Thermal insulators based on abundant waste materials

B A Alhabeeb¹, H N Mohammed¹ and S A Alhabeeb²

¹Department of Mechanical Engineering, College of Engineering, University of Kerbala, Kerbala, Iraq
²Department of Refrigeration and Air-conditioning Technologies, College of Engineering, University of Warith Alanbiyaa, Kerbala, Iraq

E-mail: baqer.a@uokerbala.edu.iq

Abstract. Any airconditioned zone must be thermally insulated from its surroundings to maintain the desired temperature. Thermal insulators thus play a significant role in reducing heat transfer between airconditioned areas and their surroundings to save energy. Thermal insulators are usually made from materials with low thermal conductivity, and to reduce the cost of such insulators, this study investigated the use of waste organic materials as thermal insulators. This study is the second part of a project that aims to achieve an optimised insulator from both the thermal and economic perspectives. To achieve this, the heat conductivity of five different samples made from hair, grass, date seed, and date palm fibre were examined. The all samples were made with industrial white glue as a binder. The heat flow method was employed to determine their thermal conductivity, with results that showed that all samples offered thermal resistance to heat transfer in the range 0.0530 to 0.1068 W/mK. The best thermal resistance was provided by the sample made from hair and fibres. The current study supports sustainability by encouraging the use of waste organic materials in thermal insulators.

Keywords: thermal insulators, natural materials, wastes, thermal resistance

1. Introduction

Thermal insulators made from waste materials have become an interesting research field for several researchers recently. Waste materials may be classified as organic and nonorganic, with organic waste materials coming from plants and animals, while nonorganic waste materials are obtained from nature or industry. The relevant literature review suggested that most previous studies in this area have focused on using waste materials produced from plants rather than other sources, with studies [1-11] using waste materials from plants. Other studies [12-14] have used materials obtained from both plants and animals, while some studies [15-26] have investigated samples made from materials obtained from plants in conjunction with nonorganic industrial waste. Table 1 shows the details of the studies examined.
| Study                  | Material                                      | Sample density $\rho$ (kg/m$^3$) | $\lambda$ (W/m K)       |
|-----------------------|-----------------------------------------------|----------------------------------|--------------------------|
| Jiri et al. [1]       | jute fibres                                  | 26.1                             | 0.0482                   |
|                       | flax fibres                                  | 32.1                             | 0.0442                   |
|                       | hemp fibres                                  | 29.6                             | 0.0488                   |
| Zach et al. [2]       | hemp fibres                                  | 30-40                            | 0.0436-0.0711            |
| Luamkanch-anaphan et al. [3] | narrow-leaved cattail fibres | 200-400                          | 0.0438-0.0606            |
| Pinto et al. [4]      | cob corn                                      | ---                              | 0.139                    |
| Tůmová et al. [5]     | rye straw + casein                            | 72-92                            | 0.056-0.045              |
| Bakatovich et al. [6] | flax boon and rye straw + liquid of glass     | 225                              | 0.049                    |
| Oushabi et al. [7]    | date palm fibres                              | ---                              | 0.041                    |
| Bouloued et al. [8]   | palm tree fibres                              | ---                              | 0.035                    |
|                       | seaweed fibres                                | ---                              | 0.049                    |
|                       | husk of rice                                  | 378                              | 0.08                     |
|                       | husk of wheat                                 | 448                              | 0.10                     |
| Muthuraj et al. [9]   | fibres of wood                                | 454                              | 0.11                     |
|                       | fibres of textile                             | 488                              | 0.14                     |
|                       | rapeseed                                      | ---                              | 0.048                    |
|                       | woodchips                                     | ---                              | 0.065                    |
|                       | barley straw                                  | 210-220                          | 0.066-0.075              |
| Palumbo et al. [11]   | corn pith                                     | 80-160                           | 0.052-0.067              |
|                       | rice husk                                     | 210-290                          | 0.073-0.098              |
| Pennacchio et al. [12]| sheep wool + hemp fibres                      | 21-142                           | 0.038-0.041              |
| Binici and Kekili [13]| stalk, goat hair and sheep wool               | 740-1230                         | 0.079-0.121              |
| Dieckmann et al. [14] | chicken feather                               | 59                               | 0.033                    |
| Adazabra et al. [15]  | clay brick + spent shea waste                 | ---                              | 0.2-0.8                  |
|                       | fired brick (ball clay, ash, husk of rice, ash of rice husk ash and fired wasted grog) | ~1130-1980                      | ~ 0.5-3.75               |
|                       | waste cotton refiner                          | 214                              | 0.0277                   |
|                       | feather of chicken                            | 214                              | 0.0478                   |
|                       | shell of walnut                               | 626                              | 0.0890                   |
|                       | husk of sunflower-seed                        | 241                              | 0.0927                   |
|                       | saw dust                                      | 274                              | 0.0933                   |
|                       | ash of saw dust                               | 401                              | 0.1508                   |
| Alhabeeb and Mohammed [17]| wheat straw + lime                        | 1002                             | 0.199                    |
| Miron et al. [18]     | e-glass fibres + bi-axial fibres + walnut peel | ---                              | 2.89-3.70                |
| Onate et al. [19]     | e-glass fibres + bi-axial fibres + walnut peel | ---                              | 2.89-3.70                |
| Liuzzi et al. [20]    | clay + sand + gravel + olive tree leaves       | 1409-1669                        | 0.428-0.593              |
| Cardinale et al. [21] | cement + reed stalk + straw                   | 1477-1646                        | 0.203-0.291              |
In the current study, the thermal conductivities of five samples made from waste human hair, dried grass, flowers of the albizia odoratissima tree, and fibres and seeds from the palm date tree were experimentally determined. Synthetic white glue was employed as a binder. This study thus sought to support sustainability by encouraging the recycling of abundant waste materials to produce environmentally friendly thermal insulators.

2. Methodology

2.1 Measuring Device

The Hilton-B480B device, shown in figure 1, was used to measure the thermal conductivity of the prepared samples. This works using the heat flow method, being made up of an insulated enclosure, a hot plate, a cold plate, a loading screw, a heat flowmeter, and relevant thermocouples. The hot plate is heated using the attached electric heater, while the cold plate is held at a low temperature by the coolant water loop. A loading mechanism is used to attach the two plates to the upper and low faces of a sample placed between them, as well as being used to measure the sample thickness. The heat flowmeter and thermocouples measure heat flow in terms of voltage flow and the difference in temperatures of the two plates, respectively. The maximum allowed conditions of the hot plate, temperature difference, and thickness of a sample are 100 °C, 15 to 20 °C, and 70 mm, respectively.
Figure 1. (a) Hilton-B480B device.

Figure 1. (b) Schematic representation of Hilton-B480B device.
2.2 Weighing Device

To determine the density of each sample, a Denver Maxx 5001 scale, shown in figure 2, was used. This weighs items up to 5 kg with ±0.002 kg accuracy. As long as a sample’s mass and volume are known, its density can be calculated by applying equation (1).

\[
\rho = \frac{M}{V} \tag{1}
\]

where \(V\) (m\(^3\)), \(M\) (kg) and \(\rho\) (kg/m\(^3\)), are the volume, mass, and density of the sample, respectively.

![Figure 2. Denver Maxx 5001 weighing scale.](image)

2.3 Sample Preparation

Five different materials, waste human hair, grass, albizia odoratissima flowers, palm date fibres, and palm date seeds were used to prepare five samples. Synthetic white-glue was used as a binder at a ratio of 1/0.125 material/glue. Figure 3 shows the process of sample preparation.
Figure 3. Sample preparation and appearance: (a) waste human hair, (b) dried grass, (c) Albizia odoratissima flowers, (d) Palm date fibres, (e) Palm date seeds.
2.4 Measuring Process

The heat conductivity of the five samples was determined using the Hilton-B480B device shown in figure 1 as follows:

- The unit was switched on and the cooling water loop valves opened.
- The relevant sample was placed, along with silicon sheets, between the two plates.
- The loading screw was used to move the hot plate up/down until the loading light was triggered at least five time, then the average value of sample thickness was calculated.
- The temperature of the hot plate was set at a desired value so that the temperature difference was in the range 15 to 20 °C.
- Waiting time was applied until the measurements of hot plate temperature and voltage flow reached steady states.
- Equation (2) was used to determine the heat conductivity for each sample in Excel.

\[
\lambda = \frac{\Delta T}{t[(S_1+(S_2+T))+((S_3+(S_4+T))HFM)+(S_5+(S_6+T)\cdot HFM^2)]}
\]

where \( t \) is sample thickness (m); \( \bar{T} = \frac{T_h+T_c}{2} \) (°C); \( HFM \) is heat flow (mV); \( \Delta T = T_h - T_c \) (°C); \( S_1, S_2, S_3, S_4, S_5 \) and \( S_6 \) are the calibration constants -31.7383, 0.4792, 6.6346, 0.0558, 0.0279, and -0.0005, respectively; and \( \lambda \) is the heat conductivity (W/mK) [27].

3. Results and Discussion

The thermal conductivities of five samples made from different waste materials (human hair, grass, flowers of albizia odoratissima tree, palm date tree fibre and date palm tree seeds), with synthetic glue used as a binder, were determined experimentally. These were measured using a Hilton-B480B device, which adopts the heat flow method, in conjunction with a thermal conductivity equation (2), provided in the operation manual of the device. The results ranged between 0.0530 and 0.1068 W/mK, as shown in figure 4. The best thermal resistance was provided by samples made from hair and palm fibres, while the sample made from the flowers of the albizia tree gave the highest thermal conductivity due to its relatively high density. The sample made from the fibres of the palm tree not only provided low thermal conductivity but also offered low density, however. Table 2 shows the density and thermal conductivity of the investigated materials, with comparisons to other relevant studies.

| Material                  | \( \rho \) (kg/m\(^3\)) | \( \lambda \) (W/m K) | Author               |
|---------------------------|--------------------------|------------------------|----------------------|
| waste human hair          | 227                      | 0.0530                 |                      |
| dried grass               | 223                      | 0.0702                 |                      |
| albizia odoratissima flowers | 644                     | 0.1068                 | Current study        |
| palm date tree fibres     | 109                      | 0.0553                 |                      |
| palm date tree seeds      | 534                      | 0.1036                 |                      |
| cob corn                  | ---                      | 0.139                  | Pinto et al. [4]     |
| date palm fibres          | ---                      | 0.041                  | Oushabi et al. [7]   |
| palm tree fibres          | ---                      | 0.035                  | Boulaoued et al. [8] |
| husk of rice              | 378                      | 0.08                   | Muthuraj et al. [9]  |
| chicken feather           | 59                       | 0.033                  | Dieckmann et al. [14]|
| feather of chicken        | 214                      | 0.0478                 | Alhabeeb and Mohammed [17] |
4. Conclusion

Insulators made from waste human hair and waste plant materials provide promising levels of thermal resistance. In the current study, the fibres and seeds of palm date trees, waste grass, waste human hair and waste flowers of the albizia tree were mixed with industrial glue in a ratio of about 1/0.125 (material to glue) to make samples of thermal insulators. All samples provided very good thermal resistance, while the best thermal insulators were made from hair and fibres. Samples made from waste flowers of albizia and palm tree seeds offered thermal conductivity of less than 0.107 W/m K, while samples made of waste dried grass provided 0.0702 W/m K. The best thermal insulating characteristics were achieved by the sample made from fibres of palm tree and waste human hair, at about 0.05 W/m K. These types of insulators may only be used in interior applications, however, as the binder is likely to be affected by water. Using waste natural materials to produce thermal insulators is encouraged to contribute to sustainability; this kind of insulator can also be considered to be more environmentally friendly than conventional alternatives.

References

[1] Jiri Z, Jitka H, Petranek V, Kosikova J and Korjenic A 2011 Investigation of thermal insulation materials based on easy renewable raw materials from agriculture Adv. Mat. Res. 335-336 pp 1412-17.

[2] Zach J, Hroudová J, Brožovský J, Krejza Z and Gailius A 2013 Development of thermal insulating materials on natural base for thermal insulation systems 11th Int. Conf. on MBMST Pro. Eng. 57 pp 1288 – 94.

[3] Luamkanchanaphan T, Chotikaprapkhan S and Jarusombati S 2012 A study of physical, mechanical and thermal properties for thermal insulation from narrow-leaved cattail fibres APCBEE Pro. 1 pp 46 – 52.

[4] Pinto J, Cruz D, Paiva A, Pereira S, Tavares P, Fernandes L and Varum H 2012 Characterization of corn cob as a possible raw building material Const. and Bui.l.Mat. 34 pp 28–33.

[5] Tůmová E, Drochytka R, Černý V and Čada P 2017 Development of organic and biodegradable insulating material for ETICS 18th Int. Conf. CRRB Pro. Eng. 195 pp 81–7.
[6] Bakatovich A, Davydenko N and Gaspar F 2018 Thermal insulating plates produced on the basis of vegetable agricultural waste Energy & Build. 180 pp 72-82.

[7] Oushabi A, Sair S, Abboud Y, Tanane O, EL Bouari A 2015 Natural thermal-insulation materials composed of renewable resources: characterization of local date palm fibres (LDPF) J. Mater. Environ. Sci. 6 pp 3395-402.

[8] Bouldoued I, Amara I and Mhimid A 2016 Experimental determination of thermal conductivity and diffusivity of new building insulating materials 8th Int. Conf. on SEB Int. J. of Heat and Tech. 34 pp 352-31.

[9] Muthuraj R, Lacoste C, Lacroix P and Bergeret A. 2019 Sustainable thermal insulation biocomposites from rice husk, wheat husk, wood fibres and textile waste fibres: Elaboration and performances evaluation. Industrial Crops and Products, Elsevier 35 pp 238-245.

[10] Pavelek M and Adamová T 2019 Bio-Waste Thermal Insulation Panel for Sustainable Building Construction in Steady and Unsteady-State Conditions Materials 12 (12) 2004.

[11] Palumbo M, Navarro A, Avellaneda J and Lacasta A M 2014 Characterization of Thermal Insulation Materials Developed with Crop Wastes and Natural Binders A: World Sust. Buidl. Conf. WSB 14 Barcelona Sustainable Building. Barcelona: pp 188:1-10.

[12] Pennacchio R, Savio L, Bosia D, Thiebat F, Piccablotto G, Patrucco A, Fantucci S 2017 Fitness: sheep-wool and hemp sustainable insulation panels Energy Pro. 111 pp 287–97.

[13] Binici H and Kekili M 2015 The Production of Thermal Insulation by Waste Animal and Vegetable Fibres J Material Sci. Eng. 4: 186.

[14] Dieckmann E, Onsiorg R, Nagy B, Sheldrick L and Cheeseman C 2020 Valorization of Waste Feathers in the Production of New Thermal Insulation Materials Springer Waste Biomass Valor.

[15] Adazabra A, Vinuthagiri G and Shanmugam N 2018 Manufacture of Lightweight Clay Brick with Improve Thermal Insulation Properties Via the Incorporation of Spent Shea Waste J. of App. Res and Tech 16 pp 186-203.

[16] Hossain SK and Roy P 2019 Fabrication of sustainable insulation refractory: Utilization of different wastes Boletín de la Sociedad Española de Cerámica y Vidrio 58 (3) pp 115–125.

[17] Alhabeeb B A and Mohammed H N 2020 Investigating New Thermal Insulators Based on Cheap Natural Organic and Waste Materials: Part 1 3rd Int. Conf. on Eng. Sci. IOP Conf. Series: Mat. Sci. and Eng. 671.

[18] Miron I O, Manea D L, Cantor D M and Aciu C 2017 Organic thermal insulation based on wheat straw 10thInt. Conf. in INTER-ENG Pro.Eng. 181 pp 674 –81.

[19] Onat A, Pazarlioglu S S, Sanck E, Ersoy S, Beyit A and Erdem R 2013 Thermal and mechanical properties of walnut shell and glass fibre reinforced thermoset polyester composites Asian J. of Chemistry 25 pp 1947-52.

[20] Liuzzi S, Rubino C, Stefanizzi P, Petrella A, Boghețich A, Casavola C and Pappalettera G 2018 Hygrothermal properties of clayey plasters with olive fibres Cons. and Build. Mat. 158 pp 24–32.
[21] Cardinale T, Arleo G, Bernardo F, Feo A and Fazio P D 2017 Investigations on thermal and mechanical properties of cement mortar with reed and straw fibres *Int. J. of Heat and Tech.* 35 pp 375-82.

[22] Hýsek Š, Neuberger P, Sikora A and Schönfelder O 2019 Waste Utilization: Insulation Panel from Recycled Polyurethane Particles and Wheat Husks *Materials (Basel)* 12 (19) 3075 pp 1-11.

[23] Arcaro S, Maia B G O, Souza M T, Cesconeto F R, Granados L, de Oliveira A P N 2016 Thermal insulating foams produced from glass waste and banana leaves *Mat. Res.* 19 pp 1064-69.

[24] Tsaousi G M, Profitis L, Douni I, Chatzitheodorides E, Panias D 2019 Development of lightweight insulating building materials from perlite wastes *Mat. de Const.* 69 pp 1-9.

[25] Ahmadi P F, Ardeshir A, Ramezanianpour A M and Bayat H 2018 Characteristics of heat insulating clay bricks made from zeolite, waste steel slag and expanded perlite *Ceramics Int.* 44 pp 7588–98.

[26] Romero-Flores M, Becerra-Lucatero L M, Salmón-Folgueras R, Lopez-Salinas J L, Bremer-Bremer M H, Montesinos-Castellanos A 2017 Thermal performance of scrap tire blocks as roof insulator *Energy and Build.* 149 pp 384–90.

[27] Experimental Operating and Maintenance Manual of Thermal Conductivity of Building and Insulating Materials Unit, *Hilton LTD. B840*. 