Materials Today: Proceedings 30 (2020) 183–189

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Effect of climatic conditions on the thermal conductivity of earth fuller

Gyan Prakash Sharma [a], Ravi Agarwal [b,c], Arti Bansal [a], Narendra Kumar Agrawal [c,d], Ramvir Singh [a]

[a] Department of Physics, University of Rajasthan, Jaipur, Rajasthan, India
[b] Centre for Converging Technologies, University of Rajasthan, Jaipur, Rajasthan, India
[c] Samnvya, The Information Management System, Jaipur 302033, India
[d] Department of Physics, Saint Wilfred's Girls College, Jaipur 302020, India

ARTICLE INFO

Article history:
Received 27 January 2020
Received in revised form 21 May 2020
Accepted 28 May 2020
Available online 9 July 2020

Keywords:
Earth Fuller
Bentonite clay
Micron size particles
Thermal conductivity
Sieve
KD2 Pro thermal analyzer

ABSTRACT

The present work deals with the study of the effect of temperature on the thermal conductivity of Earth Fuller (Bentonite Clay) at different climatic conditions. First of all Earth Fuller brought from Barmer and Jodhpur were ground to fine-grained particles using a grinder and than micron size particles were obtained using the sieves of 186 μm, 150 μm, 125 μm, and 106 μm. The transient line heat source method based KD2 Pro Thermal Analyzer has been used to measure the thermal conductivity of the prepared samples in the temperature range from 10 to 70 °C. It was observed that at a fixed temperature, the thermal conductivity increases up to 40% (samples from Barmer) and up to 30% (samples from Jodhpur) with the increase in the particle size. Results exhibit that the thermal conductivity of the same sized particles of Earth Fuller at the same temperature is different due to varying climatic conditions. Whereas the temperature was increased from 10 to 70 °C, the thermal conductivity of the same sized particles also increases by nearly 20%.
© 2020 Elsevier Ltd. All rights reserved.
Selection and Peer-review under responsibility of the scientific committee of the International Conference on Advancement in Nanoelectronics and Communication Technologies.

1. Introduction

Clays generally classified into several categories based on particle morphology and their chemical composition such as chlorite, kaolinite, smectite, halloysite and illite [1]. Nanoclays have been developed and studied for various applications, due to their availability, relatively low impact on the environment and relatively low cost [2]. With the rapid development and demand for nanotechnology, clay minerals often used as natural and easily accessible nanomaterials [3]. Nanoclays are layered structural units of layered mineral silicates that by stacking these layers form complex clay crystallites [4].To form nanoclay composites the stacks dispersed in a polymer matrix as additives/fillers for applications such as flame resistance material, thickening and gelling agents, gas permeability modifier, mechanical strength enhancer and wastewater treatment. These nanoclay composites have been widely studied due to their large surface area, high cation exchange capacity and swelling and rheological behaviour [5,6]. Nano clay composites have been used for many industrial purposes like as automotive (bumpers, interior and exterior panels, gas tanks), aerospace (high-performance components and flame retardant panels), pharmaceuticals (as carriers of drugs and penetrants), chemical processes (catalysts), construction (building sections and structural panels), textiles and food packing [7]. Recently cellular interactions with nanoclay composites have been the main interest of the investigators as they have potential uses in biomedical applications such as gene therapy, food preservation, drug delivery, bioimaging, bio-sensing and tissue engineering. This increasing interest is due to the unique properties of nanoclay composites such as high retention capacity, an affinity for interaction with biopolymers, large surface area to volume ratio. Nanoclay composites may help to repair or replace damaged tissues/organs and prevail chronic diseases and successfully implemented in cell transplantation applications in the neural tissue-engineering field. As nanoclay and their composites are usually nontoxic they have been studied for more biomedical purposes such as for wound healer, bone cement, drug delivery and enzyme immobiliser among others [8,9]. Earth Fuller (EF), commonly known as Multani mitti, is the clay-like substance contains mostly aluminium magnesium silicate. It consists of palygorskite or bentonite, which possesses the capacity to decolourize oil and other liquids without using any chemical. EF is very useful in the film industry, fillers in paint, pharmaceuticals and beauty products as an active and inactive

E-mail address: agarwal.ravi.cct@gmail.com (R. Agarwal)

https://doi.org/10.1016/j.matpr.2020.05.738
2214-7853/© 2020 Elsevier Ltd. All rights reserved.
Selection and Peer-review under responsibility of the scientific committee of the International Conference on Advancement in Nanoelectronics and Communication Technologies.

ingredient. Montmorillonite is the basic clay mineral in the structure of the EF [10]. EF accepted as the most popular material for the regeneration of industrial oils over the whole world in oil processing instruments.

Heat dissipation in electronic devices has become a serious problem in the present time for the electronic world. To minimize thermal stresses a low coefficient of thermal expansion and high thermal conductivity materials are required as heat sinks of such electronic devices [11]. Aerogel is a silica-based gel in which the liquid component replaced by gas is an innovative material to the building insulation industry due to its lower thermal conductivity [12–14]. The transfer of heat in aerogels was due to collision between gas molecules, convection in the pores, thermal radiation and conduction due to the solid Skelton. When the size of the pore is less than 1 mm then at ambient temperature convection effect neglected in porous materials [15].

Heat transfer in porous material at nanoscale decreases due to the restriction of the motion of gas molecules thus decrease the thermal conductivity [16]. In nanoporous materials, the contribution of gas heat conduction has good influences on thermal conductivity. It is slightly higher than the gas thermal conductivity in nanoporous material and used to improve the thermal insulation property of aerogels and its composites [17]. Several methods of thermal characteristics of paraffin waxes and pure paraffin performed showing no deviation in thermal properties by repeating many melting/solidification cycles, which make these materials a suitable polymer composite materials for high heat storage and shows the isothermal response in the method associated with charging and discharging. Due to these properties, PCMs used as the thermal storage capacity of the thermal system [18–23].

The thermal conductivity of the composite material depends on the size and shape of fillers. For the same concentration, spherical type fillers showed higher thermal conductivity than flake type fillers and large particle sized filled composites show higher thermal conductivity than one filled with small particles [24]. Thermally conductive polymer composites used for new possibilities in the electric system by replacing the parts of machinery due to its lightweight, ability to adapt the conductivity properties like heat sinks in the electric system [25]. Composites based on the Bio side are very useful in every day human lifelike as daily packing materials, in automobiles, and aerospace applications. Biopolymers like cellulose, pectin, hair, proteins and wood show piezoelectricity due to the internal rotation of atomic groups[26–27].Bone considered as nano-composites that have complex hierarchical structure due to its best properties: Strength and fracture toughness, high stiffness and coupled with low density for supporting the body structure in the view of engineering mechanics[28].

In composites PCMs, graphene oxide used as the supporting materials to stabilize the shape and to improve thermal properties. Graphene oxide and graphene nanoplatelets play an important role in heat transfer at the nanoscale [29]. Reinforced polymer composites with inorganic and organic fillers becoming more common for applications such as satellite devices, encapsulation and electronic packaging and areas, where low thermal expansion, good heat dissipation and light-weight materials are essential due to higher thermal conductivity [30,31]. The thermal conductivity of polymers increased by thermally conductive fillers like carbon black, carbon fibres, graphite, ceramic and metal particles into the base material [32]. To predict the thermal conductivity of composites various theoretical and empirical model suggested for many past years such as Lewis and Nielsen model [33,34], Agari and Uno model [35], Bruggeman model [36]and Tavman models [37,38] which have been employed in previous studies. Thermal conductivity is a physical property that describes heat transfer through the material. Reliable information on sedimentary rocks especially for clays is still lacking.

In the present work, we have studied the effect of climatic conditions on the thermal conductivity of EF, which is the base material in composites. We brought EF from two regions of Rajasthan *i.e.*Jodhpur and Barmer; both the regions are in the arid zone. The latitude and longitude extension of the Jodhpur region lies between 26° 0′ and 27° 37′ North latitude and 72° 55′ and 73° 52′ East longitude. The height of the Jodhpur region is about 250–300 m from sea level. The geographic location of Barmer district between 24° 58′ to 26° 32′ North latitude and 70° 05′ to 72° 52′ East longitude and height from sea level of Barmer region was about 931.8 m. These EFs converted into different sized particles and studied for change in thermal conductivity over the temperature range, which is practically useful. To the best of our knowledge, this is the first time when the effect of climatic conditions on the thermal conductivity of EF investigated thoroughly for different temperatures and sizes.

Earth Fuller, a type of clay known as Multani mitti mostly used in cosmetics and skincare products, skin decontaminant used by the military to treat exposure to chemical warfare, as an industrial cleaner to clean marble and absorb oil spills and gasoline, ingredient in commercial cat litter, gut absorbent used to treat poisoning by herbicides. It also known as mineral-rich clay. There are large variety of clay soils considered as Earth Fuller. Each of them has different composition among these 17 ingredients, which generally considered safe for cosmetics and skincare products. In skincare, products facial clays and masks including fuller's earth used to treat acne and pimples and to fight wrinkles. In cosmetics, it used to provide gentle exfoliating properties, to keep other powders from caking together, to bind other ingredients or to stabilize products. As it has a wide range of uses mostly in skincare products and cosmetics as a cooling agent and heat absorbent, the main purpose of the present study is to find out how the heat exchange process occurs. Therefore, we want to study the thermal conductivity of Earth fullers with different climatic conditions and different particle size with varying temperatures from 10-to70°C. The main purpose of our study is to observe the change in physical properties of earth fuller with increment in temperature and particle size.

2. Materials and method

2.1. Preparation of micron size EF particles

EF brought from two regions of Rajasthan (Jodhpur and Barmer) have been in the form of a small stone-like piece (Fig. 1 and 2). Using a hammer it was broken into small pieces. It then ground into fine-grain particles with the help of grinder (Remi Ato mix Blender). For converting the size of the particle in micron-sized a ball mill (Restch P100) machine was used at Centre for Non-Conventional Energy Resources, University of Rajasthan Jaipur. The ball to EF powder ratio was 10:1 with 5 min rest and 15 min work process for 5 h under atmospheric condition. After that different micron-sized sieves were used for various sized samples *i.e.* 186 μm, 150 μm, 125 μm and 106 μm (Fig. 3 and 4) respectively. These samples then filled in a cylindrical tube for the measurement at the same atmospheric conditions (fig. 5). In this study, our main interest is to observe the thermal conductivity behaviour of Earth fullers with different particle size at different temperatures. According to the availability of laboratory instruments mainly sieves of these particular sizes, we chose these particular particle sizes *i.e.* 186 μm, 150 μm, 125 μm and 106 μm of Earth Fuller.

2.2. Measurement of thermophysical properties

The cylindrical tube of 200 ml volume and 30 mm diameter taken for measuring the thermal conductivity of prepared

Fig. 1. Natural state of EF from jodhpur.

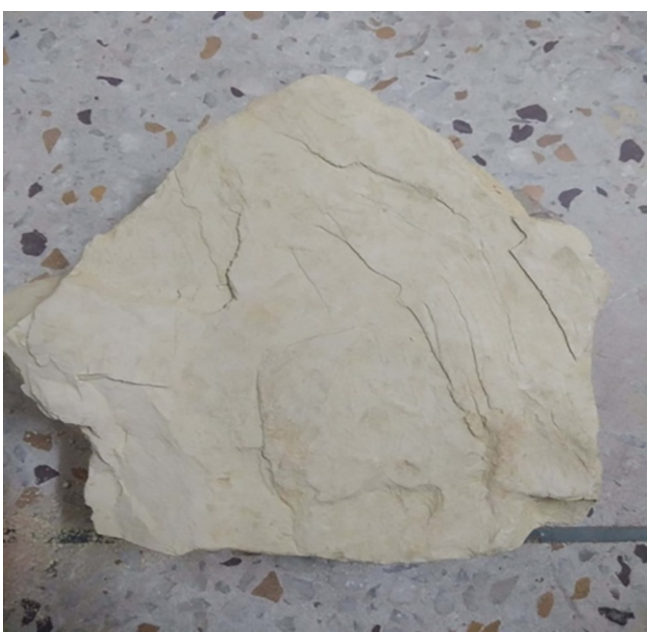

Fig. 2. Natural state of EF from barmer.

micron-sized EF by KD2 pro thermal analyzer of decagon device, Inc. USA using a TR-1 sensor (2.4 mm diameter × 100 mm long). The length of this cylindrical tube is 120 mm, which is deep sufficient for sensor needle so that the sensor was oriented vertically during the measurement. For the measurement of thermal conductivity of EF, following are the procedure adopted for each micron size Earth fullers:

1. The cylindrical tube filled with 45 g prepared micron size EF.
2. The way of filling of earth fuller in the cylindrical tube was the same for all samples.
3. Each sample put into the refrigerator and heating circulator (Julabo, F30) with the inserted needle.
4. The temperature of the machine was set at the desired temperature so the samples were heated and cooled; we wait for 1.5 h to equilibrate the sample temperature.
5. For each sample of fixed Particle Size, three readings taken at each temperature to decrease the error and for high accuracy. The mean of these three readings reported. The time gap between these three measurements was 20 min, so the effect of increment in temperature of the probe cancelled due to transient heating during the experiment.
6. After the first set of measurements, the circulator was set on the next desired temperature and switched on for 1 h 30 min. After that, the temperature equilibrated for 15 min and then at these temperature three sets of measurements performed.

For each sample, thermal conductivity measured at room temperature and temperatures varying from 10 to 70 °C for Jodhpur and Barmer sample using the setup is shown in Fig. 6. For the real-world applications, general operating temperature varies between 10 and 70 °C. Therefore, we also studied the thermal conductivity of earth fullers within the temperature range between10 and 70 °C. As our focus is on the general-purpose applications, we limited the temperature range up to 70 °C only in our study.

3. Result and discussion

3.1. Thermal conductivity of earth fullers

3.1.1. Jodhpur EF

Fig. 7 shows the variation of thermal conductivity (measured by KD2) with temperature varying from 10 to 70C. Four different graphs correspond to four different micron size of the EF particles of Jodhpur region *i.e.* 106 μm, 125 μm, 150 μm and 186 μm. Graphs show that by increasing the temperature of the sample the thermal conductivity increases and at the higher temperature the thermal conductivity increases much more like the size of the particle increases. At 40C, the changes in thermal conductivity of 125 μm, 150 μm earth fuller particles are almost the same. At other temperatures except for 40C, the variation of thermal conductivity increase as the temperature increases. When temperature increases for 106 μm, 125 μm, 150 μm and 186 μm then the increment in thermal conductivity is very small from temperature 10C to 40C. When temperature increases after 40C the increment in thermal conductivity are much more which reveals that the thermal conductivity is dependent on the size of the particles and temperature both.

3.1.2. Barmer EF

Fig. 8 shows the variation of thermal conductivity (measured by KD2) with varying temperatures from 10 to 70C. Four different graphs correspond to four different micron sizes of the EF particles of the Barmer region. The variation of thermal conductivity is different for each micron-sized particles revel the effect of geographic and climatic conditions may be due to chemical composition. The increment in thermal conductivity at each temperature and each size is almost greater for Barmer region earth fullers. For 106 μm, 125 μm the thermal conductivity variation is almost the same for the temperature 10C to 40C but when the temperature increase from 50C to 70C then thermal conductivity is slightly greater than for 125 μm. For 150 μm and 186 μm, the variation of thermal conductivity increases with temperature in the same manner with particle size increases.

From the above discussion, we can say that the EF from the Barmer region is more sensitive to temperature and particle size than the Jodhpur region. Therefore, the Barmer region, EF is good for making the composite material as the base materials.

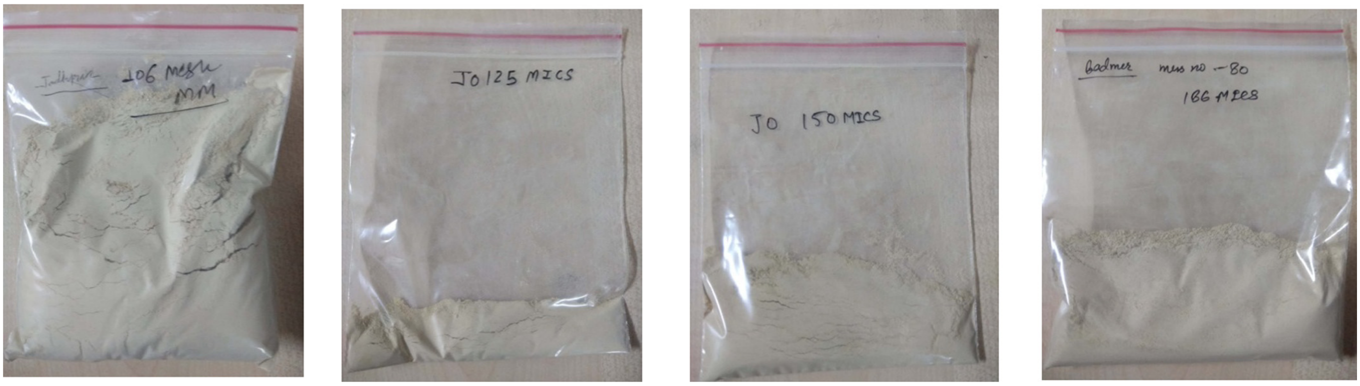

Fig. 3. After grinding, ball mill and sieving of the jodhpur sample.

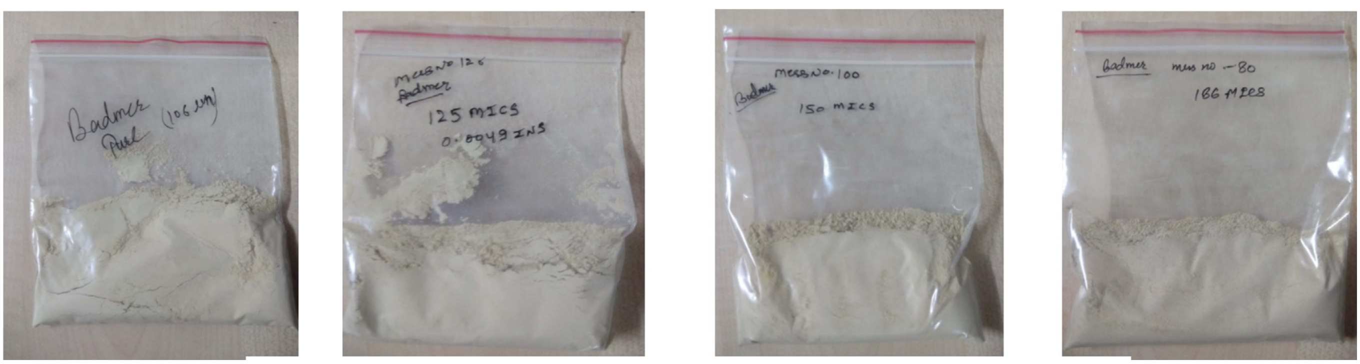

Fig. 4. After grinding, ball mill and sieving of the barmer sample.

Fig. 5. Sample stored for final measurement.

3.2. Comparative study of thermal conductivity of earth fullers at the same temperature

Fig. 9 shows the comparative schematic of the change in thermal conductivity for the samples of two different climatic conditions at a fixed temperature.

From10°C To 30°C:- The variation of thermal conductivity for both the region is same for 106 μm and 125 μm. When the size of the particles increases then thermal conductivity of Barmer EF is more in comparison to Jodhpur region, which shows that at the same temperature, the behaviour of EF particle changes due to the climatic condition.

At 40°C: - The variation of thermal conductivity is same for 106 μm size particle, but when the size of the particle increases to 125 μm then thermal conductivity of Barmer sample decreases from Jodhpur region EF, after that by increasing the size of the particle then thermal conductivity of Barmer sample increases from Jodhpur sample.

At 50°C: - The increment in thermal conductivity for Barmer region is greater from the Jodhpur region for 106 μm, 150 μm,

Fig. 6. Circulator setup and thermal conductivity measuring probe.

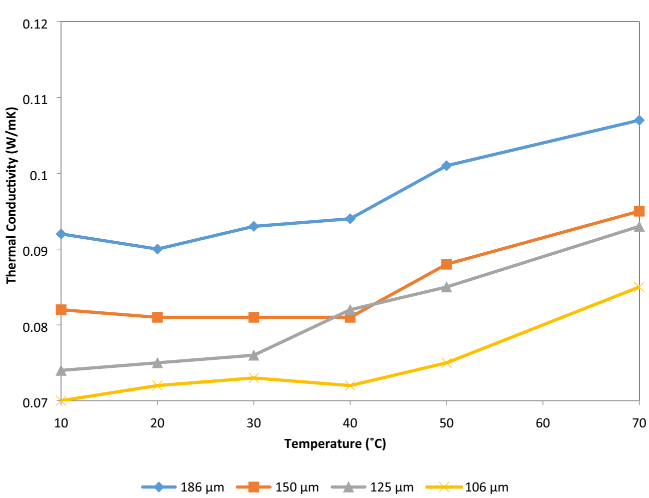

Fig. 7. Thermal conductivity variation with temperature for jodhpur sample.

186 μm approximately 7% observed. When the size of the particle was 125 μm then thermal conductivity of Barmer sample decreases approximate 8%, which shows the thermal conductivity varies with the size of the particle and climatic condition of the region.

At70C: - The same phenomena also observed as for 40C, which shows that at the higher temperature the thermal conductivity increases for Barmer and Jodhpur sample but this increment observed larger in Barmer region EF for all size of particles. The

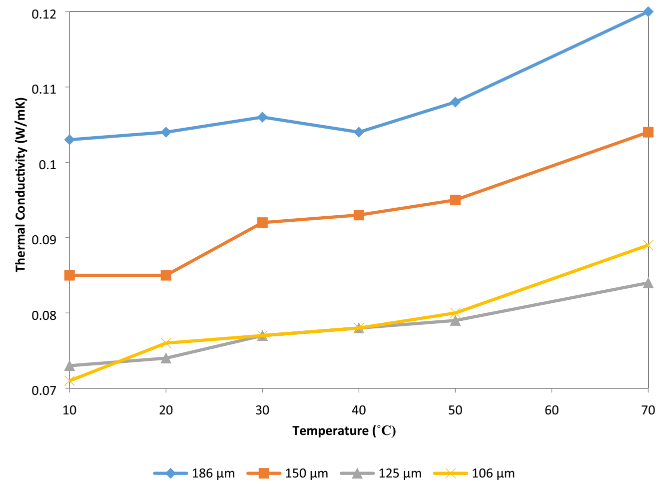

Fig. 8. Thermal conductivity variation with temperature for barmer sample.

increment in thermal conductivity also observed in the Jodhpur region for each size of particles. However, for 125 μm the thermal conductivity is higher in the Jodhpur region.

From the above discussion, we observed that the at the same temperature the thermal conductivity is higher for the larger size of particle for both the samples, but the sensitivity for Barmer samples was good, so Barmer samples may be preferred for making the base material forming the composites which may be used for all useful application.

3.3. FTIR characteristics

The FTIR characteristics for both the sample observed the same which shows the same functional grouping, stretching present in the earth fullers (Fig. 10).

The measurements conducted using a Shimadzu spectrometer at the University of Rajasthan with single reflection horizontal ATR accessories. The absorption FT-IR spectrum of the earth fullers in the range between 400 cm^{-1} to 4000 cm^{-1} recorded at room temperature. To investigate the chemical functional groups on the Earth Fullers, FTIR spectroscopy performed. The FTIR of EF powder in the range of 400 cm^{-1} to 4000 cm^{-1} shown in Fig. 10 for a pure sample of Earth Fullers. In the above spectrum mostly eight peaks of the unknown compound were detected which gives the following information

1. In the above spectrum, 3400 cm^{-1} broad absorption stretching peaks and 850 cm^{-1} deformation peaks represent the characteristics of -O–H stretching vibration of Mg–OH–Al, Al–OH–Al type bond, which may be the part of earth fuller.
2. 2100 cm^{-1}peaks corresponding to -≡N≡N- stretching frequency so we can say that N_2 like grouping responsible for the colour of earth fullers.
3. The O–Si–O asymmetric stretching mode detected at 1020 cm^{-1}. The peaks at 550 cm^{-1} and 670 cm^{-1} assigned to Si–O bending vibrations. Moreover, Al–O–Si bending vibration observed at 573 cm^{-1}, while Si–O–Si bending vibration observed at 425 cm^{-1}. The peaks at 650 cm^{-1} assigned to Ti-O stretching frequency.
4. 1600 cm^{-1}peaks indicate H-OH bending frequency of water.
5. 1450 cm^{-1} and 1340 cm^{-1} (two peaks) corresponding to NO_2 type group may be the part of the earth fuller.
6. 850 cm^{-1} corresponding to deformation of O–H linked to Al^{+3} and Mg^{+2} and Zn^{+2}.

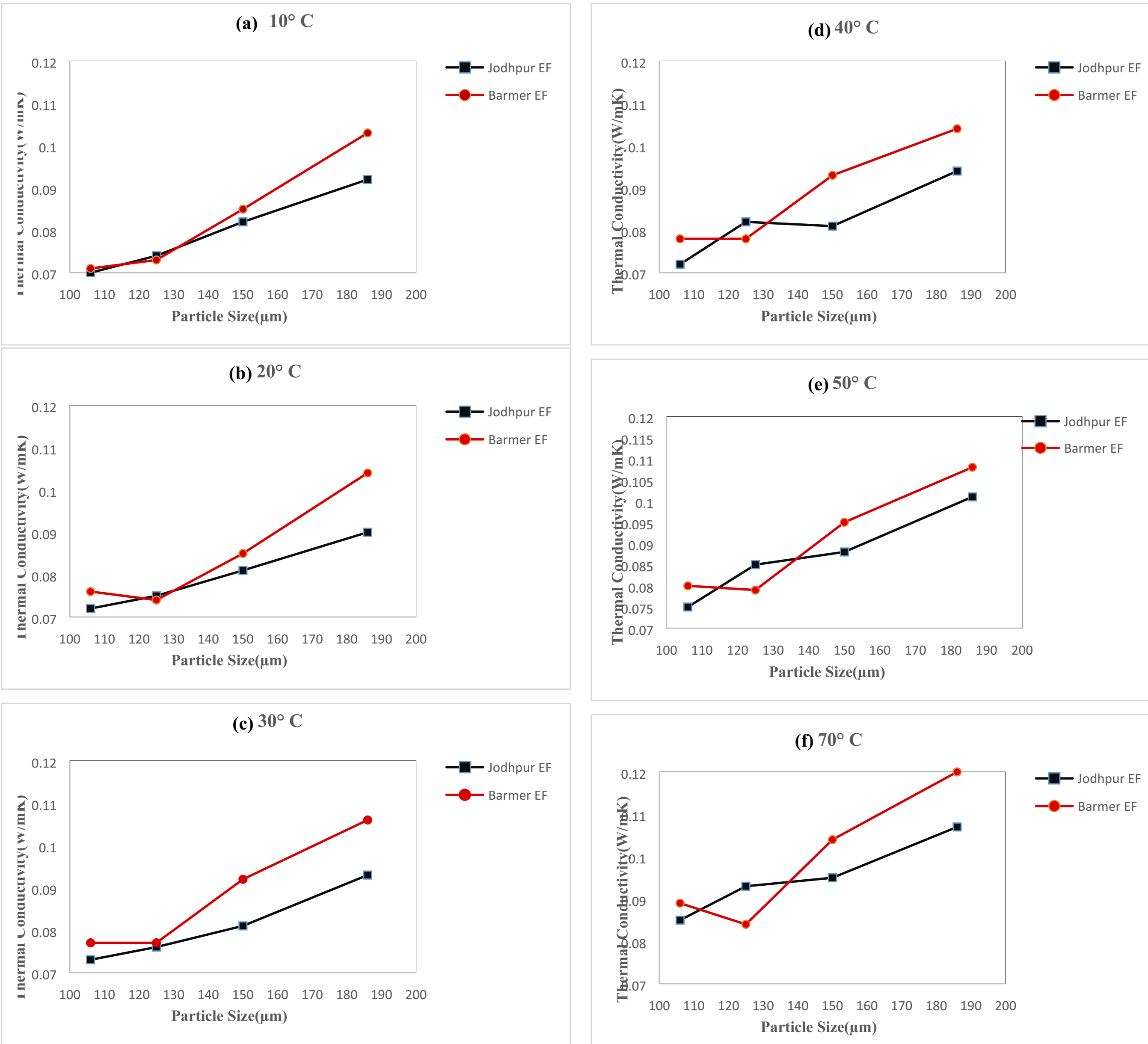

Fig. 9. Variation of thermal conductivity with particle size for different temperature.

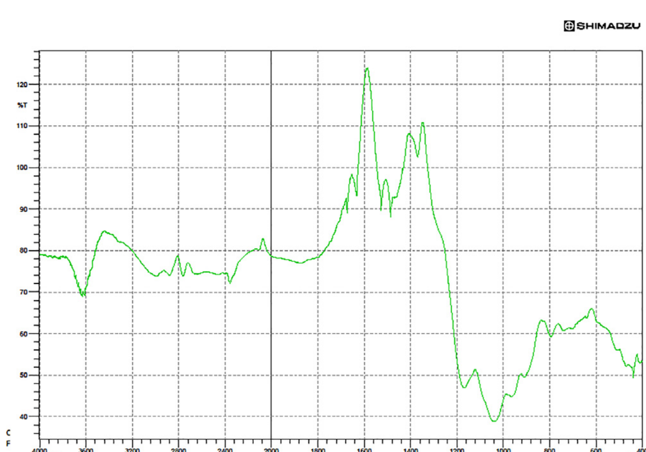

Fig. 10. FTIR characteristics of earth fullers.

4. Conclusion

From the above result, we can say that the measurement of thermal Conductivity of base material of composite of EF shows an increment in thermal conductivity with an increase in the particle size and temperature. When the size of the particle increases at fixed temperature then thermal conductivity increases approximately up to 40% for Barmer EF and up to 30% for Jodhpur EF, which is due to the difference in climatic conditions of two regions. When the temperature increases then thermal conductivity also increases in both the EF. This increment and decrement of thermal conductivity are in good agreement in beauty product to remove oil and in the film industry to create cloud and in medical sciences. The change in thermal conductivity is higher for the Barmer region due to its climatic condition. Due to these properties, it used in the Globe Core process. From the FTIR characteristics, it is evident, the earth fuller material related to a multi-component system like CaO-MgO-Al_2O_3-SiO_2-TiO_2. The thermal conductivity of earth fullers depends upon the oxides particles and climatic condition of the region.

CRediT authorship contribution statement

Gyan Prakash Sharma: Investigation, Data curation. **Ravi Agarwal:** Methodology, Writing - review & editing. **Arti Bansal:** Investigation. **Narendra Kumar Agrawal:** Writing - review & editing. **Ramvir Singh:** Conceptualization, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Research Associateship (RA) awarded by CSIR to Ravi Agarwal gratefully acknowledged (Grant ID: 09/149/0695/2016-EMR-1). FTIR measurement facility made available by the University Science Instrumentation Center (USIC) is worth mentioning. The authors are thankful to Director, Centre for Non-Conventional Energy Resources for providing the KD2 Pro Thermal Properties Analyzer and Ball Milling facility.

References

[1] M.S. Nazir, M.H.M. Kassim, L. Mohapatra, M.A. Gilani, M.R. Raza, K. Majeed, Characteristic properties of nanoclays and characterization of nanoparticulates and nanocomposite, Journal of springer, In Nanoclay Reinforced Polymer Composites, vol. 87, (2016) pp. 35–55.
[2] K. Müller, E. Bugnicourt, M. Latorre, M. Jorda, Y. Echegoyen Sanz, J.M Lagaron, O. Miesbauer, A. Bianchin, S.Hankin, U. Bölz, Review on the processing and properties of polymer nanocomposites and nanocoatings and their applications in the packaging, automotive and solar energy fields, Journal of Nanomaterials, vol. 7, (2017) pp. 4-74.
[3] G.J.M. Rytwo, Clay minerals as an ancient nanotechnology, Historical uses of clay organic interactions, and future possible perspectives, vol. 9, (2008) pp. 15–17.
[4] S.M. Lee, D. Tiwari, Organo and inorgano-organo-modified clays in the remediation of aqueous solutions, J. Appl. Clay Sci. 59 (2012) 84–102.
[5] M.R. Irshidat, M.H. Al-Saleh, Thermal performance and fire resistance of nanoclay modified cementitious materials, J. Construc. Build. Mater. 159 (2018) 213–219.
[6] S. Pavlidou, C. Papaspyrides, A review on polymer–layered silicate nanocomposites, J. Prog. Polym. Sci. 33 (2008) 1119–1198.
[7] R. Agarwal, N.K. Agrawal, A. Bansal, A. Upadhyay, R. Singh, Neutron irradiation sensitivity of thermal conductivity for Al_2O_3 nanofluids, J. Mater. Res. Express 7 (2020) 1–11.
[8] M. Mousa, N.D. Evans, R.O.C. Oreffo, J.I. Dawson, Clay nanoparticles for regenerative medicine and biomaterial design: a review of clay bioactivity, Biomaterials 159 (2018) 204–214, https://doi.org/10.1016/j.biomaterials.2017.12.024.
[9] X. Wang, M. Jiang, Z. Zhou, J. Gou, D. Hui, 3D printing of polymer matrix composites: a review and prospective, Compos. Part B Eng. 110 (2017) 442–458.
[10] J. W. Hosterman, S. H. Patterson, Bentonite and Fuller's Earth Resources of the United States, U.S. Geological Survey Professional Paper, vol. 1522, (1992) pp. 1-50.
[11] C. Zweben, Thermal materials solve power electronics challenges, Power Electron Technol. 32 (2006) 40–47.
[12] E. Cuce, P.M. Cuce, C.J. Wood, S.B. Riffat, Toward aerogel based thermal super insulation in buildings: a comprehensive review, J. Renew. Sustain. Energy Rev. 34 (2014) 273–299.
[13] M. Wang, N. Pan, Predictions of effective physical properties of complex multiphase materials, J. Mater. Sci. Eng. R 63 (2008) 1–30.
[14] J.F. Wang, K. James, F. Mike, J. Donald, A new approach to modelling the effective thermal conductivity of heterogeneous materials, J. Heat Mass Transf. 49 (2006) 3075–3083.
[15] O.J. Lee, K.H. Lee, T.J. Yim, S.Y. Kim, K.P. Yoo, Determination of mesopore size of aerogels from thermal conductivity measurements, J. Non-Cryst. Solids 298 (2002) 287–292.
[16] J.L. Gurav, A.V. Rao, D.Y. Nadargi, Study of thermal conductivity and effect of humidity on HMDZ modified TEOS based aerogel dried at ambient pressure, J. Sol-Gel Sci. Technol. 50 (2009) 275–280.
[17] D. Dan, H. Zhang, W.Q. Tao, Effective structure of aerogels and decomposed contributions of its thermal conductivity, J. Appl. Thermal Eng. 72 (2014) 2–9.
[18] A. Tinti, A. Tarzia, A. Passaro, R. Angiuli, Thermographic analysis of polyurethane foams integrated with phase change materials designed for dynamic thermal insulation in refrigerated transport, J. Appl. Thermal Eng. 70 (2014) 201–210.
[19] H. Fauzi, H.S.C. Metselaar, T.M.I. Mahlia, M. Silakhori, H.C. Ong, Thermal characteristic reliability of fatty acid binary mixtures as phase change materials (PCMs) for thermal energy storage applications, J. Appl. Thermal Eng. 80 (2015) 127–131.
[20] R. Agarwal, K. Verma, N.K. Agrawal, R. Singh, Comparison of experimental measurements of thermal conductivity of Fe_2O_3 nanofluids against standard theoretical models and artificial neural network approach, J. Mater. Eng. Perform. 28 (2019) 4602–4609.
[21] A. de Gracia, E. Oro, M.M. Farid, L.F. Cabeza, Thermal analysis of including phase change material in a domestic hot water cylinder, J. Appl. Thermal Eng. 31 (2011) 3938–3945.
[22] B. Zalba, J.M. Marin, L.F. Cabeza, H. Mehling, Review on thermal energy storage with phase change: materials, heat transfer analysis and applications, J. Appl. Thermal Eng. 23 (2003) 251–283.
[23] A.L.S. Chan, T.T. Chow, S.K.F. Fong, J.Z. Lin, Performance evaluation of district cooling plant with ice storage, Energy 31 (2006) 2750–2762.
[24] S.W. Choi, K.H. Yoon, S.S. Jeong, Morphology and thermal conductivity of polyacrylate composites containing aluminum/multi-walled carbon nanotubes, J. Appl. Sci. Manuf. 45 (2013) 1–5.
[25] J.A. King, K.W. Tucker, B.D. Vogt, E.H. Weber, C. Quan, Electrically and thermally conductive nylon 6,6, J. Polym. Compos. 20 (1999) 643–654.
[26] J.K. Pandey, S.H. Ahn, C.S. Lee, A.K. Mohanty, M. Misra, Recent advances in the application of natural fiber based composites, J. Macromolecular Mater. Eng. 295 (2010) 975–989.
[27] E. Fukada, Piezoelectricity of wood, J. Phys. Soc. Jpn. 10 (1955) 149–154.
[28] E. Hamed, I. Jasiuk, Elastic modelling of bone at nanostructural level, J. Mater. Sci. Eng.: Rep. 73 (2012) 27–49.
[29] D. Yuan, J. Chen, J. Zeng, S. Tan, Preparation of monodisperse carbon nanospheres for electrochemical capacitors, J. Electrochem. Commun. 10 (2008) 1067–1070.
[30] R. Agarwal, K. Verma, N. K. Agrawal, R. K. Duchaniya, R. Singh, Synthesis, characterization, thermal conductivity and sensitivity of CuO nanofluids, Journal of Applied Thermal Engineering, vol. 102, (2016) pp. 1024–1036.
[31] C. Liu, T. Mather, ANTEC 2004 plastics, Society of Plastic Engineers (2004) 3080–3084.
[32] S. Stankovich, D.A. Dikin, G.H.B. Dommett, K.M. Kohlhaas, E.J. Zimney, E.A. Stach, R.D. Piner, S.T. Nguyen, R.S. Ruoff, Graphene-based composite materials, Nature 442 (2006) 282–286.
[33] T.B. Lewis, L.E. Nielsen, Dynamic mechanical properties of particulate-filled composites, J. Appl. Polym. Sci. 14 (1970) 1449–1471.
[34] L.E. Nielsen, Thermal conductivity of particulate-filled polymers, J. Appl. Polym. Sci. 17 (1973) 3819–3820.
[35] Y. Agari, T. Uno, Estimation on thermal conductivities of filled polymers, J. Appl. Polym. Sci. 32 (1986) 5705–5712.
[36] D. Bruggeman, Dielectric constant and conductivity of mixtures of isotropic materials, Ann. Phys. (Leipzig) 24 (1935) 636–679.
[37] I.H. Tavman, Thermal and mechanical properties of aluminum powder-filled high-density polyethylene composites, J. Appl. Polym. Sci. 62 (1996) 2161–2167.
[38] R. Agarwal, K. Verma, N.K. Agrawal, R. Singh, Sensitivity of thermal conductivity for Al_2O_3 nanofluids, J. Exp. Thermal Fluid Sci. 80 (2017) 19–26.

Further Reading

[1] K. Verma, R. Agarwal, R.K. Duchaniya, R. Singh, Measurement and prediction of thermal conductivity of nanofluids containing TiO_2 nanoparticles, J. Nanosci. Nanotechnol. 17 (2017) 1068–1075.