Thermal Conductivities of Selected Solid Waste Materials Determined Using Lees' Disc Method

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Abstract: **In this study, the coefficients of thermal conductivities have been determined. The goal was to find out the best insulator among the recyclable and locally available materials which can be adopted for use to replace the existing thermal insulation. Rice husks, dry grass, sawdust and old/used newspapers have been studied in this study using Lees' disc method. The results showed that grass can do best as an insulating material though all the samples can be used as insulators. They all have low thermal conductivities. The coefficient of thermal conductivities ranged from $\mathbf{0.226\ W/mK}$ for grass, $\mathbf{0.27\ W/mK}$ for saw dust, $\mathbf{0.50\ W/mK}$ for rice husks and $\mathbf{1.93\ W/mK}$ for newspaper cut-outs. Due to their local abundance, and no much competing commercial interest, we recommend the studied materials as suitable thermal insulators.**

KEYWORDS: Insulators, Insulation, Lees' Disc, Thermal, Conductivities

1 Introduction

Insulators are used to prevent heat exchange across the boundaries of shelters. Application of thermal insulation has been promoted as one of the best ways of improving energy efficiency and increase of thermal comfort well across different seasons in different regions of the globe [1,2,3,4]. For example, the European Union has decided to decrease the energy use for heating of buildings with 50% in 2050 [5]. This target is set to be achieved by increasing the insulation in the building envelope among other things [5].

Thermal insulation provides a region in which thermal conduction is reduced or thermal radiation is reflected rather than absorbed by the lower temperature body. Thermal materials performance change over time as material ages or environmental conditions changes [6]. The choice of suitable thermal insulating material is normally based on its thermal behaviour which includes the thermal conductivity, surface emissivity, specific heat capacity, density, insulation thickness, thermal bridging and thermal diffusivity [7,8]. A number of high performance thermal insulation material and components have been introduced to the building market during the last decades which can give the same thermal resistance using a thinner construction [9].

Thermal insulation is not a modern concept. A review by Bozsaky [10] gives a detailed account of the development of thermal insulation materials from use of soil(earth) in first dwellings, use of vegetable fibres in the 12th and 13th centuries, use of artificial materials like asbestos, foam glass and Polystyrene foam in the 20th Century, and the eventual overtaking of natural materials by plastic foams after 1950s. All these methods over the years have had their ups and downs. For example, asbestos produced noticeable health problems that led to the eventual ban in many countries of the world [11], [12], Aerogel provide good insulation bit is more expensive[13] etc. The plastic foams mostly polystyrene, polyurethane are products of fossils fuels. There is a factual fear that fossils fuel deposits are becoming depleted e.g. in china [14], has contributed heavily to climate change and global warming [15]. Due to these reasons demand for use of recycled materials and natural thermal insulation methods and materials is becoming popular again. These materials has been termed as unconventional sustainable building insulation materials [16], but are not or little commercialized and more continues to be invented [9],[17]-[20]. Natural materials have the advantage that they are environmental friendly, economical (in maintenance) and inexpensive(in installation) and locally available [21].

Some of the recycled materials studied for insulation properties include polyester fibres PET bottles [22],[23], other plastics e.g. PE, PP and PVC [24],[25], cellulose aerogels [26], glass foams and glass powder[27],[28] and textile fibres[29],[30]. Although these recycled materials have been shown their good workability as insulators, their recycling faces two major challenges; that municipal wastes is inhomogeneous and contaminated, hence increasing costs of separation and washing before use and there is a shift in manufacturing to focus more on durability not disposability of plastics.

Natural products that has been studies are reeds [31], bagasse, coconut husks[32], cattail [33], corn cob and stover [34], cotton [35], date palm [36], durian oil palm peel and fibre [37], pineapple leaves [38], sansevieria fibre [39], sunflower [40], and many others available at the local settings of study. These are recommendable for use near or in the areas where they are available to reduce the costs of transportation to far reach areas. The findings of the listed literature motivated this study. The study aims to study the thermal insulation capabilities of recyclable materials i.e. saw dusts, grass straws, rice husks and newspaper cuttings that are heavily underutilized in our local set up.

The Rice husk is a by-product of rice, the outer covering of rice grains and is obtained during the milling process. Rice husk constitutes 20% of the total rice produced. It has low commercial value due to its indigestibility, high silica content and hence not degradable in the soil. Its use, especially in its raw form will have a two pronged benefit, i.e. reduction of its waste piling with its consequential environmental problems, and possibly make an economical and efficient thermal insulation material. [41],[42]. Therefore the reasons behind the use of rice husk as insulator is its high availability, low bulk density, toughness, resistance to weathering and unique composition. Glass straws and saw dusts are easily obtained naturally and also underutilized. Saw dust is a waste from saw milling, and in Kenya, it is illegal to burn sawdust, and dumping it in a landfills has damaging consequences to the environments. Newspaper cuttings are also readily available. The study hypothesize that these materials will be suitable alternatives and the study is a contribution towards the reduced use or total elimination of the energy hungry home heating and air-conditioning systems. The study also compares the thermal conductivities of these recycled insulators and to study the effects to the performance by combine the insulators.

1.1 Thermal conductivity

The thermal conductivity (k) of a material measures he effectiveness of the material in conducting heat, depends on density, moisture content, temperature, direction of heat flow with respect to grains for fibrous materials, the presence of defects in the material and porosity. It is hence a measure of the resistance to heat flow. Thermal conductivity is well and often modelled to that of a disk. The rate of heat loss due to radiative cooling of the disk is equal to the rate of heat conducted through it. The rate of heat loss therefore can be therefore be determined by measuring the rate at which the disc cools at a steady state temperature T_1. If we take $\frac{dT}{dt}$ to be the rate at which the disc cools, then the heat loss rate of is:

$$H = mc\frac{dT}{dt} \quad (1)$$

Where m is the mass of the disc, c-specific heat capacity of the disc. Thermal conductivity and transmittance are used to define the insulation properties in steady state; for the unsteady the most used parameter is the thermal diffusivity D, that allow to compare the ability of materials to conduct and store thermal energy.

Insulators characterized by thermal conductivity under 0.05W/mK and specific heat over 1.4J/kgK can be considered best performing even in unsteady state condition. Thermal conductivity controls the rate of heat transfer by conduction in a steady state situation. The rate of heat transfer (H) by conduction is given by Fourier law:

$$H = kA\left[\frac{(T_2 - T_1)}{x}\right] \quad (2)$$

Showing that the heat transfer rate H is directly proportional to the cross sectional area A, temperature difference across the insulator, and inversely proportional to its thickness x. The rate of heat conduction at steady state through the sample will be equal to heat radiated per second.

$$kA\left[\left(\frac{T_2 - T_1}{x}\right)\right] = mc\left(\frac{dT}{dt}\right) \quad (3)$$

Therefore, k is defined as,

$$k = \frac{mc\left(\frac{dT}{dt}\right)}{\left[A\frac{(T_2 - T_1)}{x}\right]} \quad (4)$$

Where k is the coefficient of thermal conductivity of the sample, A is the circular area of the sample, x is the thickness of the sample, $T_2 - T_1$ is the temperature difference between the two opposite faces of the sample disc, m is the mass of the metallic disc, c is the heat capacity of the Lee's disc, $\frac{dT}{dt}$ is the rate at T_2 as mentioned above. Thermal diffusivity, δ which is the thermal conductivity of a substance divided by the product of its density and its specific heat capacity is therefore given as,

$$\delta = \frac{k}{cp} \quad (5)$$

Where the product cp is volumetric heat capacity expressed as: cp = specific heat capacity*density. The resistivity, is the inverse of the conductivity k, i.e.,

$$r = \frac{1}{k} \quad (6)$$

Thermal conductivity depends on many parameters such as the nature of the material, it's density, temperature, moisture content, material defects, porosity and direction of heat flow with respect to grains for fibrous materials.

2 Materials and Methods

The materials and apparatus used for this study were, prepared circular discs of rice husk, grass, sawdust and newspapers, Micrometer screw gauge, Mass balance, Retort stands, Heat source, Steam boiler, Water, Thermometers, Stopwatch and the Lee-disc apparatus. The experimental configurations were as shown in figure 1. Lee's disc apparatus consists of a disc resting on steam chamber of the same diameter, with steam inlet and outlet tubes. The disc also allows measurements of temperature through insertion of thermometers into it through provided hole spaces. The apparatus was arranged by connecting the steam boiler to the cylinder containing water placed at the Bunsen flame. The disc made of grass as insulator was placed between steam boiler and the good conducting metal disc and the set up allowed to come to equilibrium. The thermometers T_1 and T_2 were then inserted in the radial holes of the lee's disc. The heat source was switched on. The temperature T_1 and T_2 were read when the steady state was attained. T_1 and T_2 were then interchanged and their temperatures read again when the steady state was attained. The cylinder was removed and Bunsen flame allowed playing at the bottom surface of the slab until T_1 records a temperature higher than the temperature at steady state by 10°C.

Figure 1; Experimental Set-up. A shows how the apparatus was arranged. B shows the rice husk disc and C shows the newspapers disc placed on a mass balance.

The Bunsen flame was removed from the slab and the slab allowed to cool. The temperature will then be taken at 30 seconds interval. The procedure above was repeated for the other samples, that is, the sawdust, newspapers, rice husks and combined sample of newspapers and grass and combined sawdust and rice husks samples instead of grass. The diameters and thickness of the discs were measured. The mass of the metal slab was also determined. The cooling curves of all samples were plotted. Determination of the slope was done for each sample. k- the thermal conductivity will be calculated according to equation 4 above.

3 RESULTS AND DISCUSSION

3.1 Results

The data of the parameters measured as described above were obtained and recorded in tables, then the raw data was analyzed. The coefficients of thermal conductivities for saw dusts calculated applying equation 4 was $0.2704987\ W/mK$, and the cooling curve is as shown in figure 2. The curve has a negative instantaneous gradient with an average of $5.65\ x\ 10^{-3}\ °Cs^{-1}$.

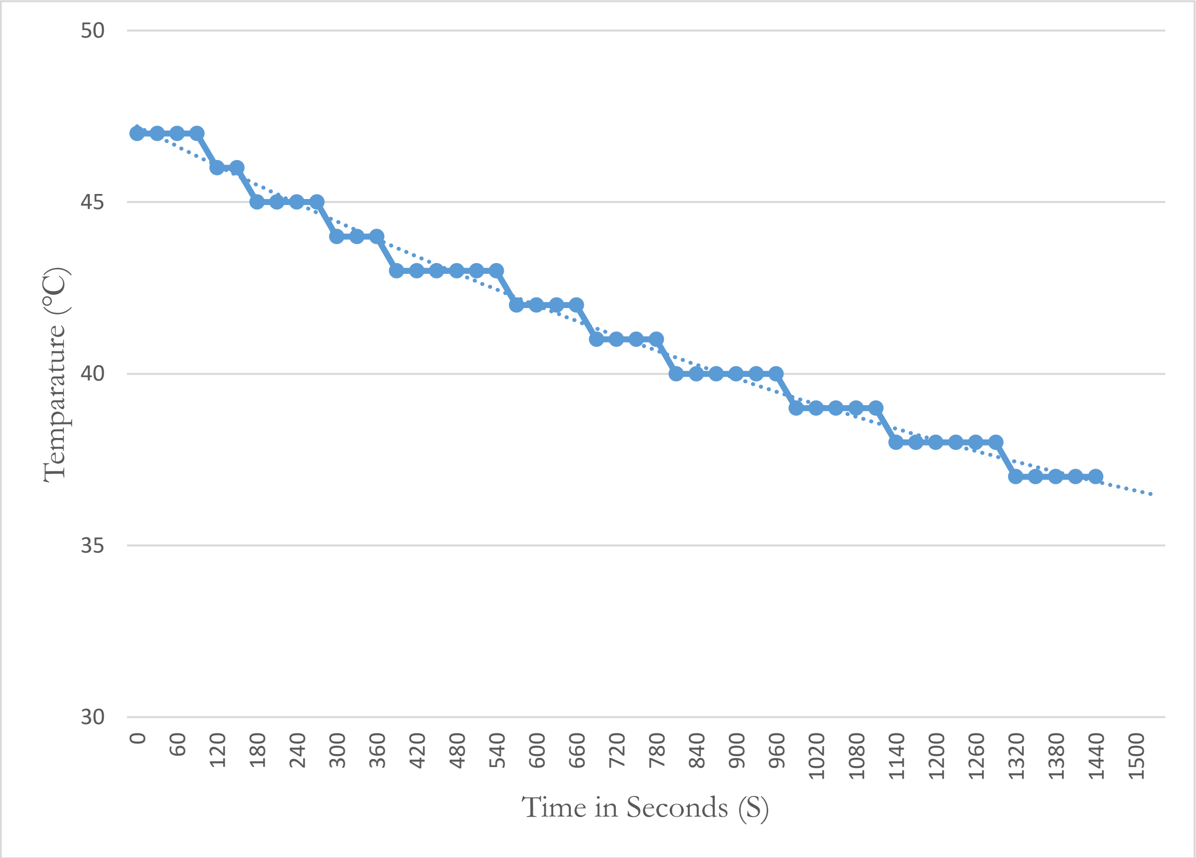

Figure 2: Cooling Curve for Sawdust

The slope gradient,

$$\frac{dT}{dt} = -5.65\ x\ 10^{-3}\ °\mathrm{C}\ s^{-1}$$

and hence the coefficient of thermal conductivity k,

$$k = \frac{0.041x900x(-5.65\ x10^{-3})}{(8.992x10^{-3})(-1.5/0.0175)} = 0.2704987\ W/mK$$

The cooling curve for rice husk is presented in figure 3, and the coefficients of thermal conductivities as calculated grass was 0.50165W/mK. The curve has a negative instantaneous gradient with an average of $6.00\ x\ 10^{-3}\ °\mathrm{C}s^{-1}$ and approximately equal to that of saw dust.

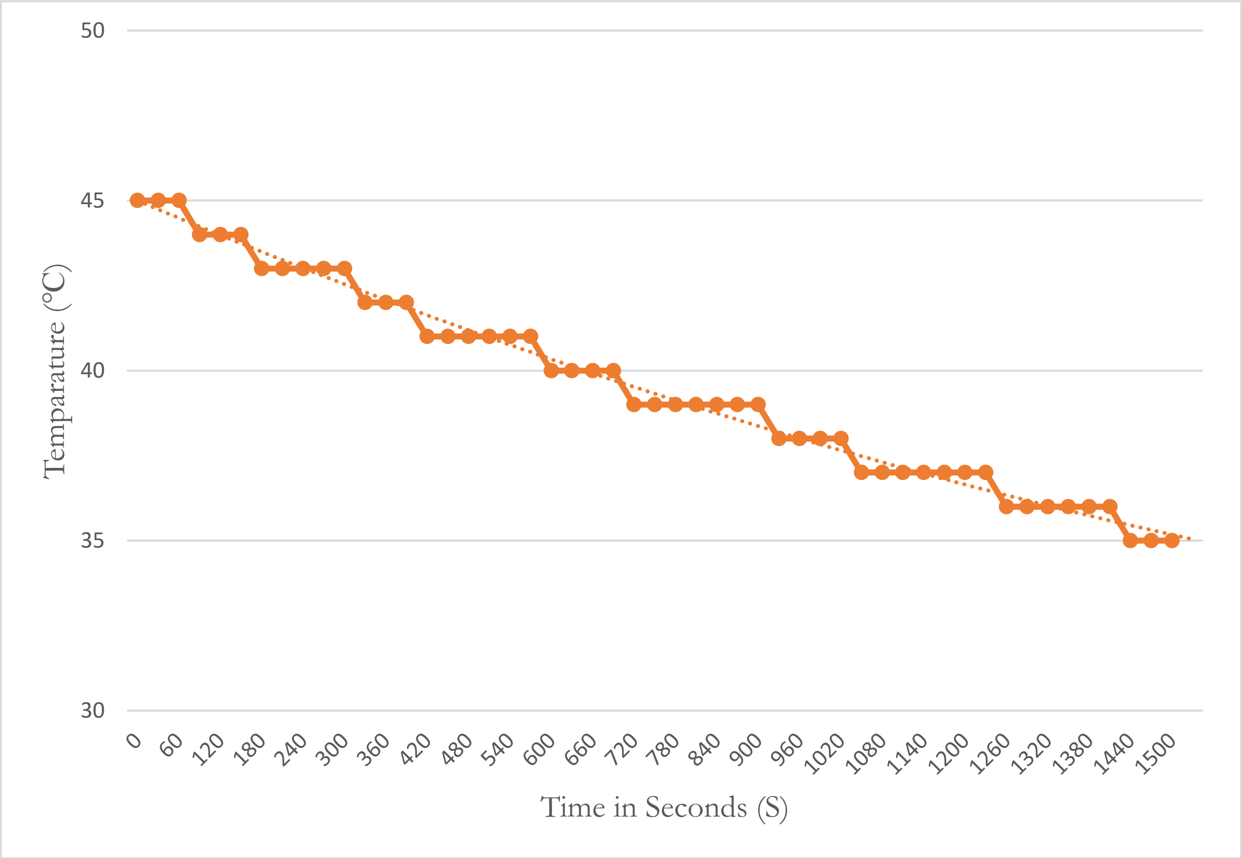

Figure 3; Cooling Curve for Rice husks

The slope gradient,

$$\frac{dT}{dt} = -6.00\ x\ 10^{-3}\ ℃\ s^{-1}$$

and hence the coefficient of thermal conductivity k,

$$k = \frac{0.033833\ x\ 1270\ x(-6.00\ x10^{-3})}{(8.992x10^{-3})(-1/0.0175)} = 0.50165\ W/mK$$

The cooling curve for grass is presented in figure 4, and the coefficients of thermal conductivities as calculated grass was 0.226653 W/mK. Similarly the curve has an negative instantaneous gradient with an average of $-4.17\ x\ 10^{-3}\ ℃s^{-1}$.

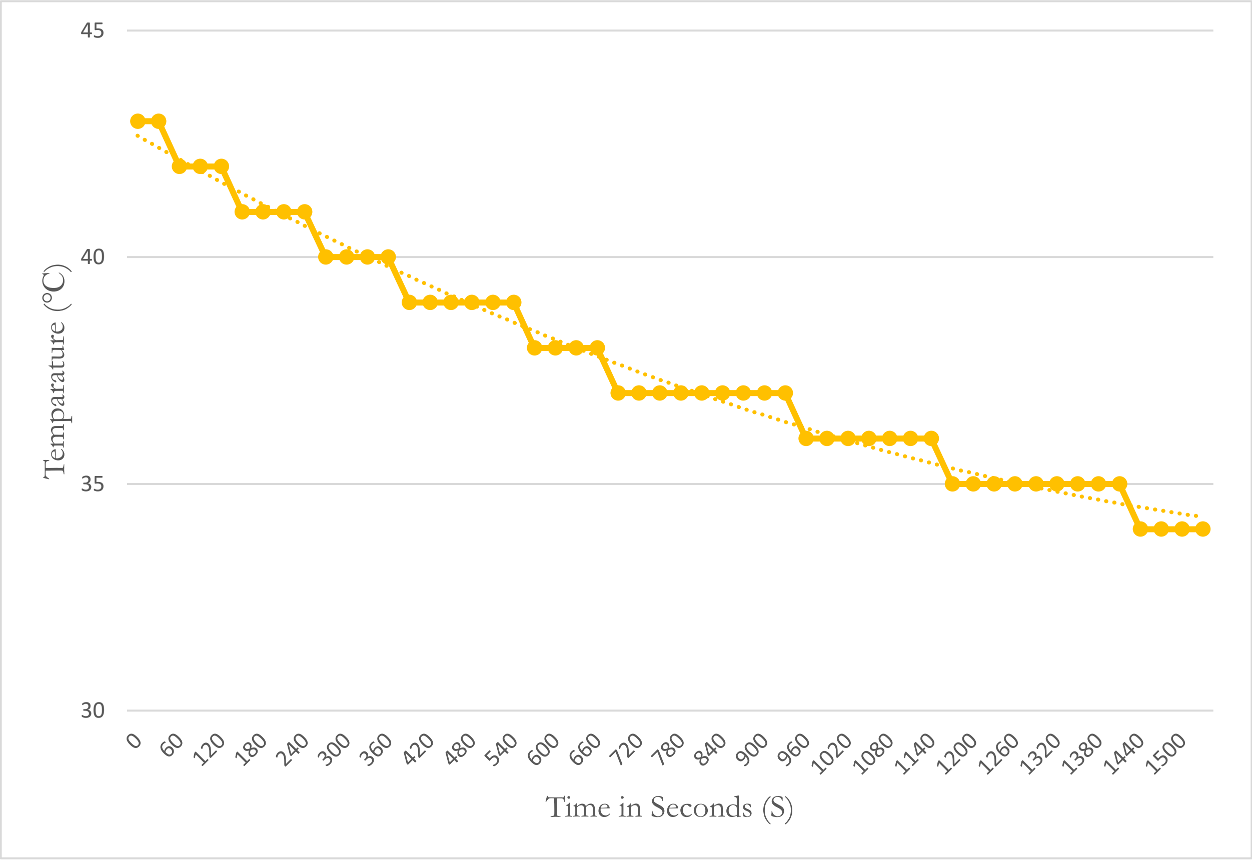

Figure 4; Cooling Curve for Grass

The slope gradient,

$$\frac{dT}{dt} = -4.1667\ x\ 10^{-3}\ °\mathrm{C}\ s^{-1}$$

and hence the coefficient of thermal conductivity k,

$$k = \frac{0.021667x1290x(-4.1667\ x10^{-3})}{(8.992x10^{-3})(-1/0.0175)} = 0.226653\ W/mK$$

The coefficients of thermal conductivity for newspaper cut-outs calculated using equation 4 was $1.93844W/mK$. The cooling curve for the newspaper cut-outs is as shown in figure 5. This study also sought to investigate the effects of mixing two insulation materials and report on their performance as compared to a single insulator.

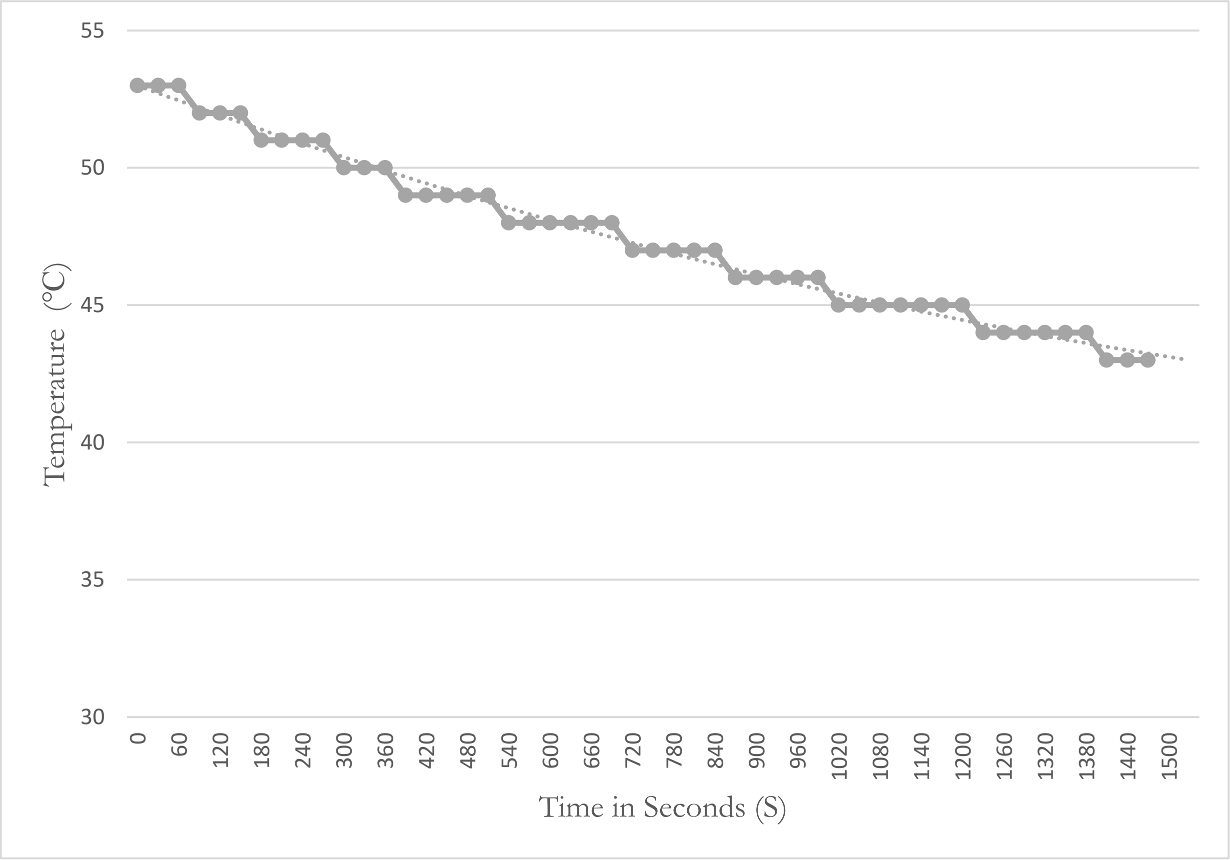

Figure 5: Cooling Curve for Newspaper Cut-outs

Figure 6 shows the cooling curve of combined sawdust and rice husks.

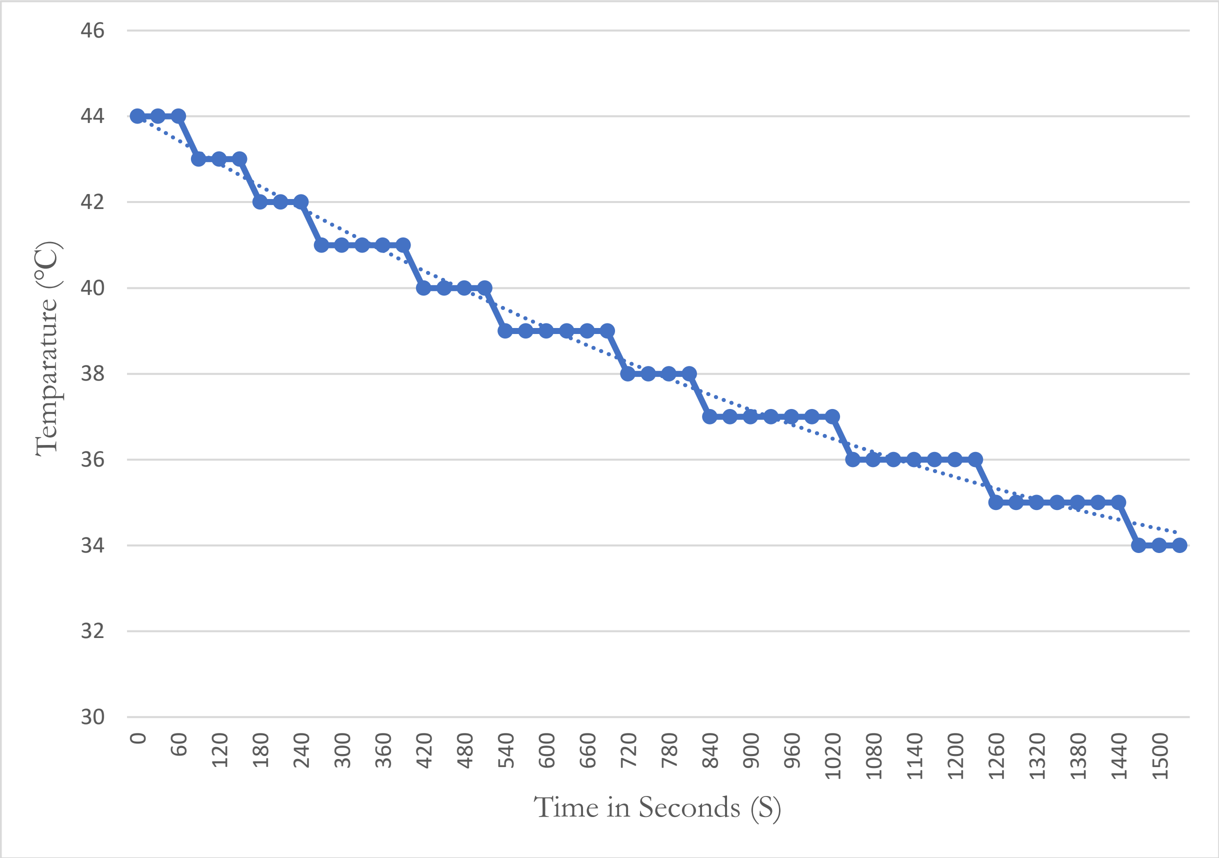

Figure 6; Colling curve for Sawdust and Rice Husks Combined

The slope gradient,

$$\frac{dT}{dt} = -5.75\ x\ 10^{-3}\ °C\ s^{-1}$$

and hence the coefficient of thermal conductivity k,

$$k = \frac{0.035\ x\ 1085\ x(-5.75\ x10^{-3})}{(8.992x10^{-3})(-1.5/0.0175)} = 0.2833152\ W/mK$$

The curve indicates a change of the cooling rate. The combined materials cools slower than rice husks alone. The cooling curve for newspapers combined with grass is as shown in figure 7.

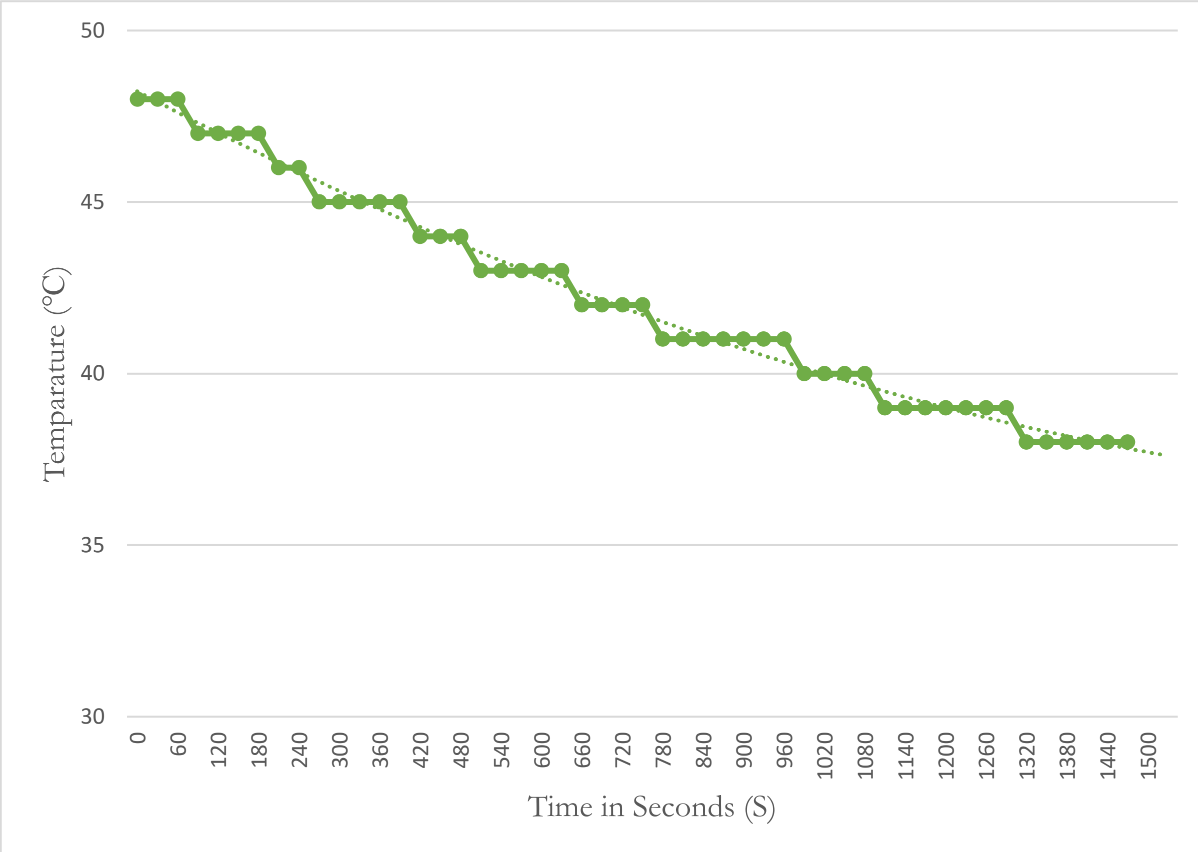

Figure 7; Cooling Curve for Grass and Newspaper cut-outs combined

The slope gradient,

$$\frac{dT}{dt} = -6.0\ x\ 10^{-3}\ °C\ s^{-1}$$

and hence the coefficient of thermal conductivity k,

$$k = \frac{0.0227x\ 1345\ x(-6.0\ x10^{-3})}{(8.992x10^{-3})\left(-\frac{1.5}{0.0175}\right)} = 0.23768\frac{W}{mK}$$

This motivated us then to compare the coolinng curves for all the materials and its is presented I figure 8.

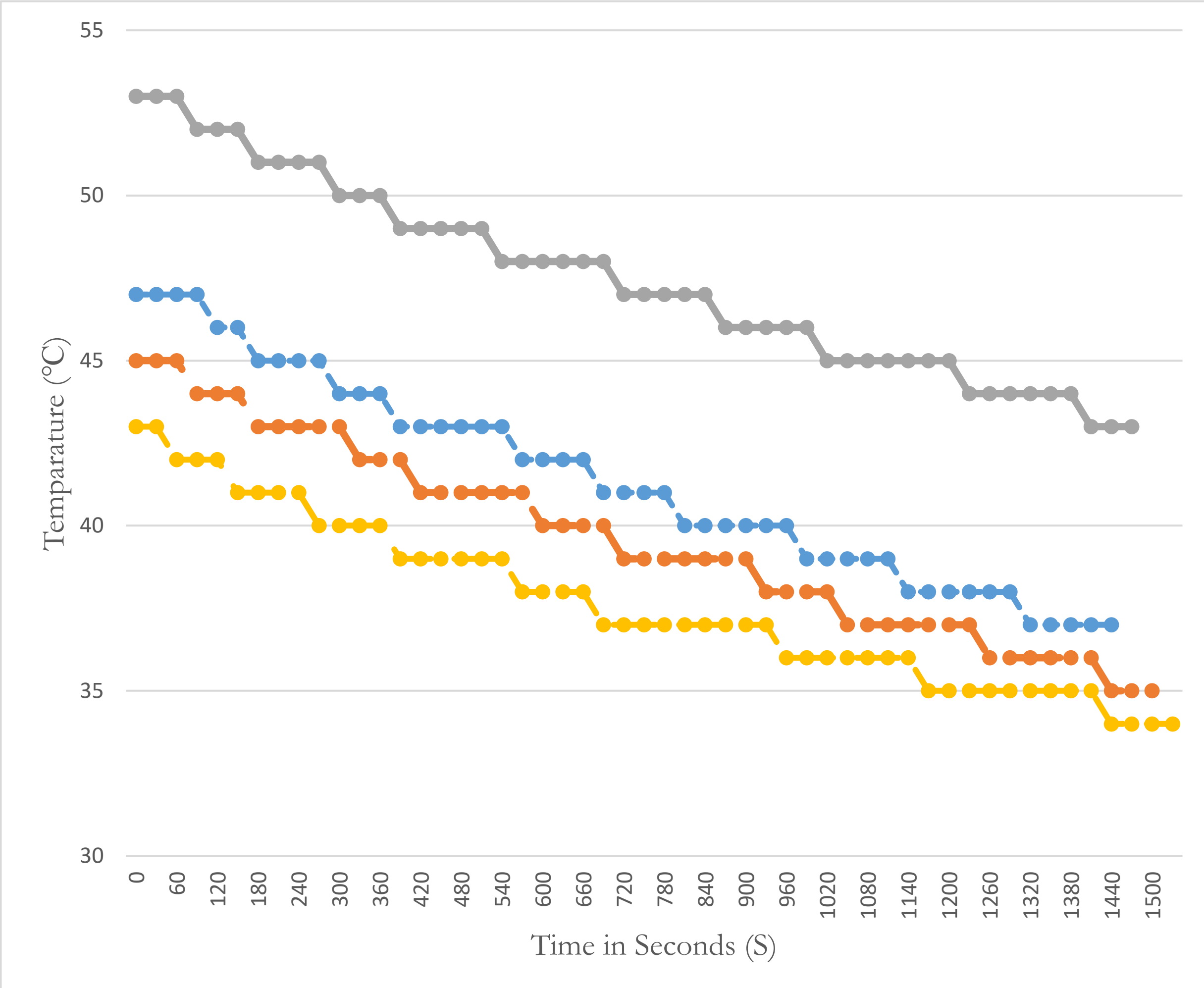

Figure 8; Cooling Curves for Newspaper cut-outs, Rice husks, Sawdust and Grass plotted on the same set of axis

Fig 8 shows the cooling curve of all the samples

The curves clearly indicate how each sample is cooling. It compares the performance of all the samples as insulator.

3.2 Discussion

The cooling curves of the studied materials have a similar cooling pattern. The gradient cooling curves range is narrow, ranging from $-5.65\, x\, 10^{-3}\, ℃\, s^{-1}$ for rice husks to $-4.16\, x\, 10^{-3}\, ℃\, s^{-1}$ for grass. When sawdust was combined with rice husks, the gradient was $-5.65\, x\, 10^{-3}\, ℃\, s^{-1}$ and when newspaper cut-outs were combined with grass the gradient was $-6.00\, x\, 10^{-3}\, ℃\, s^{-1}$. A higher negative gradient means that the sample cooled faster, and hence a 'poorer' insulator. The coefficient of thermal conductivities ranged from $0.226\, W/mK$ for grass, $0.27\, W/mK$ for saw dust, $0.50\, W/mK$ for rice husks and $1.93\, W/mK$ for newspaper cut-outs. From the analysis, the results show that grass can perform best as an insulator with the coefficient of 0.226653 W/mK, followed by sawdust with 0.2704987 W/mK, then rice husk with 0.50165W/mK, and finally the newspapers is the least performing with 1.93844 W/mK. For the combined saw dusts and rice husks the coefficient was $0.28\ W/mK$ and for combined newspaper cut-outs with grass , it was $0.23\ W/mK$. Combination of newspapers and grass perform better as insulator than the mixture of sawdust and rice husk with 0.0.23768 W/mK and 0.2833152 W/mK respectively. Asdrubali [16] reports that a material is usually considered as a good thermal insulator if its conductivity is lower than 0.07 W/mK. In general, all the samples are insulators, but not as good as other insulators. In fact the near perfect thermal insulation is for vacuum insulated panels (but very expensive) with thermal conductivity of about 0.008 W/mK and thermal conductivity of some wood fibre with thermal conductivity of 0.061 W/mK. The study materials are therefore not as good insulators as the recycled plastic materials insulators reported in literature. This is in agreement with literature findings that product made of recycled-materials are characterized by better thermal insulation performance compared to the natural ones [16]. Bearing in mind that there are other factors other than thermal performance to consider when selecting insulating materials such as, Cost, Ease of construction, safety and health issues, durability, acoustical performance, air tightness, Environmental impact and Availability [42], we cannot rule the materials studied here out as applicable thermal insulators. Despite their poor performance natural materials use is expected to lead to a reduction of economic and environmental impacts. Rice husks use for example would not conflict with food production, but ultimately led to elimination of a potential pollutant when left unutilized. They will reduce the use of oil-based and not renewable sources. However, these materials could be susceptible to natural degradation mechanism, attack by weevils and other insects, fugal and other microbes attack, and this need to be investigated.

4 Conclusion

We recommend that these materials be adopted for use as thermal insulators since their coefficients of thermal conductivities are low, they are cheap, sometimes of no other commercial use and are locally available.

4.1.1.1 Declaration:

Acknowledgments: Chuka University Physics Laboratory
Study Limitations: None
Ethical Approval: Not required.
Informed consent: Did not use human specimens
Funding source: None
Competing interests: Authors declares no conflict or competing of interests

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W. S. Author, "Title of paper," Name of Journal in italic, vol. x, no. x, pp. xxx-xxx, Abbrev. Month, year. doi or URL (link)

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