Investigating New Thermal Insulators Based on Cheap Natural Organic and Waste Materials: Part 1

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Abstract. Thermal insulation is a very important way to save energy in buildings or any other thermal application. For buildings, thermal insulation minimizes the heat transfer rate between a conditioning zone and its surroundings. For thermal applications, such as thermal storage tanks, it keeps heat or cold stored for later use. The current study is part of a project investigating thermal insulators made from cheap natural, organic and waste materials. The thermal conductivity of six different specimens of thermal insulator, made from used water cotton filter, chicken feather, walnut shell, sunflower seed husk, sawdust and ash, was measured experimentally. Industrial white glue was used as a binder to prepare the specimens. The sawdust and ash, of which the thermal conductivities are known, were chosen to validate the geometry of the specimens as well as the measurements of the testing device. The results showed that all types provide good thermal resistance performance. In particular, the insulator made from used water cotton filter was the best. It provided 0.0277 W/m K, which is a very practical value of the thermal conductivity in thermal insulation applications. This study will contribute significantly to sustainability by recycling wastes or using abundant natural and cheap materials in thermal insulators.

Keywords: Thermal insulation, Thermal resistance, Thermal conductivity

1. Introduction

The thermal insulator has an important role in reducing heat transfer between two zones having different temperatures. Buildings consume a high portion of the global energy for air conditioning [1] throughout all seasons but especially during summer and winter – unless roofs and walls are insulated well. Commonly, industrial insulators such as polystyrene, fiberglass, polyurethane foam, mineral wool and cellulose are used for thermal insulating purposes. Although polystyrene, for instance, has high thermal resistance, low water absorption, light weight and recycling characteristics, it has several disadvantages such as flammability, toxicity and poor strength [2]. Also, those types of insulator are produced using several chemical processes, producing harmful emissions, and they are relatively costly. Thus, researchers have recently shown increasing interest in producing thermal insulators based on natural and waste materials. Most modern studies have focused on using agricultural waste products, while others have been interested in industrial waste materials, and rarely, studies have used waste materials from animals.

Jiri et al. [3] investigated six samples generally made from fiber jute, fiber flax and fiber hemp, and the results showed that their thermal conductivity was relatively less than 0.05 W/m K. In the same field of using plant fibers, Zach et al. [4] modified an insulator made from hemp fiber to resist water absorption. In their research, nine samples were investigated, and they found that their thermal conductivity was between 0.04363-0.05053 W/m K. An insulator made from cattail fibers was investigated by Luamkanchanaphan et al. [5], and their thermal conductivity was in the range (0.0438-0.0606) W/m K. Pinto et al. [6] studied a thermal insulator based on cob-corn, and they found that it provided good thermal insulation characteristics of 0.139-0.05 W/m K.
Four samples of wheat straw were studied by Miron et al. [7] using lime, cement, glue or plaster as a binder. Regarding thermal insulating characteristics, the sample of straw and glue provided 0.124 W/m K. While straw with lime had 0.355 W/m K and the others were in between the two mentioned values. Tůmová et al. [8] prepared and tested ten samples from rye straw using casein as a binder in different weight ratios. The thermal conductivity of those samples was recorded as 0.045 to 0.056 W/m K. To examine a broad material type, Bakatovich et al. [9] used straw of rye, barley, wheat, oats, rice, flax, boon and rice husk as bases for raw insulating materials and three types of binder such as liquid glass, emulsion of polyvinyl acetate and latex. Thirteen specimens were prepared in their study. Seven were made from only the mentioned materials and bonded by liquid glass, while the rest were mixtures of two materials and the other binders mentioned. The thermal conductivity was in a range between 0.049 to 0.069 W/m K.

Also using agriculture products, Oushabi et al. [10] investigated seven specimens made from fibers taken from seven different local date palm trees planted in Errachidia Oasis, Morocco. The results of thermal conductivity of those specimens was relatively 0.041 W/m K. Boulaoued et al. [11] introduced two new insulators that consisted of cement mixed with five different ratios of either palm tree fiber or seaweed fiber. The results showed that the thermal conductivity decreased when the fiber ratio increases. Cardinale et al. [12] investigated the performance of thermal insulation of four specimens made from cement with reed, with wheat straw and with both. All made specimens were compared with a reference one made from cement only. The measurements showed that the combination of the three materials provided better insulating performance.

The mixing of materials obtained from plants and animals is also of interest to researchers. Pennacchio et al. [13] examined a mixture of hemp and wool to introduce a new insulating product. In their study, four samples were prepared form 100% wool (low density), 80% wool+20% hemp, 100% wool (high density) and 50% from both wool and hemp. The results showed their thermal conductivity to be almost 0.04 W/m K. Similarly, Binici and Kekili [14] investigated ten samples of composite materials based on sunflower stalk, wheat stalk, hair of goat and wool of sheep as well as materials that were added to those based materials in different mixing ratios, to enhance the structure and fire resistance. The results regarding the thermal conductivity for all samples were in the range of 0.079-0.121 W/m K.

The use of mixtures from industrial and plant materials to introduce a new insulators was conducted by Onat et al. [15], when they examined nine samples of composite materials consisting of E-glass mat, walnut shell and bi-axial fabric in which their percentages and walnut shell particle size were changed from one sample to another. The study found that the thermal conductivity of those samples ranges from 2.89 to 3.70 W/m K. Liuazzi et al. [16] investigated four composite samples made from clay (about 37%), sand (54%), gravel (2%) and four weight percentages of olive tree fibers. The results showed thermal conductivity to range between 0.428 and 0.593 W/m K. Cesconeto et al. [17] measured the thermal conductivity of samples prepared for their study made from waste glass of soda bottles and banana leaves. The results were in the range of 0.06-0.15 W/m K.

Some studies have focused on recycling waste materials to make insulators. Tsouisi et al. [18] they introduced a new porous concrete which has better thermal resistance that the traditional one, based on perlite waste material. In the same field, Almadi et al. [19] modified the traditional mixture of brick (clay and water) by adding other natural and waste material such as zeolite, steel slag and expander perlite with different ratios to create eight samples in addition to a reference sample which was made from clay and water only. In terms of thermal conductivity, the results ranged between 1.07 W/m K (for the reference) and 0.12 W/m K (for a sample made from 50% perlite, 15% zeolite, 7.5% waste steel slag, 17% water and 2 kg of clay). Romero-Flores et al. [20] examined the thermal insulating performance of a sample made from scrap tire pieces bonded by glue, and they found that the average value of thermal conductivity to be 0.1152 W/m K.

The current study is a part of a project aiming to introduced thermal insulators based on natural, waste and cheap materials. Six specimens were prepared from used cotton water filter, chicken feather, walnut shell, sunflower seed husk, sawdust and ash. White industrial glue was used as a binder to
strengthen the structure of specimens. Sawdust and ash, of which the thermal conductivities are already known, were prepared and tested for validation purposes. This study focused on finding the thermal conductivity and density of the prepared specimens.

2. Methodology

2.1 Thermal Conductivity Measuring Device

A picture and a schematic diagram of the Hilton-B480B unit are shown in Figure 1 (a and b). The unit is located at the Lab of Thermals in the Engineering College at the University of Kerbala, Iraq and was used in the current study to find the thermal conductivity of materials. It consists of an enclosure case including hot and cold plates, loading mechanism, temperature sensors and controller. The cold plate is mounted on four springs and cooled by coolant water with a relatively constant temperature to be maintained in sensible isothermal conditions. The hot plate is controlled by an electrical heater set to a desired temperature. It is raised and lowered by the loading mechanism, which presses a specimen between the two plates at the operating pressure. Also, this mechanism has a gauge to measure a specimen’s thickness (t). The maximum allowable temperature of the hot plate is 100 °C, and the temperature difference between the hot and cold plates is recommenced to be in range 15 - 20 °C. Foam insulation surrounds the heat flowmeter zone to minimize heat losses. This unit work by using the heat flowmeter method. By measuring the mean (\(\bar{T}\)) temperature, the output heat flowmeter (HFM) and thickness of a specimen, a thermal conductivity can be calculated by equation (1) [21].

\[
k = \frac{t \left[ (C_1 + (C_2 \cdot T_h) + (C_3 + (C_4 \cdot T_c) \cdot HFM) + ((C_5 + (C_6 \cdot T_h) \cdot HFM)^2) \right]}{\Delta T}
\]

Where: \(k\) is the thermal conductivity (\(W/mK\)), \(t\) is specimen thickness (m), \(\bar{T} = \frac{T_h + T_c}{2}\) (°C), \(HFM\) is heat flowmeter reading (mV), \(\Delta T = T_h - T_c\) (°C) and \(C_1, C_2, C_3, C_4, C_5\) and \(C_6\) are the calibration constants -31.7383, 0.4792, 6.6346, 0.0558, 0.0279 and -0.0005 respectively [21].

Figure 1. (a) A picture of the Hilton-B480B unit with the main components:

1. Hot Plate
2. Cold Plate
3. Main Switch
4. HFM Indicator
5. Temperature Indicator
6. Loading Indicator
7. Loading Mechanism
8. Coolant Water In/Out
2.2 Weighing Device

A picture of Denver Maxx 5001 scale is shown in Figure 2. Its maximum capacity is 5000 g with accuracy of \( \pm 0.2 \) g. It was used to find the weight of each individual prepared specimen, then to calculate its density by equation (2) after calculating its volume.

\[
\rho = \frac{M}{V}
\]  

(2)

Where: \( \rho \) (kg/m\(^3\)), \( M \) (kg) and \( V \) (m\(^3\)) are the density, mass and volume of a prepared specimen.

![Figure 2. A picture of weighing device](https://example.com/figure2.jpg)

2.3 Specimens Preparation

Six specimens were prepared from used cotton water filters, chicken feather, walnut shells, sunflower seed husk, sawdust and ash. Figure 3 shows the process of preparation. Some of used cotton water filters were chopped into small pieces with an average dimensions of 10×10 mm. The chopped filler was mixed with glue at a ratio of 1/0.25 material/glue volume fraction and compressed between sheets obtained from the same filters into the mold, under a suitable load. After that, the cast specimen was left to dry under sunshine for two days. The same procedure was used to prepare the other specimens, with some differences according to the materials used as declared in Figure 3.
Figure 3. Processes of specimen preparation: (a) used cotton water filter, (b) chicken feather, (c) sunflower seed husk, (d) walnut shell, (e) sawdust and (f) ash.
2.4 Measuring Process

Calculating the thermal conductivity of the six composite specimens prepared from different six materials mentioned above with glue was conducted depending on measuring the required parameter for equation (1). Those parameters were measured by the Hilton-B480B device shown Figure 1, as follows:

- Turning on the device and making sure that coolant water cycle valves are open.
- Inserting a specimen between the two silicon mats provided with the device and putting the combination on the cold plate then closing the enclosure.
- Lowering the hot plate by the loading mechanism until the loading indicator is being extinguished.
- Setting the hot plate at 50 °C.
- Waiting for appropriate time (90-120 min) to allow the unit to reach stability in which the hot and cold plate temperatures, along with heat flowmeter measurements, are stable.
- Recording all required measurements and using equation (1) to calculate the thermal conductivity for a specimen by using the Excel program.

3. Results and Discussion

Thermal conductivity values for six different materials (e.g. used water cotton filter, chicken feather, walnut shell, sunflower seed husk, sawdust and ash) were obtained in this study. Table 1 shows the specimens’ dimensions and density, with a comparison between the obtained current results with the minimum value of thermal conductivity obtained by some of the previous studies mentioned. It shows that the current study obtained the lowest value of thermal conductivity of a specimen prepared based on used cotton water filter, compared with all other materials used in the given study and the mentioned studies.

Table 1. Thermal conductivity of current investigated materials comparing with others tested in previous studies.

| Material                                | l × w (m) | t (m) ± 0.001 | ρ (kg/m³) | k (W/m K) | Source                          |
|-----------------------------------------|-----------|---------------|-----------|-----------|---------------------------------|
| Waste water cotton filter               | 0.3×0.3   | 0.03          | 214       | 0.0277    |                                 |
| Chicken feather                         | 0.3×0.3   | 0.03          | 214       | 0.0478    |                                 |
| Walnut shell                            | 0.3×0.3   | 0.03          | 626       | 0.0890    | Current study                   |
| Sunflower seed husk                     | 0.3×0.3   | 0.03          | 241       | 0.0927    |                                 |
| Sawdust                                 | 0.3×0.3   | 0.03          | 274       | 0.0933    |                                 |
| Sawdust                                 | -         | -             | 224       | 0.0700    | [22]                            |
| Ash                                     | 0.3×0.3   | 0.03          | 401       | 0.1508    | Current study                   |
| Ash                                     | -         | -             | 740       | 0.15-0.3  | [22]                            |
| Fiber jute                              | -         | -             | 26.1      | 0.0482    |                                 |
| Fiber flax                              | -         | -             | 32.1      | 0.0442    | Jiri et al.                     |
| Fiber hemp                              | -         | -             | 29.6      | 0.0488    |                                 |
| Narrow-leaved cattail fiber             | -         | -             | 200-400   | 0.0438-0.0606 | Luamkanch-anaphan et al.   |
| Wheat straw + lime                      | -         | -             | 1002      | 0.199     | Miron et al.                    |
| Rye straw + casein                      | -         | -             | 72-92     | 0.056-0.045 | Tůmová et al.                   |
| Rye straw and flax boon + liquid glass  | -         | -             | 225       | 0.049     | Bakatovich et al.               |
| Palm tree fibers                        | -         | -             | -         | 0.035     | Boulaoued et al.                |
| Seaweed fibers                          | -         | -             | -         | 0.049     |                                 |
Figure 4 shows the values of thermal conductivity obtained from the current study. The insulator based on used cotton water filters provides the minimum of thermal conductivity, compared with other insulating materials used in this study. The chicken feather insulating property came in second place. The specimens made from wooden materials such as walnut shell, sunflower seed husk and sawdust showed almost the same thermal insulating characteristics. Ash gave the lowest thermal insulating property, possibly due to loss of fibers during the burning process.

![Figure 4. Thermal conductivity of insulating materials used in this study.](image)

4. Conclusion

Thermal insulators help to reduce energy consumption in the heating and cooling of buildings. Introducing insulators based on waste and natural materials could make a valuable contribution to sustainability. This study investigated, for the first time according to the authors’ literature review, used water cotton filter, waste chicken feather, waste walnut shell and sunflower seed husk. The best insulating material was the used cotton water filter, which provided 0.0277 W/m K of thermal conductivity while the wooden materials provided thermal conductivity in a range between 0.089 to 0.0933 W/m K. It is recommended that waste materials from animals be investigated for a similar purpose. This research is part of a project aiming to introduce very good thermal insulators based on abundant, waste, cheap and environmentally friendly materials.

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