

Influence of heavy metals on thermal conductivity of clay as a building material

Egbeyale Godwin Babatunde & Adegoke James Adeyemo

To cite this article: Egbeyale Godwin Babatunde & Adegoke James Adeyemo (2019): Influence of heavy metals on thermal conductivity of clay as a building material, Egyptian Journal of Basic and Applied Sciences, DOI: [10.1080/2314808X.2019.1670426](https://doi.org/10.1080/2314808X.2019.1670426)

To link to this article: <https://doi.org/10.1080/2314808X.2019.1670426>



© 2019 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.



Published online: 07 Oct 2019.



[Submit your article to this journal](#)



Article views: 30



[View related articles](#)



[View Crossmark data](#)

Influence of heavy metals on thermal conductivity of clay as a building material

Egbeyale Godwin Babatunde^a and Adegoke James Adeyemo^b

^aDepartment of Physics, Kwara State University, Malete, Nigeria; ^bDepartment of Physics, University of Ibadan, Ibadan, Nigeria

ABSTRACT

Thermal conductivity of contaminated clay is an emerging field of interest in building construction. This study investigated the influence of some heavy metals on thermal conductivity of clay. The objective of this study is to investigate the influence of heavy metal in clay for energy-efficient in building constructions. The clay sample was collected from clay deposit and prepared. The samples were mixed (contaminated) with nitrates of Pb, Fe, Zn, Ni and Cu at different concentrations and slabs then were formed. The thermal conductivity of clay slabs were measured to determine the suitability of contaminated clay as building material for heat emitting modern equipment room. The thermal conductivity of clay slabs contaminated with nitrate of Pb, Fe, Zn, Ni and Cu ranged 0.06–0.15 Wm⁻¹K⁻¹; 0.06–0.18 Wm⁻¹K⁻¹; 0.06–0.22 Wm⁻¹K⁻¹; 0.06–0.19 Wm⁻¹K⁻¹ and 0.06–0.38 Wm⁻¹K⁻¹, respectively. Results showed that thermal conductivity of clay increases with increase in the concentration of heavy metal absorbed by the clay to an optimum level. Hence, heavy metals influenced the thermal properties of clay building material.

ARTICLE HISTORY

Received 26 June 2019

Accepted 18 September 2019

Published online 7

September 2019

KEYWORDS

Concentration; thermal conductivity; clay slab; heavy metals; contamination; building

Introduction

Soils have been subject to increasing sources of metal contamination due to human activities. Atmospheric deposition, waste disposal, fertilizer and pesticide applications, industrial waste and nuclear waste are some of the sources of heavy metals. Heavy metal contamination of soil is one of the environmental problems throughout the world [1]. Obviously, these sources can cause metal accumulation in soils. The excessive amounts of heavy metals introduced into the soils can affect soil matrices particularly involving metal–soil interactions, which further affect thermal conductivity.

Thermal conductivity of a material is an important engineering property, which is related to heat transfer characteristics. This parameter is essential in studying heating, drying and cooling processes for crop (seeds) and building materials. Thermal properties of many materials have been reported in literature, and most of this information is compiled for engineering research and design purposes [2,3]. The physical, chemical and mineralogical characteristics of Odukpani clay deposits and their brick-forming properties in Cross-River, (Nigeria) have recently been reported [4,5]. Lead adsorption on clay and its application were investigated and conclusion was made [6]. Variation of thermophysical properties of clay with adsorption

CONTACT Egbeyale Godwin Babatunde godwinegbeyale@gmail.com Department of Physics, Kwara State University, Malete, Nigeria

© 2019 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.

This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (<http://creativecommons.org/licenses/by-nc-nd/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way.

optimization was reported [7]. The effect of Cation Exchange Capacity (CEC) of clay on thermal conductivity was investigated. They conclude that thermal conductivity depends on the number of cations adhere to clay surface [8]. The geotechnical properties of clay materials in Nigeria were investigated by Akpokodje [9], Akinyemi [10] and Gbadebo [11]. They reported that differences in mineralogical and engineering properties of clays were caused by pedogenic factors such as parent rocks, relief and climate. Borode et al. [12], reported the alumina content of some Nigerian clay to be low, for their use alone without blending. Obikwelu [13], suggested blending two or more clays from different locations helps to improve the characteristics of clay materials for industrial applications. Abu-Hamdeh [14], analyzed that the increase of the concentration of water on bulk density of soils led to decrease in bulk density. Tang et al. [15], investigated compacted bentonite and the influence of dry density, water content, and saturation on conductivity. Abuel-Naga et al. [16], presented experimental tests showing that the values of thermal conductivity were higher with the rise in soil density. O'Donnell et al. [17] considered a relation between thermal conductivity and moisture of soil. Noborio and Mcinmset [18] worked on how salts and water affect thermal conductivity of soil.

Though clays are regarded as low thermal conductor, additive agents on clay have not received good attention. In addition, the functional relationship between thermal conductivity and the heavy metal concentration has not received sufficient attention. This study therefore aimed at investigating the influence of heavy metals on thermal conduction of clay as a building material.

Geographical location of the study area

The study area lies within latitudes 7°23' and 7°52'N and longitudes 4°58' and 5°31'E, covering about 534 km²) in the southwestern sector of

the Nigerian Basement Complex, which formed the southern part of the Trans-Saharan mobile belt of Neo-proterozoic (750–500Ma) age [19]. The geology of Nigeria is dominated by sedimentary and crystalline basement complex formations which occur in almost equal proportions all over the country [20–23]. The sediment is mainly Upper cretaceous to recent in age while the basement complex rocks are thought to be Precambrian.

Theoretical background

The rate heat energy flow in an isotropic material [24] is given by;

$$H = \frac{Q}{t} = -kA \frac{dT}{dx} \quad 1$$

Where k is the thermal conductivity, A is the total cross-sectional area of conducting surface, dT is the temperature difference and dx is the thickness of the conducting surface separating the two temperatures.

Hence, Equation (1) becomes

$$k = \frac{-Q dx}{Adt dT} \quad 2$$

From this equation, thermal conductivity can be defined as flux of heat (energy per unit area per unit time) per unit temperature gradient (temperature per unit length). The S.I unit for thermal conductivity is W/mk.

Materials and methods

Clay sample was collected from Isan, southwestern part of Nigeria. The sample was processed and prepared for used in the Physics laboratory, University of Ibadan. A 1.0 g of the clay was poured into Teflon beaker and digested (using nitric acid extraction method). Digested solution was analyzed for heavy metal presence using Atomic Absorption Spectrophotometer (AAS). The remaining portion of the clay sample was further divided into six. Each of the five portions was mixed with

different concentration of nitrate of lead, copper, nickel, zinc and iron, respectively, at 400, 800, 1600, 3200 and 6400 ppm while the sixth serves as control. Slabs were made from the mixture and oven dried up to 110 °C for 300 s. The thermal performances of the slabs were determined by using a KD2 probe thermal analyzer.

A KD2 probe thermal analyzer consist a 60 mm single needle sensor with diameter of 0.9 mm was inserted into the medium being investigated. The working theory of a KD2 is based on the assumption that the heat source placed in an isotropic and homogenous medium is infinitely long under a uniform initial temperature. The governing equation according to Carslaw and Jaeger [24], is:

$$\frac{dT}{dt} = \alpha \left(\frac{d^2T}{dr^2} + r^{-1} \frac{dT}{dr} \right) \quad 3$$

where r is the radial distance (m), T is the temperature (°C), α is the thermal diffusivity (m^2/s), and t is the time (s).

A reading is initiated by pressing the left button on the readout. The controller waits for 90 s to ensure temperature stability, and then heats the probe for 30 s. At the end of the reading, the controller computes the thermal properties based on the measurement of temperature rise in the needle during the heating period of the probe. The temperature change was used to calculate thermal conductivity using the expression $k \approx q/(4\pi m)$, where $k = \alpha \rho c_p$ is the thermal conductivity ($\text{W}/(\text{m}\cdot\text{K})$), ρ is the material dry-basis bulk density, c_p is the specific heat at constant pressure ($\text{J}/(\text{kg}\cdot\text{K})$), q is the heat produced per unit time per unit length (W/m) and m is the slope of the linear relationship between ΔT and $\ln t$.

Results and discussion

Table 1 shows the thermal conductivity of the clay mixed at different concentrations. For the studied clays, the variability of thermal

Table 1. Variation of thermal conductivities and concentration of heavy metals in clay sample.

Concentration ppm	Thermal conductivity W/mK				
	Ni	Cu	Pb	Zn	Fe
0	0.06	0.06	0.06	0.06	0.06
400	0.09	0.16	0.08	0.09	0.08
800	0.12	0.24	0.10	0.13	0.11
1600	0.13	0.27	0.12	0.14	0.13
3200	0.17	0.32	0.14	0.20	0.15
6400	0.19	0.38	0.15	0.22	0.18

conductivity is obvious when clay was mixed with nitrate of Lead, Copper, Iron, Nickel and Zinc.

The thermal conductivity of clay slabs contaminated with nitrate of Pb, Fe, Zn, Ni and Cu ranged 0.06–0.15 $\text{Wm}^{-1}\text{K}^{-1}$; 0.06–0.18 $\text{Wm}^{-1}\text{K}^{-1}$; 0.06–0.22 $\text{Wm}^{-1}\text{K}^{-1}$; 0.06–0.19 $\text{Wm}^{-1}\text{K}^{-1}$ and 0.06–0.38 $\text{Wm}^{-1}\text{K}^{-1}$, respectively. Results showed that thermal conductivity of clay increases with increase in the concentration of heavy metal absorbed by the clay to an optimum level. Lead nitrate shows lowest value 0.15 W/mK , and the clay mixed with copper nitrate shows the highest value 0.38 W/mK at 6400 ppm. Table 1 also shows explicit relationship between concentration of heavy metal and thermal conductivity.

Accordingly, the observed variability of thermal conductivity and thermal diffusivity in the studied clay could be attributed to the concentration of heavy metals.

Figure 1(a–f) presents thermal conductivity versus concentration of heavy metal. It is shown from the graph that the increase in concentration leads to increase in thermal conductivity of clay slab. For example, addition of lead nitrate increases the thermal conductivity by approximately 51%, copper by 80%, zinc by 70%, Nickel by 65% and Iron by 60% which is a very significant amount in terms of energy saving. This implies that clay slab mixed with copper conduct heat energy better than other heavy metals.

The changes in the thermal conductivity were presented in relation to concentration.

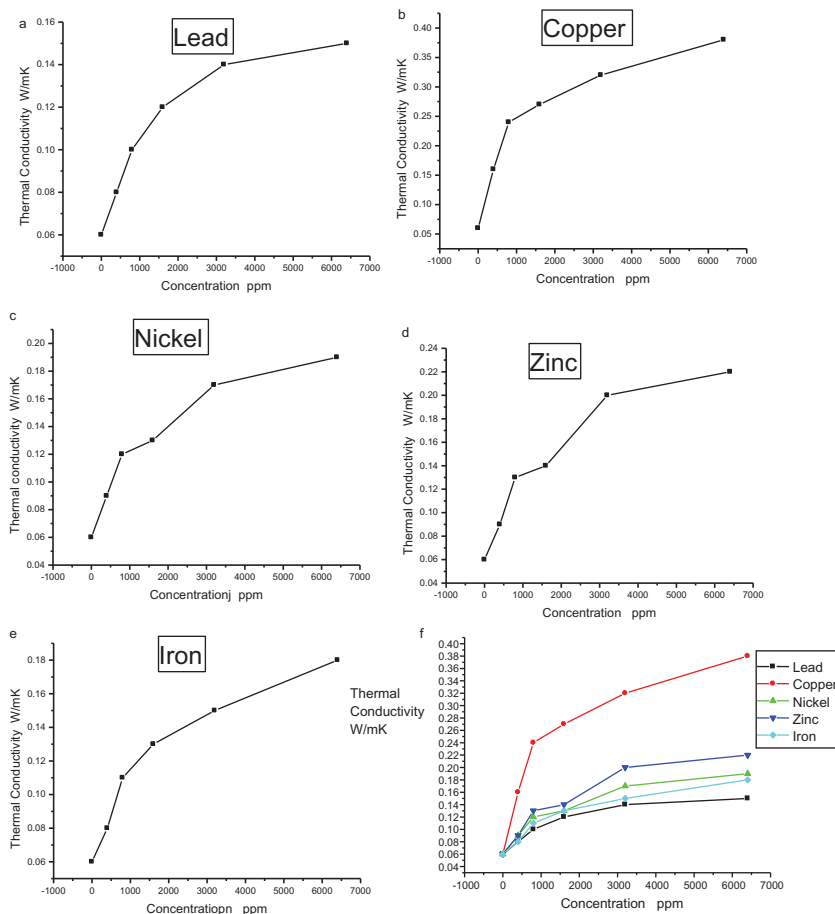


Figure 1. (a) Thermal conductivity against concentration of lead nitrate. (b) Thermal conductivity against concentration of copper nitrate. (c) Thermal conductivity against concentration of Nickel nitrate. (d) Thermal conductivity against concentration of Zinc nitrate. (e) Thermal conductivity against concentration of Iron nitrate. (f) Thermal conductivity against concentration of selected heavy metals.

Experiments showed that thermal conductivity increases sharply between 0 ppm and 1000 ppm concentration and gradually increases as the concentration was above 1000 ppm and later reach its optimal level as concentration increases, for all the chemical elements used.

the concentration of heavy metal absorbed by the clay to an optimum level. Thermal conductivity values were increased from 5 to 18% and the thermal diffusivity increased by 20%. Hence, heavy metals influenced the thermal properties of clay as a building material.

Conclusion

The study investigated the influence of heavy metals on thermal conductivity of clay as building material. Results showed that thermal conductivity of clay increases with increase in

Acknowledgments

I would like to thank Professor Akinyemi and staff of Department of Physics, Federal University of Agriculture Abeokuta, for providing KD2 thermal analyzer. I also like to appreciate Mr Wilhelm,

department of Agronomy University of Ibadan, for the analysis of heavy metal in the clay sample.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

- [1] Usowicz B. A method for the estimation of thermal properties of soil. *Agrophys.* **1993**;7(1):27–34.
- [2] ASAE. **2001**. Thermal properties of grain and grain products. ASAE, St. Joseph, Standards. D243.3.
- [3] Polley SI, Synder OP, Kotnour F. A compilation of thermal properties of foods. *Food Technol.* **1980**;34(11):76–78.
- [4] Oden MI, Attah LE, Ibok UJ. Brick forming properties of Odukpani clay deposits from physical, mechanical and mineralogical studies. *West Afr J Res Develop Educ.* **2001**;8(1):93–98.
- [5] Attah LE, Murray HH, Murray NK. Clay deposits of Southern Cross River State: mineralogy, chemical and physical properties. A paper presented at the 24th Annual Internal conference of the chemical society of Nigeria (CSN) Abuja. **2001**. Vol. 1, p. 1–15.
- [6] Adegoke, Egbeyale. Lead adsorption in clay and its application. *Electron J Geotech Eng.* **2010**;17:1877–1899. Bund M.
- [7] Adegoke JA, Ogunsile B, Adetoro O. Variation of thermophysical properties of clay with adsorption optimization. *Pac J Sci Technol.* **2010**;11(2):639–647.
- [8] Adegoke A, Egbeyale GB. Effect of cation exchange capacity of clay on thermal conductivity. *Malaysian J Sci.* **2015**;1–18.
- [9] Akpokodje N. The geological evolution of the Nile River. New York: Springer Verlag; **1992**. p. 151.
- [10] Akinyemi GO. Major elements geochemistry and strength characteristic of three highway sub-grade soils in South Western Nigeria. *Clay mineralogy.* *Bull Int Assoc Eng Geol.* **1994**;5:5–823.
- [11] Gbadebo AM. Evaluation of engineering and industrial potentials of tidal flat clays in parts of Niger Delta, Nigeria. *Nigerian J Eng Res Dev.* **2002**;1(3):20–27.
- [12] Borode JO, Onyemaobi OO, Omotoyinbo JA. Suitability of some Nigerian clay as refractory raw materials. *Nigerian J Eng Manage.* **2000**;1:14–18.
- [13] Obikwelu OI. A discussion of the origin of clay minerals in sedimentary rocks. *Clays Clay Min.* **1987**;5(1971a):159–173.
- [14] Abu-Hamdeh NH. Thermal properties of soils as affected by density and water content. *Biosyst Eng.* **2003**;86(1):97–102.
- [15] Tang A-M, Cui Y-J, Trung-Tinh LE, et al. A study on the thermal conductivity of compacted bentonites. *Appl Clay Sci.* **2008**;41(3–4):181–189.
- [16] Abuel-Naga HM, Bergado DT, Bouazza A, et al. Thermal conductivity of soft Bangkok clay from laboratory and field measurements. *Eng Geol.* **2009**;105(3–4):211–219.
- [17] Donel O. Tyher conductivity and moisture of soil. *Appl Clay Sci.* **2009**;41(3–4):181–189.
- [18] Noborio K, McInnes KJ. Thermal conductivity of salt-affected soils. *Soil Sci Soc Am J.* **1993**;57:329–334.
- [19] Caby R. Precambrian terranes of the Benin-Nigeria and Northeast Brazil and the late Proterozoic South Atlantic fit. *Geol Soc Am Spec Pap.* **1989**;230:145–158.
- [20] McCarthy DF. Essentials of soil mechanics and foundations: basic geotechnics. 2nd ed. Reston, VA: Reston Publishing; **1989**.
- [21] Rahaman MA, Malomo S. Sedimentary and crystalline rocks of Nigeria. In: Ola SA, Balkema AA, editors. *Tropical soils of Nigeria in engineering practice*. Rotterdam; **1983**. p. 17–38.
- [22] Shitta KA. Lithostratigraphy of Nigeria—an overview. Proceedings of 32nd workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California; **2007**. p. 1–9.
- [23] Durotoye B. Geomorphology and quaternary deposits of Nigeria. In: Ola SA, editors. *Tropical soils of Nigeria in engineering practice*. Rotterdam: A.A. Balkema; **1983**. p. 1–17.
- [24] Carslaw HS, Jaeger JC. Conduction of heat in solids. 2nd ed. Oxford: Clarendon; **1959**. p. 101–106.