U^2}{R}$
6,3	43,4	5	1,5	0,00075	0,91451

Determination of thermal conductivity

The thermal conductivity (λ) is determined by plotting the function $\Delta\theta = f(lnt)$. It is determined between 100 and 150 seconds. The set of data considered is obtained using the best linear regression. The slope α of this curve can be used to calculate the effusivity E, using relationship (2).

$$\alpha = \frac{\varphi_0}{4\pi\lambda L} \tag{2}$$

This gives the thermal conductivity λ $(W.m^{-1}.K^{-1})$. The various parameters involved in the relationship are shown in Table 3.

Table 3. Parameter values for thermal conductivity calculation.

U (Volts)	R (Ohms)	L (m)	$\varphi_0 = \frac{U^2}{R}$
6,3	43,4	0,05	0,91451

3. Results and Discussion

3.1. Presentation of Baskets Produced

The baskets were made and are shown in Figure 9. The greenish colour is given by the dried cow dung. The woven structure of the oil palm leaf fibres can be seen. The shape of the baskets, their relatively large size and the requirements of the experimental equipment available meant that we had to make suitable test tubes. Two types of specimens were designed and presented in the following paragraphs.

Figure 9. Packaging made from oil palm fibers.

3.1.1. Composite Specimen

By monitoring the specimens during drying, it is possible to adjust the shape due to the shrinkage caused by the departure of water. According to the work of Djossou (2014), the difference between two specimens must not exceed 0.5 g [8].

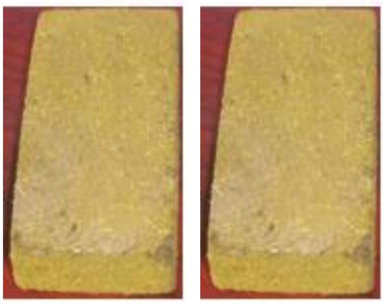


Figure 10. Pair of composite material samples.

3.1.2. Homogeneous Specimen

Figure 11 shows the two homogeneous specimens made using the same mould.

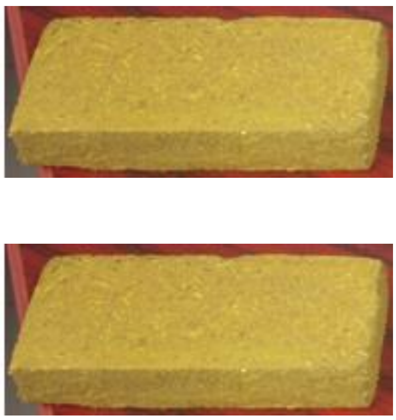


Figure 11. Pair of homogeneous material samples.

3.2. Monitoring the Rise in Temperature of Materials Coated with Cow Dung

Figure 12 shows the visualization curves of the temperature rise within the cow dung coating materials and those of the composite materials of cow dung coating and oil palm leaf rachis fibres. These curves, displayed on the computer, represent the behaviour of the pair of materials when heated, linked to the gradual rise in temperature within the materials when the resistor is energised. They have a similar appearance to half of a parabola whose axis of symmetry is the horizontal line passing through the initial temperature. They can be subdivided into three (03) parts:

1. between 0 and 50 seconds, the part with the fastest rise in temperature. This part of the curve is linearised to calculate the effusivity E;
2. between 50 and 100 seconds, the part where we feel a tendency towards stabilisation. This is shown by a slight increase in the curve;
3. the third part, between 100 and 150 seconds, shows a further increase in the speed of the temperature rise. This can be explained by the more ascending portions of the curves than in the previous section. It was used to calculate the thermal conductivity of the different materials produced.

Nevertheless, the curves for both materials exhibit similar trends, suggesting that the addition of fibers does not significantly alter the overall heat transfer behavior.

In addition, given the identical domain of definition of the plotted functions and the same trend observed in the curves, a quantitative comparison, such as the differences observed at specific time points, does not allow us to deduce which material performs better. This leads to their modelling, which would provide a better understanding of the relative performances of the materials and allow us to deduce which would be the best performer.

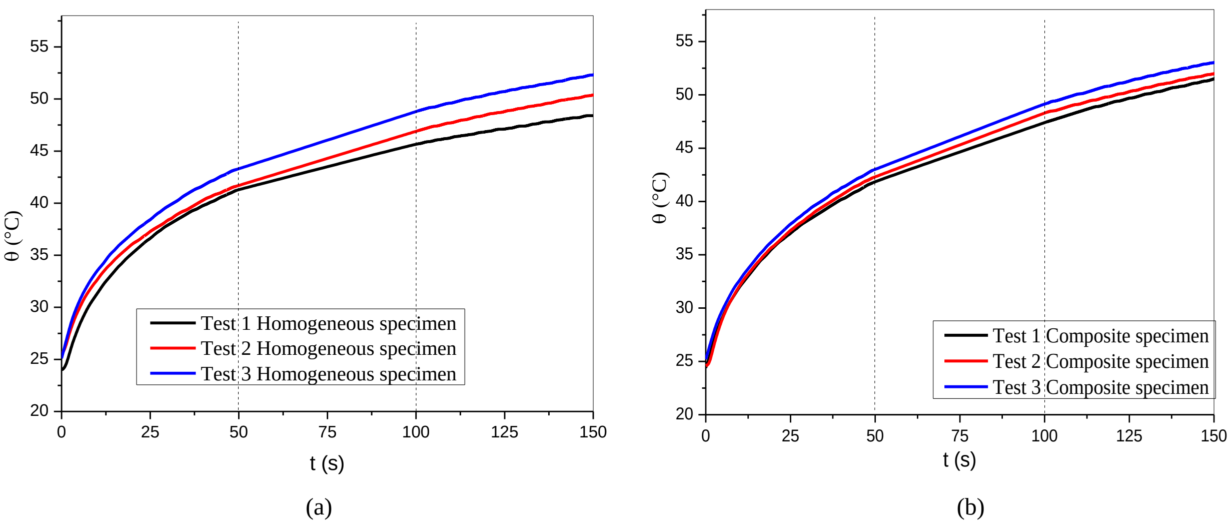


Figure 12. Curves showing the rise in temperature in materials coated with cow dung (a) and those coated with cow dung and oil palm leaf rachis fibres (b).

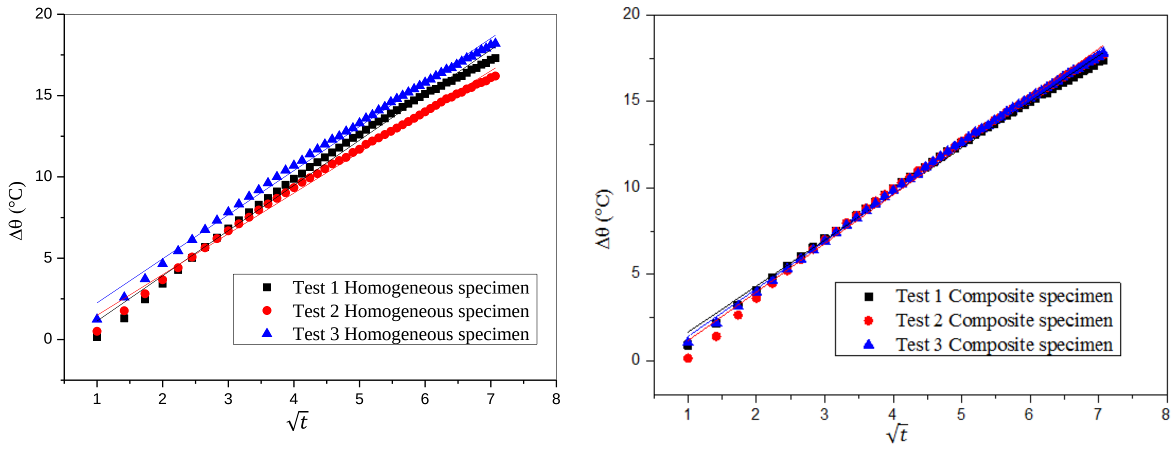
3.3. Modelling of Temperature Rise Curves in Homogeneous and Composite Cow Dung Coating Materials

3.3.1. Calculation of Effusivity of Materials

Figure 13 show the regression lines for the curves showing the rise in temperature in cow dung slurry materials (a) and cow dung slurry and oil palm leaf rachis fibre materials (b) for the calculation of effusivity. These figures also show the coefficient of determination (R2), which varies between 0.99187 and 0.99826, thus demonstrating good linear regression. In addition, they show the values of the coefficients of the regression lines used to calculate the effusivity.

From relationship (1), the various effusivity values are determined. Their average gives the desired effusivity of the material. Table 4 shows the effusivity of the two types of material used in this work.

The results indicate that cow dung has a higher effusivity (E' = 517.32 J m^{-2}. $℃^{-1}$.$s^{-1/2}$) than its composite (E = 501.20 J m^{-2}. $℃^{-1}$.$s^{-1/2}$). Effusivity describes how quickly a material absorbs heat. In other words, the higher the effusivity, the more energy the material absorbs without heating up quickly, and the lower the effusivity, the faster the material heats up. So, the insulating properties of the composite structure come essentially from cow dung.



(a) (b)

Figure 13. *Regression lines for temperature rise curves for cow dung coating materials (a) and cow dung coating materials and oil palm leaf rachis fibres (b) for calculating effusivity E.*

Table 4. *Results of effusivity determination.*

Samples	Homogeneous materials			Composite materials		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Determination coefficient (R^2)	0.99187	0.99446	0.9950	0.99617	0.99477	0.99826
Effusivity E (J.m^{-2}. ℃$^{-1}$.s$^{-1/2}$)	495.154	549.189	507.613	515.718	488.821	499.015
Average Effusivity (J.m^{-2}. ℃$^{-1}$.s$^{-1/2}$)	517.319			501.185		

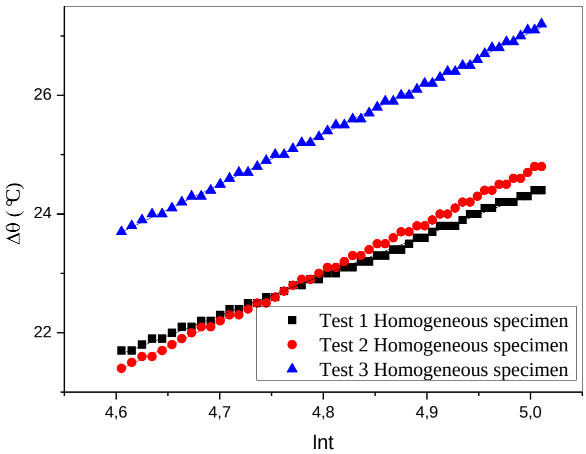
3.3.2. Calculating the Thermal Conductivity of Materials

Figure 13 show the regression lines of the curves showing the rise in temperature in materials coated with cow dung (a) and those coated with cow dung and oil palm leaf rachis fibres (b) over the time interval between 100 and 150 seconds.

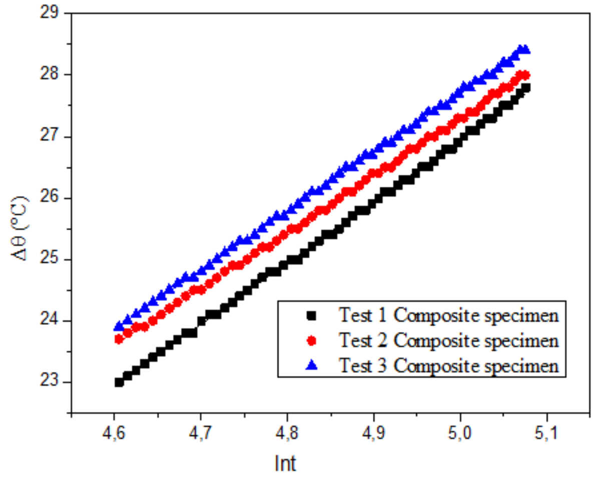
These Figs also show the coefficient of determination (R^2), which varies between 0.99762 and 0.99948. These R^2 values are very close to unity, so the linear regressions are very good. Next, the Figures show the values of the coefficients of the regression lines used to calculate thermal conductivity. The thermal conductivity values obtained indicate that the cow dung has a better conductivity (λ'=0.19 W.m^{-1}.K^{-1}) than the composite structure (λ=0.15 W.m^{-1}.K^{-1}). This indicates that the presence of a fibre frame has the effect of reducing thermal conductivity, with the advantage of improving the insulating properties of the material. This confirms the interest in using these cow dung-coated baskets for hot preservation purposes. The value of 0.15 W.m^{-1}.K^{-1} for the thermal conductivity of the composite material is within the range of known values for eco-materials. This could be explained by the intrinsic properties of the reinforcing materials in the composite. The presence of voids and the interaction between the cow dung matrix and the reinforcement provided by the oil palm leaf rachis fibres influence the thermal properties. Due to their smaller size, oil palm leaf rachis fibres should be well packed and allow a more uniform flow of matrix than cow dung. This will reduce voids and consequently reduce thermal conductivity. The thermal conductivity of composites depends not only on the inherent properties of the matrix and reinforcement, but also on the method of preparation and the structure of the composites.

Synthetic insulating materials have low thermal conductivity values, often between 0.029 and 0.040 W.m^{-1}.K^{-1}, while those from biomass and their composites rarely reach 0.060 W.m^{-1}.K^{-1} [1, 7]. Previous studies on the development of composites using feathers as reinforcement for polypropylene have reported a thermal conductivity of between 0.058 and 0.083 W.m^{-1}.K^{-1} [1]. A report by Mrajji *et al.* (2021) showed that feather-wool needle-punched carpets had a thermal conductivity of 0.031-0.046 W.m^{-1}.K^{-1}, lower than the values reported for wool alone (0.058 W.m^{-1}.K^{-1}) [9,10]. In another study, gypsum reinforced with wool or coconut fibres had a thermal conductivity 0.3 W.m^{-1}.K^{-1} higher than that of pure gypsum (0.17 W.m^{-1}.K^{-1}) [4].

The values of 0.15 W.m^{-1}.K^{-1} for the thermal conductivity of the composite material is within the range of biodegradable insulants such as light hardwoods (0.15 W.m^{-1}.K^{-1}), medium-heavy hardwoods (0.23W/m.K), very light hardwoods (0.12 W.m^{-1}.K^{-1}), light softwoods (0.12 W.m^{-1}.K^{-1}), medium-heavy softwoods (0.15 W.m^{-1}.K^{-1}) and very heavy softwoods (0.12 W.m^{-1}.K^{-1})



(a)



(b)

Figure 14. *Regression lines of temperature rise visualisation curves within cow dung plaster materials (a) and those of cow dung plaster and oil palm leaf rachis fibres (b) for the calculation of thermal conductivity λ.*

Table 5. *Thermal conductivity determination results.*

Samples	Homogeneous materials			Composite materials		
	Test 1	**Test 2**	**Essai 3**	**Test 1**	**Test 2**	**Essai 3**
Determination coefficient (R^2)	0.99762	0.99902	0.99892	0.99926	0.99927	0.99948
Thermal conductivity λ ($W.m^{-1}.K^{-1}$)	0.213	0.171	0.170	0.145	0.157	0.151
Average thermal conductivity λ (W.m^{-1}.K^{-1})	0.185			0.151		

3.4. Comparative Analysis

Table 6 presents a comparative study of results obtained with those of literature. It is noted that eco-insulating developed and characterized has better thermal performance compared to insulating based on vegetable fibers encountered in literature. Thermophysical properties of all insulating materials characterized with hot strip method used agree well with standardized thermophysical properties of insulating provided by literature [11]. This observation testifies to the quality of experimental device and reliability of results obtained.

Research has revealed approximately 0.15 W.m^{-1}.K^{-1} for light hardwoods, 0.23 W.m^{-1}.K^{-1} for medium-heavy hardwoods, 0.12 W.m^{-1}.K^{-1} for very light hardwoods, 0.12 W.m^{-1}.K^{-1} for light softwoods, 0.15 W.m^{-1}.K^{-1} for medium-heavy softwoods and 0.12 W.m^{-1}.K^{-1} for very heavy softwoods [12].

The vacuum insulation panels (VIP) offer one of the lowest thermal conductivity values available on the insulation market. The thermal conductivity of a vacuum board in its initial state is around 4 mW.m^{-1}.K^{-1}, whereas other conventional insulation materials such as expanded polystyrene (EPS) or mineral wool (MW) have a thermal conductivity of around 35 to 40 mW.m^{-1}.K^{-1} [5]. Lower thermal conductivity and higher effusivity enable planners to achieve higher insulation and more usable space, thus avoiding certain architectural integration problems [13].

This shows that the insulations in the present study are better than those of the insulating bio-material based on Parkiabiglobosa pod macerate and cow dung. However, the results are somewhat inferior to those of NF EN 316 fibreboard and Posidonia oceanica waste biosaturation.

Table 6. Comparative study of results obtained and those of literature.

Eco-materials	Thermal conductivity ($W.m^{-1}.K^{-1}$)	Thermal Effusivity ($J\ m^{-2}.\ ℃^{-1}.s^{-1/2}$)	Sources
Fiberboard NF EN 316 120 $g.L^{-1}$ - 180 $g.L^{-1}$ of néré pods	0.08 - 0.14	247.732 - 270.732	[6, 14]
Insulating Bio-material Based on the Macerate of "Néré" (Parkiabiglobosa) Pods and Cow Dung	0.181 - 0.186	561.068 - 562.508	[11]
Biosature of Posidonia oceanica waste	0,052 - 0,067	-	[15]
Homogeneous materials	0.170 - 0.213	495.154 - 549.189	This study
Composite materials	0.145 - 0.157	488.821 - 515.718	

4. Conclusion

Eco-materials have proven insulating properties. Their thermophysical characteristics are a very important criterion in assessing their thermal performance. These parameters provide indications for a judicious choice of insulating materials with a view to reducing heat transfer through food preservation enclosures. To this end, given the results obtained for the thermal conductivity (0.170 - 0.213 $W.m^{-1}.K^{-1}$) and (0.145 - 0.157 $W.m^{-1}.K^{-1}$) and effusivity of the composite material, it can be stated that the cow dung coatings and oil palm leaf rachis fibres used have insulating material properties. Thanks to the results obtained, the materials characterised in this work will be able to improve the energy efficiency of these food preservation enclosures.

From an ecological point of view, the material based on cow dung and fibres from the rachis of the oil palm leaf can make an effective contribution to limiting greenhouse gas emissions and protecting the environment compared with the use of synthetic enclosures. It would therefore be interesting to consider promoting and then popularising this model of biodegradable and economically accessible packaging.

Abbreviations

EPS: Expanded Poly-Styrene
MW: Mineral Wool
NF: Norme Française (French Norm)
EN: Norme Européenne (European Standard or European Norm)
φ_0: Electrical Power is the Watt (W)
R: Electric Resistance is Measured in Ohms
I: The Intensity of the Current is Measured in Amperes (A)
U: Electric Tension of the Current is Measured in Volt (V)

Disclosure Statement

Compliance with Ethical Standards

This article does not contain any studies involving human or animal subjects.

Acknowledgments

This work received no funding. No funding is available for open access publications from our institution or other sources.

Conflicts of Interest

The authors declare no conflicts of interest.

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