Thermal coefficients of Earth fuller reinforced with nano-oxide particles

Gyan Prakash Sharma, Arti Bansal and Ramvir Singh ©
Department of Physics, University of Rajasthan, Jaipur 302004, India
E-mail: rvs2020@gmail.com

Keywords: earth fuller, oxide nano-particles, thermal coefficients

Abstract
The present work deals with the study of thermal coefficients of Earth fuller based nanocomposites (EFBNC) with the change in the mass fraction of nano-oxide particles (Al₂O₃, TiO₂) in EF at different temperatures. Thermal Constants Analyser (TPS 2200) has been used to measure thermal conductivity, thermal diffusivity, and specific heat capacity simultaneously of the prepared EFBNC at varying temperatures ranging from 10 °C to 60 °C in steps of 10 at 2 wt%, 4 wt%, 6 wt%, and 8 wt%. Percentage increment in thermal conductivity of EFBNC with TiO₂ was observed approximately 16% and 13% at 30 °C and 60 °C with the increase in the mass fraction of nanoparticles from 2 wt% to 8 wt%. On the other hand, at the same temperature and concentration, a decrement in thermal conductivity of EFBNC with Al₂O₃ was noticed approximately 8% and 3%. The decrement in thermal diffusivity of EFBNC with TiO₂ was found approximately 23% at 30 °C and 11% at 60 °C when concentration increases from 2 wt% to 8 wt% and with Al₂O₃ was approximately 11% and 13% respectively at the same temperature and concentration. Percentage increment in the specific heat of EFBNC with TiO₂ and Al₂O₃ was observed approximately 38% and 9% at 30 °C and 26% and 17% at 60 °C with increment in the mass fraction of nanoparticles from 2 wt% to 8 wt% in EF.

1. Introduction
Clays are normally classified into several particulars on the basis of their chemical composition and particle morphology such as kaolinite, chlorite, halloysite, smectite, and illite [1]. Nanoclays have been studied for various useful applications because of their relatively low impact on the environment, low cost, and availability in abundance [2]. Clay minerals are often used as natural and comfortably accessible nanomaterials with the advanced development and demand of nanotechnology [3]. Nano-clays are layered structural entities of mineral silicates that by stacking these layers form complex clay crystallites [4]. The thermal properties of nanocomposites have become a significant area of research in recent years on account of diverse applications in many fields [5–8]. The advances in processing and synthesis of nano-composites necessitate a better understanding of the interfacial thermal transportation between the host matrix material and nano-particles due to the consequence of interfaces at the nanoscale [9]. To form nanoclay composites the stacks are dispersed in a polymer host matrix as additives for several applications such as flame resistance material, gas permeability modifier, thickening, and gelling agents, wastewater treatment, and mechanical strength enhancer. These nanoclay composites have been widely developed and studied due to their high cation exchange capacity, large surface area, swelling, and rheological behavior [10, 11]. Nanoclay composites have been used for many industrial purposes like aerospace (flame retardant panels and high-performance components), pharmaceuticals (as carriers of drugs and penetrants), construction (structural panels and building sections), automotive (bumpers, gas tanks, exterior and interior panels), chemical processes (catalysts), textiles and food packaging [12]. Recently, cellular interactions with nanoclay composites have been the subject of the main fascination for the researchers as they have potential uses in biomedical applications such as gene therapy, drug delivery, food sustentation, 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, and a large surface area to volume ratio. Nanoclay composites have the capacity to repair or replace damaged organs/tissues and persuade persisting complicated diseases and can be successfully executed in cell transplantation applications in the neural tissue-engineering field. As nanoclay and their composites are usually non-toxic, they have been studied for more biomedical purposes such as wound healing, drug delivery, bone cement, and enzyme immobilizer [13, 14].

The loading of nanoparticles provides an efficacious scattering mechanism for long and mid wavelength phonons that influences heat conduction. Although; interfacial scattering plays a crucial role in nanocomposites, where the increased collisions of phonon prevent the phonons with elevated energy in the hot region of material from moving to the cold region of material and vice versa [15].

There are several techniques to fabricate nano-composites. Sol-gel chemistry is one of the broadly used methods to prepare organic and inorganic nano-composites with manageable experimental conditions [16]. The potential of the material, such as thermal stability, wettabiity, flexibility, and chemical resistance, could be intensified when composites fabricated at a nano-scale. In contrast with bulks, nanostructures hydrophilic and hydrophobic nature was enhanced by generating hierarchically textured surface and penetrable structure from materials with small surface energies [17]. For preparing nano-materials, electro-spinning is a grown-up technology being used for fabricating one-dimensional solid structure at a nano-scale [18–25]. Bio and medical-based composites at nano-scale are the material of choice in all aspects of human life, ranging from usual daily packaging materials, beauty products, and paint fillers to aerospace and automobile applications [26]. Heat transfer rate in porous materials at nano-scale decreases due to the restriction of the movement of gas molecules present between the pores [27]. The heat transfer in aerogels took place due to collision between molecules of gas, thermal radiation, convection in the pores, and conduction due to the solid-skeleton [28, 29]. Thermal properties of composite materials are influenced by the shape and size of reinforcing fillers in host matrix material [30]. Thermally conductive polymer composites used for new innovations in electronic systems by exchanging the parts of machinery due to their lightweight, durability, flexibility, and ability to release heat quickly from the electronic systems [31]. Earth Fuller (Multani Mitti) is a clay type substance that contains mostly magnesium aluminum silicate. It possesses the capacity to decolorize oil and other liquids without using any chemicals. It consists of palygorskite and bentonite and is very useful as fillers in paints, pharmaceuticals, cosmetic products as an active/inactive ingredient, and the most popular material for the regeneration of industrial oil in the world in oil processing instruments [32]. Multani mitti known as calcium bentonite has the capacity to reduce impurities. Multani mitti helps us to improve skin radiance and is excellent for irritated and aggravated skin. Its cooling agents soothe the skin, relieves the inflammation caused due to aggravated sunburns, and removes the dirt and dead skin cells accumulated, and replace it with fresh, radiant, and glowing skin [33].

In the present investigations, thermal constants analyzer TPS 2200 is used due to its fast reaction time, robust design, and its ability to measure thermal parameters simultaneously. The TPS 2200 instrument uses a thin, electrically insulated resistive Kapton sensor that works both as a resistance temperature detector and a heat source [34]. When used to investigate the thermal properties of powders, the sensor is inserted between the test powder in the sample holder. Low power is applied across the sensor in order to produce a consistent heat flux at the resistive element interface. The increase in temperature of the sensor is recorded. Temperature increase depends on the surrounding material’s thermophysical properties. The selection of the sensor in TPS for the measurement of thermal properties depends on the nature of the composite material, size of the sample holder, and temperature range [34–38].

### 2. Materials and method

#### 2.1. Preparation of Matrix Phase Material (EF) for composites

For the preparation of matrix phase material for composite, naturally available EF collected from an arid zone of Rajasthan, India in the form of a rock type in small pieces. It was ground to fine-grain particles with the help of a girding machine (REMI Ato mix Blender), hammer, and mortar-pesle. After that, a ball mill (Restch P100) was used for converting the size of the particles of EF in micro/nano-scale. The ratio of EF powder and ball in ball mill machine was 10:1 with 5 min rest and 15 min work process for 2 h under the atmospheric pressure

### Table 1. Particulars of the metal oxide nanoparticles.

| S. No. | Material                   | Manufacturer       | Average Particle Size | Assay  |
|--------|----------------------------|--------------------|-----------------------|--------|
| 1.     | Al₂O₃ powder               | Sigma Aldrich      | 13 nm (TEM)           | 99.8%  |
| 2.     | TiO₂ powder Titanium(IV)oxide | Sigma Aldrich   | 21 nm (TEM)           | 99.5%  |
temperature. Then it was sieved with mess no. 80, 0.0017 INS, the micron-size fine porous material of less than 186 μm was obtained for the investigation.

2.2. Preparation of EFBNC

For the preparation of EFBNC, nano oxide powder of Al₂O₃ and TiO₂ with specifications given in Table 1 were used as filler in the host matrix. As per requirement, nano oxide material was weighed in different amounts using a digital sensitive balance (Electronic balance; Precisa; XB 220A) having a high resolution of 0.0001 g. These nano oxide particles were loaded and then mixed in the base matrix material of EFB (size ≤186 μm) with varying weight concentration (2 wt%, 4 wt%, 6 wt%, and 8 wt%) of each with the help of a grinding machine and mortar-pestle for about an hour at atmospheric conditions.

2.3. Measurement of thermophysical properties

Thermal Constants Analyser (TPS 2200) equipment, which is based on the transient plane heat source, was used to investigate the thermal coefficients such as thermal conductivity, thermal diffusivity, and specific heat capacity of the prepared EFBNC. In this work, an electrically conducting metallic double spiral Kapton sensor 5501 (Red cable, radius 6.403 mm, probing depth 30 mm) covered by an insulating material in both sides was used to measure the thermal coefficients for the pulse of 30 mW power for 10 s. For measuring accurate thermal properties, the EFBNC powder was filled in the sample holder with the sensor (5501) inserted horizontally between two halves of the holder. The sample was filled in the sample holder correctly with the help of a spatula. During the filling of the sample in the sample holder, it was confirmed that the material should be uniformly distributed in the holder to abstain from the error in the measurements. During the measurements, an electrical current passes through the sensor and increases the temperature of the sensor which was recorded with time. To achieve and regulate the desired temperature, each sample was cooled and heated in a high-quality thermal chamber (Tenney-environmental) with the sensor fixed in the sample holder, which mounted on a stand. To record the internal environment temperature of the thermal chamber, a digital meter connected with a thermocouple was used and fitted in the center of the chamber near the sample holder. The temperature of the
nano-composite sample equilibrated for two hours in the TPS thermal chamber. Three observations were recorded for each EFBNC sample within the gap of 15 min at a constant temperature and mass concentration to ascertain accuracy and consistency in the measurements. The average value of three observations of thermal properties of nano-composites was reported and the deviation of these three sets of experimental observations was minimized ensuring the accuracy in the measurements. In this investigation, two types of oxide particles at a nano-scale were loaded and mixed in the base host matrix (EF) at varying mass concentrations (2, 4, 6, and 8 wt%). For each sample, thermal properties were measured at temperatures varying from 10 to 60 °C using TPS 2200 setup as shown in figure 1. For the real-world applications, normal operating temperature varies between 10 °C to 60 °C.

2.4. Standard deviation for thermal properties measurement

In order to eliminate sequential mechanical errors and temperature instabilities, we performed three measurements at each temperature within a span of 15 to 20 min. Standard deviation (SD) in the measurement of thermal properties of nano-composites [39] for different concentrations was obtained using the equation below,

$$ SD = \sqrt{\frac{\sum (TP_i - \overline{TP})^2}{n^2}} $$

where $(TP_i)$ is the thermal property of a nano-composite for each measurement, $(\overline{TP})$ is the average thermal property and $n$ is the number of measurements.

3. Results and discussion

Figure 2 shows significant variation in thermal conductivity of pure host matrix material EF and nano-oxide particles $\text{Al}_2\text{O}_3$ and $\text{TiO}_2$ with the change in temperature from 10 °C to 60 °C. Observations indicated that the thermal conductivity of all three samples increases with the increment in temperature. Percentage increment in thermal conductivity of EF, $\text{Al}_2\text{O}_3$, and $\text{TiO}_2$ was approximately up to 10%, 17% and 9% when we increase the temperature from 10 °C to 30 °C. Further increasing the temperature thermal conductivity increases significantly and it was approximately 42% in EF, 56% in $\text{Al}_2\text{O}_3$, and 18% in $\text{TiO}_2$ at 60 °C. Results show that increment in thermal conductivity of pure EF was due to the molecular and phonon vibrations, decrement in the mean free path among the molecules of EF at room and at higher temperatures, and also due to its metallic chemical composition so that transfer of heat takes place easily through the particles with increasing

![Figure 2. Variation in thermal conductivity of EF, $\text{Al}_2\text{O}_3$, and $\text{TiO}_2$ powder with temperature.](image-url)
temperature. Enhancement in thermal conductivity of nano oxides was due to larger available surface area for heat transfer, packing density, and larger scattering at the nanoscale with increasing the temperature. Nano Al₂O₃ particles have larger thermal conductivity variation at room and high temperatures from nano TiO₂ particles because; at nanoscale Al₂O₃ has a larger surface area for heat transfer than TiO₂. It reflects that nano Al₂O₃ has a much better heat conduction ability than TiO₂.

Figure 3. Variation in thermal conductivity of EFBNC with Al₂O₃ and TiO₂ at different temperatures.
Figure 3 represents the schematic variation of thermal conductivity at temperatures for EFBNC with 2 wt%, 4 wt%, 6 wt%, and 8 wt% mass fraction of Al$_2$O$_3$ and TiO$_2$ in host matrix material EF. Figures 3(a) and (e) show the variation in thermal conductivity of EFBNC with the loading of 2 wt% of Al$_2$O$_3$ and TiO$_2$ nano-oxide particles in EF powder within the temperature range from 10°C to 60°C. It was observed that thermal conductivity increases approximately up to 9% with Al$_2$O$_3$ and 13% with TiO$_2$ in EFBNC if we increase the temperature from 10°C to 30°C. Further increase in thermal conductivity in both EFBNC was observed with increasing temperature up to 60°C. Percentage increment in thermal conductivity was observed approximately up to 40% in EFBNC with Al$_2$O$_3$ and 37% in EFBNC with TiO$_2$ oxide particles. Results show that from 30°C to 50°C, EFBNC with TiO$_2$ has higher variation in thermal conductivity than EFBNC with Al$_2$O$_3$ but when it increases to 60°C, EFBNC with Al$_2$O$_3$ shows a slightly higher variation in thermal conductivity than EFBNC with TiO$_2$ because at higher temperatures TiO$_2$ NPs restrict the thermal vibration that is responsible for heat transfer in comparison to alumina NPs. Figures 3(b) and (f) show the variation in thermal conductivity of EFBNC within the temperature range from 10°C to 60°C with a 4 wt% mass fraction of nano oxide particles in EF powder. Observation reveals that thermal conductivity increases approximately up to 47% in EFBNC with...
Al$_2$O$_3$ and approximately up to 31% in EFBNC with TiO$_2$ with the increase in temperature from 10 °C to 60 °C. Although the percentage increment in thermal conductivity for EFBNC with TiO$_2$ is higher than that of EFBNC with Al$_2$O$_3$ with 6 wt% and 8 wt% particle loading as shown in figures 3(c), (d), and (g), (h). Higher thermal conductivity of EFBNC attributed to enhanced heat transfer that mainly depends on the available surface area, packing density, molecular vibration, phonon scattering, and heat transfer characteristics of EFBNC. As the particle size is smaller and higher the temperature more will be the molecular vibrations and phonon scattering that in turn enhances the thermal conductivity of EFBNC.

Figure 4 shows the variation in thermal conductivity with the mass fraction of nano oxide particles in EFBNC for 10 °C, 20 °C, 30 °C, 40 °C, 50 °C, 60 °C temperatures. All six graphs showed that the thermal conductivity of EFBNC with TiO$_2$ increases, however, the thermal conductivity of EFBNC with Al$_2$O$_3$ gradually decreases with the increase of the weight fraction of nanoparticles. It was observed that for EFBNC with TiO$_2$, increment in thermal conductivity from 2 wt% to 4 wt% concentration is more as compared to increment in thermal conductivity from 4 wt% to 8 wt% concentration at all temperatures.

At room temperature (30 °C) and at the highest temperature which is taken for this experiment (60 °C), percentage increment in thermal conductivity of EFBNC with TiO$_2$ was found to be approximately 16% and 13% respectively and percentage decrement in thermal conductivity of EFBNC with Al$_2$O$_3$ was found to be approximately 8% and 3% respectively with the increase in the mass fraction of nanoparticles from 2 wt% to 8 wt%. The result shows that the thermal conductivity increases in EFBNC with TiO$_2$ due to the large surface area of the nanoparticles for heat transfer, change in the density of the material, large scattering at the powder interface, decrement in the air void present in the EF, phonon-phonon scattering takes place at the interface of the powdered material so that thermal conductivity increases. Thermal conductivity decreases in EFBNC with Al$_2$O$_3$ because of the restrictions in thermal vibration of EFBNC.

Figure 5 shows the significant variation in thermal diffusivity of pure EF, pure nano Al$_2$O$_3$ and pure nano TiO$_2$ with the change in temperature from 10 °C to 60 °C. Results indicated that thermal diffusivity of EF and nano Al$_2$O$_3$ increases with the increment in temperature. Percentage increment in thermal diffusivity for Al$_2$O$_3$ (27%) is greater than that of EF (16%) when we increase the temperature from 10 °C to 60 °C. The thermal diffusivity of nano TiO$_2$ increases as the temperature increases up to 30 °C with the increment of 1% and after that, the thermal diffusivity decreases with the decrement of 3% when we reach 60 °C. Thermal diffusivity of pure EF and pure nano Al$_2$O$_3$ increases due to the large amplitude of molecular vibration, the available surface area, packing density, molecular vibration, phonon scattering, and heat transfer characteristics of EFBNC.
area for heat transfer, and heat-conducting particles present in the material. But thermal diffusivity of pure nano 
TiO$_2$ decreases with increasing the temperature due to higher amplitude of thermal vibrations and thus the effect 
of Unklapp-scattering (phonon-phonon scattering) is dominant, which are taking place in nano TiO$_2$, resulted 
in reducing the phonon mean free path length and small surface area for transfer of heat.

Figure 6 represents the variation in thermal diffusivity with temperature for EFBNC at 2 wt%, 4 wt%, 6 wt%, and 8 wt% loading of nano Al$_2$O$_3$ and TiO$_2$ in the matrix material EF. Observation shows that the thermal 
diffusivity of EFBNC with TiO$_2$ increases with the increase in temperature for all the prepared EFBNC and 
found that increment in thermal diffusivity is approximately 16%, 13%, 11%, and 18% with 2 wt%, 4 wt%, 
6 wt%, and 8 wt% for EFBNC with TiO$_2$ as we increase the temperature from 10 °C to 30 °C. Thermal diffusivity 
of EFBNC with Al$_2$O$_3$ decreases up to 30 °C and after that, it increases with the increase in temperature from 
30 °C to 60 °C. Maximum percentage decrement (7%) was found with 8 wt% concentration as the temperature 
increases from 10 °C to 30 °C and maximum percentage increment (33%) was found with 2 wt% concentration 
as the temperature increases from 30 °C to 60 °C. Minimum percentage decrement (2%) in thermal diffusivity 
was found with 6 wt% concentration as the temperature increases from 10 °C to 30 °C and minimum 
percentage increment (24%) was found with 6 wt% concentration as the temperature increases from 30 °C to 
60 °C. Result reveals that as increasing the mass fraction of TiO$_2$ oxide particles in EF then particle-particle 
interaction and small amplitude of thermal vibration between the particles of TiO$_2$ becomes more dominant 
than EFBNC with Al$_2$O$_3$ to increase the surface area for transferring the heat but the increment in thermal diffusivity of EFBNC with Al$_2$O$_3$ at higher temperature retarded due to higher amplitude of thermal vibrations 
present in the material with increasing the temperature.

Figure 7 shows the variation of thermal diffusivity with the mass concentration of nano Al$_2$O$_3$ and TiO$_2$ in 
the EF matrix material for 10 °C to 60 °C temperatures. Observation reveals that thermal diffusivity of both 
EFBN C decreases with the increase of the mass fraction of nanoparticles in EF. It was observed that EFBNC with 
TiO$_2$ showed about a linear decrement in thermal diffusivity from 2 wt% to 8 wt% concentration for all 
temperatures. At room temperature (30 °C) and at the highest temperature which is taken for this experiment
results show that by increasing the mass fraction of Al\textsubscript{2}O\textsubscript{3} in EF at a fixed temperature, thermal diffusivity decreases a little bit as compared to EFBNC with TiO\textsubscript{2} because at a higher mass fraction of Al\textsubscript{2}O\textsubscript{3} in EF particle-particle interaction becomes negligibly small to increase the thermal vibration which is responsible for the phonon-phonon scattering, decrease in surface area for heat transfer and diffusion rate of particles decreases so that thermal diffusivity shows decrement with Al\textsubscript{2}O\textsubscript{3} oxide particles. Because of linear decrement in thermal diffusivity of EFBNC with increasing mass fraction of TiO\textsubscript{2} nanoparticles, it may be used as a cosmetic product to protect the human skin from the harmful radiation present in the environment and restrict the heat transfer.

Figure 8 shows the variation in the specific heat of pure EF, pure Al\textsubscript{2}O\textsubscript{3}, and pure TiO\textsubscript{2} with the change in temperature from 10 °C to 60 °C. Results indicated that the specific heat of all pure samples increases with the increase in temperature. Percentage increment in the specific heat of pure Al\textsubscript{2}O\textsubscript{3} (23%) is greater than that of pure EF (22%) and pure TiO\textsubscript{2} (17%) as we increase the temperature from 10 °C to 60 °C. Specific heat is a measure of the ability of the material to absorb heat. The heat first increases the kinetic energy of the molecules
Figure 8. Variation in Specific heat capacity of EF, Al₂O₃ and TiO₂ powder with different temperatures.

Figure 9. Variation in specific heat capacity of EFBNC with Al₂O₃ and TiO₂ at different temperatures.
and molecules can also store energy in vibrations and rotations. The result shows that nano Al$_2$O$_3$ shows a higher increment in specific heat with temperature because as the substance heats up, the average kinetic energy of the molecules increases. The collisions impart enough energy to allow rotation to occur in the material molecules and then contribute to the internal energy and raise the specific heat.

Figure 9 shows the variation in specific heat capacity of EFBNC with varying the temperature from 10 °C to 60 °C keeping the mass fraction of nano oxide particle in EF fixed. Figure 9(a) represents the variation in specific heat with 2 wt% loading of nano oxide particles in base powder EF with varying the temperature. It was observed that specific heat increases approximately up to 7% in EFBNC with TiO$_2$ and 13% in EFBNC with Al$_2$O$_3$ at 30 °C. Further increasing the temperature up to 60 °C, the specific heat capacity of EFBNC with TiO$_2$ increases to 32%, and a 19% increment is observed in EFBNC with Al$_2$O$_3$. The result shows that the specific heat capacity in EFBNC increases with increasing the temperature but higher increment was observed in EFBNC with TiO$_2$ because the particles of TiO$_2$ are more sensitive and contributed to increasing kinetic energy of the molecules with increasing the temperature, which is responsible to increase in internal energy of EFBNC with TiO$_2$ as compared to EFBNC with Al$_2$O$_3$. Approximately

Figure 10. Variation in specific heat capacity of EFBNC with Al$_2$O$_3$ and TiO$_2$ at the different mass fractions.
similar behavior is observed for the specific heat capacity of EFBNC with 4 wt%, 6 wt%, and 8 wt% mass fraction of nano oxide particles in EF from temperature 10 °C to 60 °C as shown in figures 9(b)–(d).

Figure 10 shows the variation in the specific heat of EFBNC with different concentrations at temperatures ranging from 10 °C to 60 °C. All six graphs show that the specific heat of EFBNC with TiO$_2$ increases, however, the specific heat of EFBNC with Al$_2$O$_3$ gradually decreases with the increase of weight concentration of nanoparticles for all temperatures. It was observed that for both the EFBNC, increment in specific heat from 2 wt% to 8 wt% concentration is almost linear but the increment in the specific heat of EFBNC with TiO$_2$ was more than that of EFBNC with Al$_2$O$_3$ for all temperatures.

Percentage increment in the specific heat of EFBNC with TiO$_2$ and Al$_2$O$_3$ was found to be approximately 38% and 9% at 30 °C and 26% and 17% at 60 °C with the increase in the concentration of nanoparticles from 2 wt% to 8 wt% in EF. Results reveal that by increasing the mass fraction of TiO$_2$ in EF at a constant temperature, a faster increase in specific heat capacity is noticed as compared to the increment in specific heat with Al$_2$O$_3$ because at a higher mass fraction of TiO$_2$ in EF, a large amplitude of rotational and vibration contribution is responsible to increase the kinetic energy of the material.

4. Conclusions

In the present work, thermal coefficients of Earth fullers based nano-composites (EFBNC) were investigated experimentally using Thermal Constant Analyser. Oxide nanoparticles were used as additives with various concentrations in the base matrix of EF to form EFBNC. The rate of increase in thermal conductivity with an increase in the mass fraction of oxide nanoparticles at different temperatures for EFBNC with Al$_2$O$_3$ was lower as compared to EFBNC with TiO$_2$. Thus EFBNC with TiO$_2$ would be more efficient as compared to EFBNC with Al$_2$O$_3$ for heat transfer applications. Our analysis shows that:

1. Thermal conductivity of EFBNC with TiO$_2$ was increased up to 16% at 30 °C and 13% at 60 °C with the increase in the mass fraction of nanoparticles from 2 wt% to 8 wt%. On the other hand, at the same temperature and concentration, a decrement in thermal conductivity of EFBNC with Al$_2$O$_3$ was noticed approximately 8% and 3%.

2. Thermal diffusivity of EFBNC with TiO$_2$ decreases approximately 23% and 11% and decrement in thermal diffusivity of EFBNC with Al$_2$O$_3$ was noticed approximately 11% at 30 °C and 13% at 60 °C respectively when loading increases from 2 wt% to 8 wt%.

3. The specific heat of EFBNC with TiO$_2$ and Al$_2$O$_3$ was increased approximately 38% and 9% at 30 °C and 26% and 17% at 60 °C with the increase in the mass fraction from 2 wt% to 8 wt% of nanoparticles.

4. It also observed that the thermal conductivity increases with an increase in temperature for both types of EFBNC. This opens up a new direction of research for medical sciences, agriculture engineering, and thermal engineering as heat storage devices, development of beauty products to remove oil from skin, the oil exploration industry, in thermal paints, and in the film industry also.

Acknowledgments

The authors are thankful to DST Purse and RUSA grants for providing the nano oxide particles and instrumental facilities.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

ORCID iDs

Ramvir Singh © https://orcid.org/0000-0003-3380-039X

References

[1] Nazir M S, Kassim M H M, Mohapatra L, Gilani M A, Raza M R and Majeed K 2016 Characteristic properties of nanoclays and characterization of nano particulates and nanocomposite J. of Spr. in Nanoclay Reinf. Poly. Comp. 87 35–55
[2] Muller K, Buginicourt E, Latorre M, Jorda M, Sanz Y E, Lagaron J M, Miesbauer O, Bianchin A, Hankin S and Bolz U 2017 Review on the processing and properties of polymer nanocomposites and nanocoatings and their applications in the packaging, automotive and solar energy fields J. of Nanomater. 74–74
[3] Sharma G P, Agarwal R, Bansal A, Agrawal N K and Singh R 2020 Effect of climatic conditions on the thermal conductivity of earth fuller J. Mater. Today Proc. 30 183–9
[4] Lee S M and Tiwari D 2012 Organo and inorganico–organic–modified clays in the remediation of aqueous solutions J. Appl. Clay Sci. 59 84–102
[5] Costescu R M, Cahill D G, Fabreguette F H, Sechrist Z A and George S M 2004 Ultralow thermal conductivity in W/Al2O3 nanolaminates Sci. 303 989–90
[6] Frasher R 2006 Thermal interface materials: historical perspective, status, and future directions Proc. IEEE 94 1571–86
[7] Dresselhaus M S, Chen G, Tang M Y, Yang R G, Lee H, Wang D Z, Ren Z F, Fleurial J P and Gogna P 2007 New directions for low-dimensional thermoelectric materials Adv. Mater. 19 1043–53
[8] Tian W X and Yang R G 2007 Thermal conductivity modeling of compacted nanowire composites J. Appl. Phys. 101 054320
[9] Srivastava G P 1990 The Physics of Phonons Book (Taylor & Francis CRC Press) pp 1–438
[10] Irsheid M R and Al-Saleh M H 2018 Thermal performance and fire resistance of nanocementitious materials J. Constr. Build. Mater. 15 213–9
[11] Pavlidou S and Papaspyridou C 2008 A review on polymer–layered silicate nanocomposites J. Prog. Polym. Sci. 33 1119–98
[12] Agarwal R, Agrawal N K, Bansal A, Upadhyay A and Singh R 2020 Neutron irradiation sensitivity of thermal conductivity for Al2O3 nanofluids J. Mater. Res. Express 7 1–11
[13] Mousa M, Evans N D, Orefio R O C and Dawson J J 2018 Clay nanoparticles for regenerative medicine and biomaterial design: a review of clay bioactivity Biomat. 159 204–14
[14] Wang X, Jiang M, Zhou Z, Gou J and Hui D 2017 3D printing of polymer matrix composites: a review and prospective Compos. Part B Eng. 110 442–58
[15] Choi S H, Maruyama S, Kim K K and Lee J H 2003 Evaluation of the phonon mean free path in thin films by using classical molecular dynamics J. Korean Phys. Soc. 43 717–53
[16] Lai S M, Wang C K and Shen H F 2005 Properties and preparation of thermoplastic polyurethane/silica hybrid using sol-gel process J. Appl. Polym. Sci. 97 1316–23
[17] Lim H S, Baek J H, Park K, Shin H S, Kim J and Cho J H 2010 Multifunctional hybrid fabrics with thermally stable superhydrophobicity Adv. Mater. 22 2138–41
[18] Wu J, Wang N, Zhao Y and Jiang L 2013 Electrospinning of multilevel structured functional micro/nanofibers and their applications J. Mater. Chem. 1. 17290–5
[19] Son W K, Youk J H, Lee T S and Park W H 2004 Electrospinning of ultrafine cellulose acetate fibers: studies of a new solvent system and deacetylation of ultrafine cellulose acetate fibers J. Polycy. Sci. Polycy. Phys. 42 5–11
[20] Agarwal R, Verma K, Agrawal N K and Singh R 2017 Sensitivity of thermal conductivity for Al2O3 nanofluids J. Exp. thermal fluid Sci. 80 19–26
[21] Xu X, Jiang L, Zhou Z, Wu X and Wang Y 2012 Preparation and properties of electros spun soy protein isolate/polyethylene nano fiber membranes ACS Applied Materials & Inter. 4 4331–7
[22] Zhao Y, Cao X and Jiang L 2007 Bio-mimic multichannel microtubotes by a facile method J. Am. Chem. Soc. 129 764–5
[23] Zheng R, Meng X, Tang F, Zhang L and Ren J 2009 A general, one-step and template-free route to rattle-type hollow carbon spheres and their application in lithium battery anodes J. Phy. Che. 113 13065–9
[24] Jia C L, Sun L D, Yan Z G, Pang Y C, You L P and Yan C H 2007 Iron oxide tube-in-tube nanostructures J. Phy. Che. 111 13022–7
[25] Xia Y, Yang P, Sun T Y, Wu Y, Mayer B, Gates B, Yin Y, Kim F and Yan H 2003 One-dimensional nanostructures: synthesis, characterization, and applications J. Adv. Mater. 15 353–89
[26] Pandey I K, Ahn S H, Lee C S, Mohanty A K and Misra M 2010 Recent advances in the application of natural fiber-based composites Macromol. Mater. Eng. 295 975–89
[27] Guruswamy L, Rao A V and Nadargi D Y 2009 Study of thermal conductivity and effect of humidity on HMDZ modified TEOS based aerogel dried at ambient pressure J. Sol-Gel Sci. Technol. 50 275–80
[28] Dan D, Zhang H and Tao W Q 2014 Effective structure of aerogels and decomposed contributions of its thermal conductivity J. Appl. Thermal Eng. 72 2–9
[29] Lee O J, Lee K H, Yim T J, Lee J H and You K P 2002 Determination of mesopore size of aerogels from thermal conductivity measurements J. Non-Cryt. Sol. 298 387–92
[30] Choi S W, Yoon K H and Jeong S S 2013 Morphology and thermal conductivity of polycarbonate composites containing aluminum/multi-walled carbon nanotubes J. Appl. Sci. Manuf. 45 1–5
[31] King J A, Tucker K W, Vogt B D, Weber E H and Quan C 1999 Electrically and thermally conductivity polye nyl 6,6 J. Polym. Compos. 20 643–54
[32] Hosterman J W and Patterson S H 1992 Bentonite and Fuller’s earth resources of the United States US Geological Survey Professional Pap. 1522 1–30
[33] Yadav N and Yadav R 2015 Preparation and evaluation of herbal face pack Int. J. of Recent Sci. Research 6 4334–7
[34] Gustafsson M, Karawacki E and Gustafsson S E 1994 Thermal conductivity, thermal diffusivity and specific heat of thin samples from transient measurements with hot disk sensors Rev. Sci. Instrum. 65 3856.
[35] Bohac V, Gustafsson M K, Kubicar L and Gustafsson S E 2000 Parameter estimations for measurements of thermal transport properties with the hot disk thermal constants analyzer Rev. Sci. Instrum. 71 2452
[36] Gustafsson S E, Suleiman B, Saxena N S and UHaq I 1991 Transient plane source technique: experimental design criteria High Temp-High Press. 23 289–93
[37] Goyal V, Sumant A V, Teweldebrhan D and Balandin A A 2012 Direct low-temperature integration of nanocrystalline diamond with GaN substrates for improved thermal management of high-power electronics Adv. Punct. Mater. 22 1525–30
[38] Warzoha R J and Fleischer A S 2014 Determining the thermal conductivity of liquids using the transient hot disk method. Part II: establishing an accurate and repeatable experimental methodology J. Heat and Mass Transfer 71 790–7
[39] Karimirpour A, Ghasemi S, Darvanjooghi M H K and Abdollahi A 2018 A new correlation for estimating the thermal conductivity and dynamic viscosity of CuO/liquid paraffin nanofluid using neural network method Int. Commun. Heat Mass Transfer. 92 90–9