THERMODYNAMIC STUDY OF THE EFFECTS OF NANOPARTICLES ON THERMAL ORIGIN
A Review

by

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Review paper
https://doi.org/10.2298/TSCI220827193W

According to ISO and ASTM specifications, nanoparticles are described as the particles with a size in the range of 1-100 μm with one or more dimensions, being the base of nanotechnology. In this study, a comprehensive review on the thermodynamic effects of nanoparticles on thermal origin is carried out. Firstly, the classification of nanoparticles, which includes organic, inorganic, and carbon-based nanoparticles are introduced. Then, various applications of nanoparticles in many fields including cosmetics, sunscreens, electronics, catalysis, mechanics, manufacturing, materials, environment, and energy harvesting are briefly highlighted. A comprehensive review on the recent research trends on the impacts of nanoparticles on thermal origin is collected and summarized. Afterwards, the physical, chemical, and thermal properties of nanoparticles are highlighted. In the end, a conclusion is withdrawn.

Key words: *heat transfer, nanoparticles, thermodynamic, thermal origin, thermal conductivity, thermal coefficient*

Introduction

Nanotechnology is a field of science, which includes various areas that include chemistry, physics [1, 2], biology, material science, medical science [3], therapeutics, and engineering [4, 5], having been implemented in several devices and materials at nanoscale [6]. The word *Nano* is originated from the Greek word of nanos, which means extremely very small or dwarf obtained through nanostructure fabrication. Nanois combined with a wide range of techniques in various fields including nanoscience, nanomaterials, nanochemistry, and nanotechnology. Nanotechnology has been utilized by craftsmen around the world nearly since 2600 BC [7]. Some of the most famous examples of matter molecular-scale manipulation in ancient empires include, Maya Blue pigment (AD 800, Chichen Itza), The Lycurgus cup (AD 400, Rome), steel sword of Damascus (AD 300-1700, Middle East), luster pottery (AD 800-1600, Mediterranean region), Deruta ceramics (AD 1450-1600, Umbria, Italy), and air-purifying church windows (medieval Europe) [8]. The concept of nanotechnology was first introduced in 1959 by Richard Feynman [9], who was a theoretical physicist during his well-known lecture entitled as *There is plenty of room at the bottom* at the annual American Physical Society meeting at Caltech. Later,

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the concepts of nanomaterials have started after the mid of 20th century [10]. Nanomaterials are described as the materials having one dimension ranging from 1-100 μm [11]. They differ from their bulk materials in numerous features including surface are, shape, size, and reactivity. Therefore, they show an excellent performance when they used in various applications [12-14]. They are capable of providing new devices and products with higher efficiency as compared to the traditional bulk materials [15, 16]. In recent years, they have been used in various commercial products [17, 18], such as biomedical imaging, energy storage, electronic products, cosmetics, paints, and conversion devices [19, 20].

The basic element of nanomaterials are the nanoparticles, which refer to the particles with dimensions in the nanometers range. They are a novel class of materials that consist of particulate substances, with at least one dimension smaller than 100 μm [21-23]. Nanoparticles can be originated from organic, inorganic or/and combination of natural organic, for instance from living organisms, such as sear salt, pollen, dust, volcanic eruption and erosion particles; incident origin, such as emissions of diesel engine and industrial processes; and engineered particles such as metal, metal oxides, nanotubes, or fullerenes [24-28]. Nanoparticles are of different dimensions, shapes and sizes, depending on their materials [29]. For instance, nanoparticles can be zero-dimensional, 1-D, 2-D or 3-D. Zero-dimensional nanoparticles, such as nanodots, have a fixed breadth, height and length at a single point, while 1-D nanoparticles, such as graphene, only possess a single parameter. The 2-D nanoparticles, such as carbon nanotubes (CNT), only have breadth and length, while 3-D nanoparticles, such as gold nanoparticles, have all the parameters (breadth, length, and height). The nanoparticles can be formed of various sizes and structures, such as tubular or irregularly shaped particles, which can exist in fused, spherical, agglomerated or aggregated forms. The surface of nanoparticles can be irregular, with varied surfaces, uniform or non-uniform. Some of the nanoparticles are amorphous or crystalline, and can be agglomerated or loose, and single or a multi-crystal solid [30].

Nanoparticles have a different property than their bulk materials, since they exhibit exceptional nanoscale chemical, physical and biological properties, in comparison their respective counterparts at larger scales. Nanoparticles can be easily suspended in liquids, having a higher ratio of strength to weight, improved conductivity and enhanced optical or magnetic properties. They are also characterized by ratios of surface area to volume [31]. Nanoparticles exist in aquatic environments, having the ability to affect the chemistry of water and processes in various manners, to macro-sized counterparts, as they are mostly more reactive [32, 33]. Due to their specific properties, they are considered as valuable materials, since they have significant economic potentials and benefits to both individuals and organisms [34, 35].

In this paper, an extensive review is carried out regarding the effects of nanoparticles on the thermal origin. also, a classification of nanoparticles is briefly summarized, as well as a presentation of the properties and characterization of nanoparticles.

Classifications of nanoparticles

Nanoparticles can be classified into various types, including the organic nanoparticles, inorganic nanoparticles, and carbon-based nanoparticles, as shown in fig. 1.

Organic nanoparticles

Organic nanoparticles are characterized by being biodegradable, and non-toxic, being mostly used in the field of biomedicine. Dendrimers, micelles, liposomes, and polymers are some of the most commonly known types of the organic nanoparticles:

– Dendrimers

Morphologically, dendrimers are characterized by a high branched structure, which is generated from one or more cores, having star-shaped macromolecules with non-ometric dimensions [36]. There are different shapes and sizes of dendrimers, when compared between them [37]. Their size is controlled by the generation numbers, which are permitted to grow over the cores. Dendrimers have potential applications in both materials and biological sciences, including delivery of drug [38], transfection of gene, catalysis, harvesting of energy [39], molecular weight, determination of size, photo activity, modification of rheology, and nanoscale science and technology [40]. Figure 2 depicts the organic dendrimers nanoparticles.

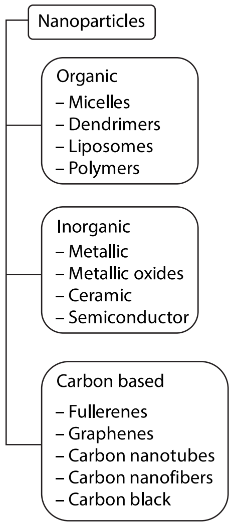

Figure 1. Classification of nanoparticles [41]

– Micelles

Micelles are described as nanostructures produced of amphiphilic molecules, such as lipids and polymers [43]. They have the capability of hiding their hydrophobic sets inside the structure, exposing the hydrophilic sets. They organize their structure in a reverse way in lipid-rich environments [44], where fig. 3 illustrate the micelles organic nanoparticles.

– Liposomes

Liposomes are vesicles made completely of lipidic compounds, where various types of liposomes, such as multilamellar vesicle and unilamellar vesicle, have different sizes depending on their formation. The unilamellar liposomes are the most common type of liposomes with size ranging from 100-800 μm [46]. They have high production cost and content leakage. Figure 4 shows the liposomes organic nanoparticles.

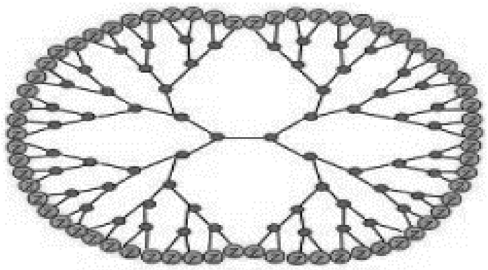

Figure 2. Organic dendrimers nanoparticles [42]

– Polymeric nanoparticles

Polymeric nanoparticles are generally made of biodegradable and biocompatible polymers. They can be nanospheres or nanocapsular in shape [47], where nanospheres are particles

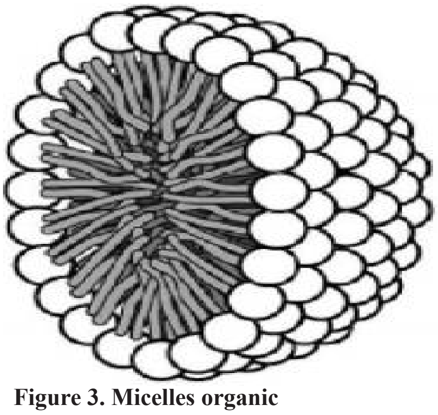

Figure 3. Micelles organic nanoparticles [45]

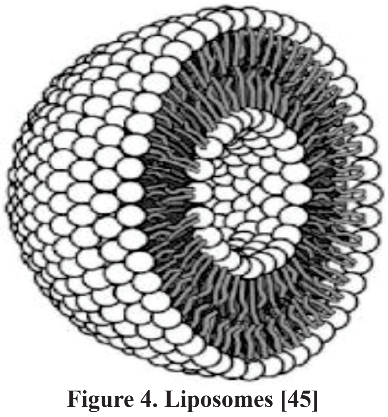

Figure 4. Liposomes [45]

matrix with solid mass, while the rest of molecules are adsorbed at the external boundary of spherical surface. In the case of nanocapsular, the solid mass is entirely encapsulated within the particle [48]. They have a size in the range of 1-1000 μm. Polymeric nanoparticles can be subdivided into natural and biosynthesis polymers as well as chemo-synthesis-based polymeric nanoparticles [49].

Inorganic nanoparticles

Inorganic nanoparticles are generally made of non-carbon matter. The inorganic particles include metallic, metallic oxides, ceramic and semiconductor nanoparticles.

– Metallic nanoparticles

Metallic nanoparticles are made of the precursors of metals, which are synthesized from metals to nanometric sizes by using either destructive or constructive techniques [50]. Several metals such as Al, Cd, Cu, Co, Au, Fe, Pb, Zn, and Ag can be synthesized into nanoparticles [51]. These nanoparticles have specific properties, such as lower size between 10-100 μm, can have spherical and cylindrical shapes, amorphous and crystalline structure, higher surface area to volume ratios, charge density and surface charge, pore size, color, the reactivity and sensitivity to various environmental factors, such as moisture, air, sunlight and heat [33].

– Metallic oxides nanoparticles

The metallic oxide nanoparticles are derived and synthesized, by modifying their respective metal counterparts' properties due to their enhanced reactivity and efficiency [52]. They are generally synthesized, and they mostly use metal oxides nanoparticles include Fe_2O_3, Al_2O_3, Ti_2O_2, Ce_2O_2, Mg_2O_3 (magnetite), Si_2O_2, and ZnO. These nanoparticles derive their exceptional physical-chemical properties from their smaller size, as well as their higher corner density or the sites of edge surface [53].

– Ceramics nanoparticles

Ceramic nanoparticles are referred to non-metallic and inorganic non-metallic solids, synthesized using heat and successive cooling. In general, they are formed of oxides, carbonates, phosphates, and carbides of metals, being known as metalloids. They can be made of various forms, such as dense, porous or hollow, polycrystalline, and amorphous [54].

– Semiconductor nanoparticles

Semiconductor nanoparticles have properties between metallic and non-metallic nanoparticles. They have wider bandgaps, and hence, they show an outstanding alteration in their properties with bandgap turning [55].

Carbon based nanoparticles

These nanoparticles are entirely composed of carbon [56]. They could be subdivided into fullerenes, graphenes, CNT, carbon nanofibers and carbon black.

– Fullerenes

Fullerenes are molecules of carbon, with zero-dimensional SP-bonded and spherical close-caged structures. The composition of these nanoparticles includes a globular-hollow cage like allotropic carbon forms. These nanoparticle are organized in hexagonal and pentagonal carbon units, while each carbon unit is SP2 hybridized. The most extensively investigated molecule of this group is scientifically named as *buckminsterfullerene*, C_{60}, from which the word *fullerene* originates from C_{60} molecule. Fullerenes, C_{60}, is formed of carbon atoms, which are held together by SP^2 hybridization. Figure 5 represents the most famous fullerenes of C_{60} and C_{70}.

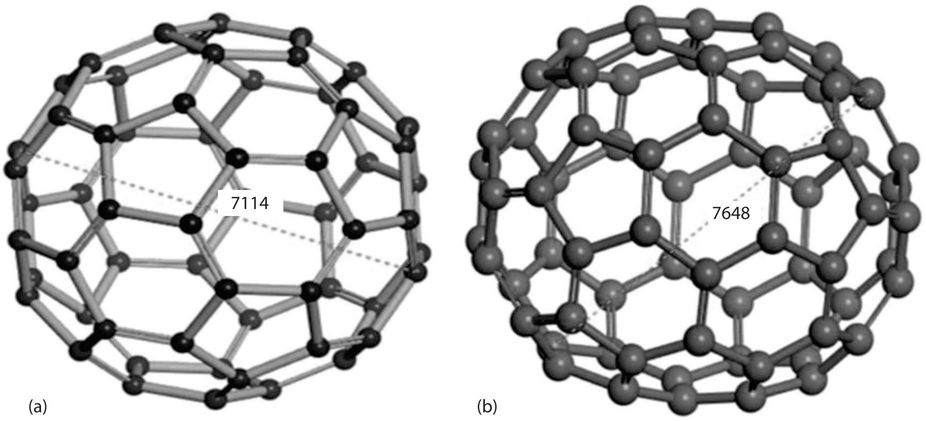

Figure 5. Various types of Fullerenes/buck balls [57]; (a) C_{60} and (b) C_{70}

– Graphene

Graphene is made of carbon atoms in a 2-D planar surface. They are a hexagonal honeycomb lattice network, where a graphene sheet thickness is approximately 1 μm. Graphene is considered as the thinnest and most strongest material that exists. It has an extraordinary quantum hall influence, higher chemical and mechanical strengths. It has also a lower cost of production [58].

– Carbon nanotubes

The CNT are described as seamless, strong and lightweight cylindrical hollow fibers that compose a single and pure graphite sheet, with hexagonal carbon atoms network with a 1 μm diameter and a 100 μm length [59]. Nanotubes can be easily bent, and can return back to their original shape when released [60]. They are formed to graphite sheet rolling upon itself, in structural manner. They are sub-classified into two types, which include single-walled CNT (SWCNT) [61] and multi-walled CNT (MWCNT) [62]. The SWCNT are composed of a single graphene sheet, rolled up into tubular form, whereas MWCNT are composed of two or more cylindrically rolled concentric sheets of graphene as shown fig. 6.

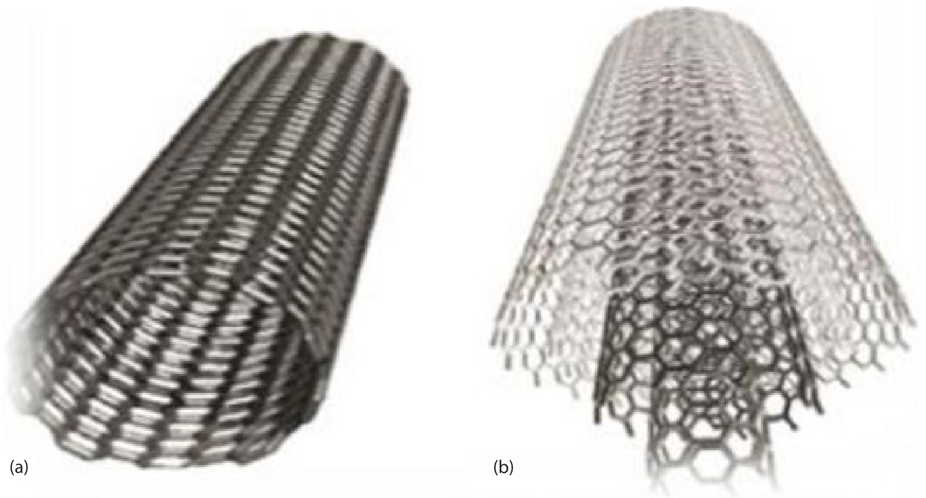

Figure 6. Types of CNT [42]; (a) SWCNT and (b) MWCNT

– Carbon nanodots

Carbon dots refer to the nanoparticles of amorphous carbon, which do not exhibit quantum comfinement, being simply known as all quasi-spherical carbon nanoparticles [63]. Carbon dots are 1-D fluorescent nanoparticles, and are classified into carbon quantum nanodots (CQD), and graphene quantum dots (GQD). The CQD are zero-dimensional particles with a size less than 10 μm. They were accidently made during the electro-phoretic separation of SWCNT [64]. Regarding GQD, these are less than 100 μm in lateral size.

– Carbon nanofiber

Carbon nanofibers are similar to graphene nanofoils. They are produced from graphene nanofoils in the same way CNT are produced, however, they are formed into a cupped or conical shape different from a regular tubes cylinder.

– Carbon back

Carbon black is a spherical-shaped amorphous carbon material with diameters from 20-70 μm, which is obtained by incomplete combustion of petroleum at high temperature (1300 °C).

Applications of nanoparticles

Considering the various nanoparticles properties, nanoparticles can be used i in several applications. Below are some of the nanoparticles enormous applications.

Nanoparticle applications in cosmetics and sunscreens

Screen lacks long-term stability during usage, due to the use of conventional ultraviolet (UV) protection. Therefore, nanoparticles such as TiO_2 should be used in order to enhance the performance of screen. The UV protection property of Zn and TiO nanoparticles, as they have transparency and an excellent light visibility, as well as having the ability to reflect and absorb UV rays, so they can be used in certain sunscreens. Some of lipsticks use nanoparticles of iron oxide as a pigment [65].

Nanoparticle applications in electronics

Due to a higher requirement for devices with a larger size and displays of higher brightness, such as the case of computer monitors and televisions. Besides, nanoparticles have become the best and ideal choice for batteries separator plates, due to the high need for compact, lightweight, and higher capacity batteries for the development of portable electronics, such as laptop, computer and mobile phones. These batteries can provide more energy storage as compared with conventional batteries, which is attributed to their aerogel (foam like) structures. Batteries manufactured from nanocrystalline metal hydrides and nickel, because their larger surface area can be slightly recharged, and can have the ability to last longer [66]. The nanoparticles show higher electrical conductivity, which is used for detecting gases like NO_3 and NH_3 [67], because of the increase in the nanoparticles pores, which is attributed to the charge transfer from nanoparticles to NO_2, due to their bonding by the gas molecules, making them better gas sensors. The nanoparticles such as metallic nanoparticles, CNT, ceramic nanoparticles, and organic molecules have been used in the production of printed electronics, with different functional inks [68].

Nanoparticle applications in catalysis

Nanoparticles offer higher catalytic features, attributing to their larger surface area and ratio of surface to volume. Therefore, they can be efficiently used as catalyst in chemicals production [69]. Nanoparticles, such as platinum nanoparticles, can be used in the automotive catalytic converters because they can decrease the required platinum amount as they have a larger surface area. Therefore, the cost can be significantly decreased by enhancing the performance. The decrease of some chemical reaction, such as the decrease of NiO to metal Ni can be made by utilizing nanoparticles.

Nanoparticle applications in medicine

Nanoparticles have been extensively used in many medical applications, such as delivery of drugs [70], therapy and diagnostic techniques [71, 72], anti-microbial techniques [73], cancerous cell targeting, cell repair, delivery of gene [74], or bioimaging and diagnosis [75]. Polymeric nanoparticles have been used in drug delivery since they can attain the control of drug release and specific localization of the disease [76, 77]. Nanoparticles have also been applied in therapy techniques, including cancer treatment using combination therapy [78, 79]. They have been used in treating all Gram-positive and Gram-negative bacteria, viruses and fungi [80, 81].

Nanoparticle applications in manufacturing and materials

Nanoparticles have numerous benefits in manufacturing marketable produced and have been used in many manufacturing and materials massive production, such as pharmaceutical, microelectronics, food processing and packing, canola oil production industry and aerospace industries [82]. They have been utilized in health fitness products, electronic, computers chemical sensors, and biosensors [83].

Application in environmental remediation

Nowadays, nanoparticles have become an ideal choice for the remediation of environment to improving the performance in renewable energy sector [84], attributing to their distinctive physical and chemical properties. They exist in nature for curing the environment, providing effective solutions for *in situ* treatment and elimination of ground-water contaminants. The nanoparticles are also used for treating the surface water by purification, desalination, and disinfection. They replace the conventional techniques to clean certain contaminants such as pathogens, heavy metals, oil spill and organic contaminants. Nanoparticles are used in the treatment of industrial and municipal wastewater and the produced sludge. The most extensively usage of nanoparticles is in stacks of different industries to decrease the level of contaminant to the permitted limits, or to reduce or completely remove the air pollution.

Applications in mechanical industries

Nanoparticles have been used in numerous applications mechanical industries, such as in adhesive and lubricants coating, owing to their excellent stress, strain, young modulus, properties, which can be beneficial to attain mechanically stronger nanodevices for different applications. The Tri-biological properties of nanoparticles enable them to be used to increase the mechanical strengths the metal and polymer matrix, mainly due to the provision of lower friction and wear by the nanoparticles rolling mode in the lubricated contact area. Besides, nanoparticles offer excellent properties of sliding and delamination, which could also be effective in low friction and wear, and hence increase lubrication effect [85]. The use of nanoparticles in coating can result in strengthening the mechanical characteristics, due to the improved toughness and wear resistance.

Renewable energy harvesting

Nanoparticles have been widely used in generating energy from photo electrochemical, as well as electro-chemical water splitting [86, 87]. They can also be used in splitting water, electrochemical reduction of CO_2 to solar cells, fuels precursors and piezoelectric generators, which provides an improved energy generation [88, 89]. Nanoparticles have been also implemented for storing energy and reserving it in various forms at nanoscale level [90, 91]. Nanoparticles have been used in the creation of nanogenerators to generate energy, by converting the mechanical energy into electricity by using piezoelectricity [92]. They have been used in the production of self-cleaning solar cells, which leads to their hydrophobic property. Some nanoparticles are used in coating solar concentrators and boilers owing to their higher thermal conductivity and heat absorption capacity, leading to the improvement of the thermal efficiency of boilers and solar concentrators.

Properties of nanoparticles

Physical properties

Nanoparticles physical properties include color, absorption and reflection abilities penetration of light, absorption and reflection capabilities in a solution and surface coating. It also includes mechanical properties as tensile strength, ductility, elasticity and flexibility, which are essential for their applications. Other properties such as suspension, settling, diffusion, hydrophobicity, and hydrophilicity have made the nanoparticles to find their way in numerous modern applications [35].

Chemical properties

The applications of nanoparticles can be determined by their chemical properties of nanoparticles, such as stability and sensitivity to atmosphere, moisture, light and heat, as well as the reactivity property to the target. Nanoparticles properties, such as anti-fungal, anti-bacterial, toxicity and disinfection properties make them ideal for environmental and biomedical applications. Nanoparticle's characteristics, such as flammability, corrosive, anti-corrosive, oxidation, and reduction can determine their respective utilization.

Thermal properties

The metallic nanoparticles have a higher thermal conductivity as compared than fluids in solid forms. For instance, the thermal conductivity of Cu is approximately 700 times greater than that of water, and nearly 3000 times higher than that of engine oil. The Al_2O_3 has a thermal conductivity greater than its counterpart of water. Hence, suspension of solid particles in fluids can improve the thermal conductivity, in comparison conventional heat transfer fluids. It was found that the nanofluids that contain CuO or Al_2O_3 nanoparticles, in ethylene or water, can provide enhanced thermal conductivity [93, 94].

Literature review on thermodynamic effects of nanoparticles on thermal origin

Several research efforts have been carried out to evaluate the impact of nanoparticles on thermal origin. Chieruzzi *et al.* [95] carried out a study to investigate the nanoparticles influence on nanofluids heat capacity, which is based on molten salts as PCM for storing thermal energy [96]. The mixture of base salt was a $NaNO_3$-KNO_3 with a ratio of 60 to 40 binary salt. The nanoparticles including SiO_2, Al_2O_3, TiO_2, and a mix of SiO_2-Al_2O_3 were utilized. Three weight concentrations were investigated, including 0.5, 1, and 1.5 wt.%. It was shown that the added nanoparticles concentration of 1% to the base salt can increase the specific heat from 15% to 57% in the solid phase, and from 1-22% in the liquid phase. It was also indicated that the inclusion of SiO_2-Al_2O_3 nanoparticles indicated an enormous potential for improving the thermal storage capability of the $NaNO_3$-KNO_3 binary salt. Guo *et al.* [85] carried out a study on thermodynamic and heat transfer properties of Al_2O_3 nanolubricants. The nanoparticles were dispersed in POE lubricant by using various surfactants and dispersion techniques. It was found that the nanolubricants solubility was low, as compared to that of R-410A with no interference of solid nanoparticles, with the solubility characteristics of POE oil. It was also observed that surfactants can slightly affect the thermal conductivity, more specifically heat, viscosity, and solubility of the nanolubricants properties. Besides, the specific heats of the nanolubricants were lower than that of POE oil, at temperatures ranging from 0-20 °C, while they were the same at 40 °C . Nanolubricants thermal conductivity was higher than that of POE lubricant. Besides, the viscosity at nanoparticle concentration of 10% of weight was 30-40% higher, when compared to the one of POE. Aghayari [97] carried out research to study the impacts of temperature and nanoparticles concentration on the variation of heat transfer and coefficient of overall heat transfer in a countercurrent double tube heat exchanger with turbulent flow. It was reported that the heat transfer and the coefficient of overall heat transfer of the heat exchanger that contains nanoAl_2O_3 with ca. 20 μm particle size and volume concentration, in the range of 0.001-0.002 were improved. It was also shown that the mean heat transfer and overall heat transfer coefficient were remarkably improved with a rise of 8-10%. Besides, increasing the temperature of processing and particle concentration lead to an increase coefficient of overall heat transfer. Yaduvanshi *et al.* [98] conducted a research to study the influence of Cu nanoparticles on the dielectric, optical, and thermal parameters of a liquid crystalline material 2,3,6,7,10,11-hexabutyloxytriphenylene (HAT4), indicating a wide temperature range (~65 °C) of hexatic columnar mesophase. A composite has been prepared, by dispersing 0.6% weight of Cu nanoparticles. In this study ut was observed that the availability of Cu nanoparticles causes surface plasmon resonance, decreasing the optical band gap of HAT4. It was also found that the isotropic to mesophase transition temperature is not affected. However, mesophase-crystal transition temperature has reduced and therefore, the mesophase range was improved because of the inclusion of Cu nanoparticles. While d_c conductivity was improved by approximately twice of magnitude, dielectric permittivity has also increased moderately. It was found that enhancing the properties of HAT4-Cu hybrid nanoparticles are beneficial for 1-D conduction, and PV applications. Dalir *et al.* [99] conducted research to investigate the ferro-electricity nanoparticles of both the thermodynamics and electro-optics of a novel mixture of cyanobiphenyl eutectic binary liquid crystals. It was observed that there is a clear difference in terms of thermodynamic properties and the temperature of nematic-isotropic phase transition, which includes enthalpy as well as entropy changes, between the pure and doped compounds. It was also indicated that the influence of FeO_3 nanoparticles on semiconducting properties of liquid crystals (LC) is pronounced in comparison with TuO_2. Based on the calculation of the diffusion coefficient it was shown that the insertion of nanoparticles decreases the diffusion of LC, towards the electrode surface. Machrafi *et al.* [100] conducted a study to propose transient heat conduction thermodynamic model in ceramic-polymer nanocomposites, as well as to investigate the influence of size, volume concentration, and interface characteristics of nanoparticles with emphasis in the impact of particles agglomeration on the nanocomposite effective thermal conductivity. It was indicated that the effective thermal conductivity can either increase or reduce the agglomeration degree. He *et al.* [101] conducted a study to investigate the influence of doping eutectic binary salt solvent with Al_2O_3 nanoparticles on its specific heat capacity, C_p. It was found that increasing the nanoparticle concentration can enhance the nanocomposites specific heat capacity, with the maximum improvement found to be 8.3%, at a 2% concentration of nanoparticles. It was also observed that special nanostructures were formed, at the same time the specific heat capacity of nanocomposites was improved, by increasing the nanoparticles quantity, which was a good agreement between simulation results of C_p and experimental data. Chaichan *et al.* [102] conducted research on thermal conductivity improvement of Iraqi origin paraffin wax by nanoalumina. In their study, (Al_2O_3) nanoparticles with concentration of 1-3% by weight were included to the paraffin wax. The Iraqi paraffin wax was obtained from the local markets and was used as a PCM. It was found that the thermal conductivity of the paraffin wax was expanded, by using higher Al_2O_3 nanoparticles concentration, as compared to pure wax conditions. Ali *et al.* [103] carried out research to model the phenomena, in order to augment the heat transfer rate of diathermic oils, engine-oil (EO) and kerosene-oil (KO) are used to investigate the shape influences of molybdenum-disulf, MoS_2 nanoparticles in the free convection MHD fow of Brinkman-type nanofluid, in a rotating frame. It was found that the heat transfer rate of both fluids tended to be improved by using platelet and blade shape of MoS_2 nanoparticle, in comparison with nanoparticles of cylinder and brick shapes. It is also shown that the rate of heat transfer was improved by 13.51% by using MoS_2 in engine oil, which enhanced its lubrication characteristics. Hassan *et al.* [104] carried out a research to study the convective heat transfer performance and fluid-flow characteristics of Cu-Ag/H_2O hybrid nanofluids. It was observed that the hybrid nanofluid exhibits higher thermal conductivity, as well as enhanced convective heat transfer attributes, when compared to the base fluid and nanofluids. Fadodun *et al.* [105] carried out research to investigate the influence of Reynolds number, and concentration of nanoparticle on the thermal performance of SWCNT nanofluids flowing through a straight pipe with constant heat flux in a turbulent flow regime. The Reynolds number was in the range of 10000-200000 and the concentration of s ranging from 0-0.25%. Based on the results of simulation, it was shown that convective heat transfer was improved by 7.48%, while the pressure drop and pumping power were enhanced by 119% and 199%, respectively. Besides, with a low Reynolds number (10000), the rate of entropy production was decreased by 16.95%, increasing the concentration of nanoparticles from 0-0.25%. However, with a higher Reynolds number (200000), the rate of entropy production was increased by 149.77%. Therefore, it was demonstrated that SWCNT nanofluid will only be useful at low Reynolds number of (10000-50000). Gomez-Rodriguez *et al*. [106] conducted a study to investigate the influence of α-Al_2O_3 nanoparticles up to weight concentration of 5% on the mechanical, physical, and thermal properties, as well as on the evolution of a dense magnesia refractory micro-structure. It was found that using an increased temperature of sintering led to an enhanced density and a decreased apparent porosity. But, using a higher α-Al_2O_3 can reduce the density and microhardness. It was also shown that inclusion of α-Al_2O_3 nanoparticles in the magnesia matrix can induce the magnesium-aluminate spinel formation $MgAl_2O_4$, which enhanced the mechanical resistance with increasing the temperature. Jalal [107] carried out a study to study the influence of size on thermodynamic parameters of nanoparticles, such as melting and Debye temperatures, as well as melting entropy and specific heat capacitt. The Si and Au nanoparticles were considered in the study, due to their potential applications in science and technology. It was found that melting temperature, Debye temperature, and melting entropy of nanoscale size material are reduced with the decrease of the size up to their critical sizes. Whereas, the specific heat capacity tends to enhance the reduction in nanoparticle size. In this study, melting temperature, melting entropy and Debye temperature are compared with experimental and theoretical observations, showing an adequate agreement between themthem. Llusco *et al.* [108] carried out a research on kinetics and thermodynamics of thermal decomposition for synthesis of doped $LiMn_2O_4$, which was used to study the influence of Mg doping concentration on thermal decomposition of synthesis precursors, obtained by ultrasound-assisted Pechini-type sol-gel process, and its significance on nucleation and growth of Mg-doped $LiMn_2O_4$ nanoparticles. It was found that Mg doping can result in the increase of thermal inertia on rate of conversion. Based on thermos-gravimetry experiments, as well as the effect of Mg on thermal decomposition, it was indicated that $LiMg_xMn_{2-x}O_4$ (x = 0.00, 0.02, 0.005, 0.10) nanocrystalline powders are promising cathode materials for lithium-ion batteries. Li *et al.* [109] conducted a study to investigate the concentration nanoparticle effect on physical and heat transfer properties, as well as evaporation characteristics of graphite-n-decan nanofluid fuel. It was found that the density and thermal conductivity linearly increase with a binomial improve the viscosity and binomial effect on the surface tension with the increase of the concentration of graphite nanoparticles. It was observed that using graphite nanoparticles in the weight range of 0-1.75% can benefit the evaporation, while increasing to a range of 1.75-4% can decrease the evaporation performance. It was concluded that the concentration of surfactants has a binomial impact, while it was noticed that the ambient temperature rate of evaporation the ambient is linearly affected.

Conclusion

This study was conducted to provide an extensive review on the thermodynamic effects of nanoparticles on thermal origin. Firstly, the classification of nanoparticles, which include organic, inorganic and carbon-based nanoparticles are summarized. Then, various applications of nanoparticles in many fields include cosmetics, sunscreens, electronics, catalysis, mechanics, manufacturing, materials, environment and energy harvesting are briefly highlighted. After that, the physical, chemical and thermal properties of nanoparticles are summarized. A comprehensive review on the recent research trends on the impacts of nanoparticles on thermal origin is collected and provided in this paper.

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Paper submitted: August 27, 2022
Paper revised: September 18, 2022
Paper accepted: October 1, 2022