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REVIEW

A Review on Heat Transfer Modulation using Experimental Approach

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Abstract The fluids play a progressively significant role in our ordinary lives including enhanced heat transfer. The development and applications of nanofluids have major opportunities used for engineers and industry. Thermal features of the conventional fluids approach to their best optimum value do not permit the satisfaction of current age requirements. Thus, it is a serious requirement to develop new kinds of fluids tailored to the heat transfer industry's needs. Further progress in the past few decades has increased impetus for the improvement of heat transfer coefficients of fluids because of nano-materials development. Current investigations on the nanofluids specify the suspended nanoparticles change the heat transfer features of the suspension. Nanofluids at low-volume fractions enhance their thermal conductivity over base fluid beliefs proving to be a promising material for cooling applications. Therefore, it is possibly suitable for advanced cooling of thermal systems. This review report summarizes their concepts, current research on the heat transfer features, and further uses of nanofluids in the heat transfer industry. The review tends to be a state of art article giving insights to the reader about nanofluids research including constituents of nanofluids, synthesis of constituents for preparation of nanofluids, the approach used for the preparation of nanofluids, application and potentials of nanofluid research.

Keywords Heat transfer enhancement · Nanofluids · Soft computing

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Abbreviations

°C	Degree centigrade
α	Alpha
γ	Gamma
g	Gram
h	Hours
k	Thermal conductivity
m	Mean
s	Standard deviation
au	Arbitrary unit
ml	Milliliter
nm	Nanometer
SC	Soft computing
ANN	Artificial neural network
SVM	Support vector machine
MAE	Mean absolute error
UV–Vis	Ultraviolet–visible Spectroscopy
PL	Photoluminescence Spectroscopy
XRD	X-ray diffraction
SEM	Scanning electron microscope
TEM	Transmission electron microscope
AFM	Atomic force microscope
DLS	Dynamic light scattering
JCPDS	Joint committee on powder diffraction standard
ICDD	International center for diffraction data
THW	Transient hot wire
Al_2O_3	Aluminium oxide
CuO	Copper oxide
SVC	Support vector classification

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SVR Support vector regression
RBF Radial basis function

1 Introduction

Thermal load is growing because of the trends toward small microelectronic devices, much higher output (power) for engines, and the brightest beams for optical devices. The cooling of these devices and associated systems is an essential matter in advanced industries such as microelectronics and transportation. The conventional approach increases the cooling rates by using extended surfaces as micro-channels that have already stretched their limits. Thus, there is a crucial requirement for novel and advanced ideas to succeed in ultra-high cooling performance. Though, the minimum thermal conductivity value is the main limitation in emerging energy-efficient heat transfer fluids, which are essential for cooling drives [1]. Heat transfer fluids, which have been extensively utilized in numerous manufacturing industries, transportation, power generation, microelectronics, heating/cooling processes and so on that also suffer because of their minimum thermal conductivity nature. Despite numerous studies on the thermal conductivity of the liquid/solid suspensions covering millimeter/micrometer elements/particles, the quick settling of these elements in fluids has main difficulty to develop further suspensions for practical utilities.

The Argonne National Laboratory has developed ultra-high thermal conductivity fluids, by suspending nanoparticles in conventional coolants and these engineered fluids are termed nanofluids. Nanofluids are engineered fluids containing nanoparticles suspended in the base fluid utilizing a lesser size of around 100 nm. It is required to use a large total surface area of the particles, as the heat transfer occurs at the particles' surface.

On the other side, the nanoparticles deal enormous large surface area and thus they have vast probable applications in heat transfer. Nanofluids display greater features/properties compared to that ordinary heat transfer fluids and fluids covering the particles with micrometer volume. It displays improved thermal conductivity and convective heat transfer coefficient relative to the base fluids. These fluids are engineered colloidal suspensions of nanoparticles in base fluids. This colloidal suspension can be prepared using a one-step approach or two-step approach. In the one-step approach, the synthesis of nanoparticles and preparation of nanofluids undergoes in a single step whereas in the two-step approach first nanoparticles are synthesized and then these synthesized nanoparticles are used for the synthesis of nanofluids. Both the one-step approach and two-step approach are extensively utilized for nanofluids preparation, however, a two-step approach of synthesis is preferred as the concentration of prepared nanofluids can be controlled more accurately in a two-step approach.

The irregular enrichment of heat transfer through the nanofluids has been first described by Choi et al. [2] in 1995. It also confirmed that the nanofluids have significantly more heat transfer appearances than the base fluids due to the enhanced Brownian motion of the nanoparticles [3]. Well-suspended particles and high thermal conductivities make nanofluids more strong applicants for the next generation of coolants for thermal schemes. Recently, nanofluids have gained much-fascinated attention due to their much higher performance of the heat transfer fluids in electronic, automotive cooling, and microchannel heat sinks [4].

The initial patent on the nanofluid heat transfer technology is developed by Choi et al. [5]. In the meantime, more than twenty patents have been granted to the nanofluid heat transfer techniques and their utilities have been acquired. Among them, a lot of patents are related to heat transfer enhancement by further improvement of thermal conductivities. Anomalous enhancement of convective heat flux values [6] and specific heat capacity [7] of the nanofluids have also been reported. Li et al. [8] summarized the developments in the preparation and further characterization of fixed nanofluids and tried to invent a few challenging problems, which are essential to be resolved for further investigation. Wang et al. [9] conducted a brief review report on the heat transfer features of nanofluids and established that the suspended nanoparticles significantly modify transport features and heat transfer properties of the suspension. Wen et al. [10] suggested the need for inter-disciplinary collaboration among colloidal science, physics, and engineering researchers to engineer nanofluids and accelerate their applications.

2 Constituents of Nanofluids

Nanofluids are alternative to widely used fluids by incorporating nanoparticles that give enhanced heat transfer coefficients. Common base fluids for the preparation of nanofluids consist of water, bio-fluids, oils and lubricants, polymeric solutions, and organic liquids. Furthermost significant features when selecting the liquid cooling technology are having compatibility of heat transfer fluid with wetted surfaces of the cooling scheme for real-world applications. Alongside compatibility, much higher thermal conductivity, low freezing point, low viscosity, specific heat, low toxicity, high flash point, and thermal stability are other prime features of a good heat transfer fluid. Based on these criteria, ethylene glycol and water are better base fluids [11]. Among these, water displays greater thermal conductivity values related to the ethylene glycol of a similar nanoparticle volume fraction [12]. Thermal conductivity value of water and ethylene glycol are about 0.61 W/m.K and 0.26 W/m.K respectively at normal temperature (25 °C) [13] [14] [15].

Water, a good choice for cooling applications, is a transparent and nearly colorless chemical substance. Ethylene glycol, another good choice for cooling applications, is an odorless and colorless organic compound. It has a low viscosity that reduces pumping requirements. Even though ethylene glycol's thermal conductivity is not as higher as water's, it offers freeze protection that is useful in many applications.

Nanoparticles used in nanofluids are usually prepared through the chemically stable metals (Cu, Au), metal carbides (SiC), metal oxides (CuO, Al_2O_3), metal nitrides (SiN, AlN), carbon graphite, (diamond, fullerene, carbon nanotubes) as well as functionalized nanoparticles. Metal oxide nanoparticles show enhanced heat transfer efficiency of commonly used base fluids. Eastman et al. [16] demonstrated that the oxide nanoparticles (CuO, $A1_2O_3$) have outstanding dispersion features in water/ethylene glycol and form stable suspensions.

Aluminum oxide (Al_2O_3) is an alloy of aluminum and oxygen and is recognized as aluminum (III) oxide [17]. It is usually named alumina, is an electrical insulator with high thermal conductivity, lower neutron cross-section capture area, and also is transparent to microwave frequencies [18]. The nano-powders of alumina are utilized in many different applications in fire retard [19], catalyst, catalyst support, absorbent [20], electronics, optoelectronics, insulator [21], surface protective coating [22], wear-resistant coating [23], metallurgy, fine ceramic composites, composite materials [24], refractories and abrasives [25]. The potential applications are because of their hardness, non-volatility, upper melting point, chemical inertness, high compression strength, high abrasion resistance, resistance to oxidation, high insulation, high dielectric strength [26], and high thermal shock resistance, high stability and transparency [27]. Properties of alumina particles depend on their particle size, surface morphology and phase homogeneity which could be organized by choosing a proper synthetic method [28]. The crystallographic phases of alumina are distinct, among them α and γ forms are utilised for an extensive range of uses because of their distinct characteristics. The γ phase related to the metastable phase and on heating, it forms a thermodynamically stable α phase [29]. The higher surface area of the γ phase makes it more useful for catalyst-based applications, whereas the polycrystalline α phase is broadly utilized for ceramics applications [30].

Among transition metals oxides, CuO nanoparticles have also been driven special interest because of their efficiency in nanofluids heat transfer uses [31], the existence of water catalysts for gas modification reaction [32], vapor improvement [33], the oxidation of CO through exhaust (automobile) gases [34], as well as the application for photo-electrochemical [35]. The copper oxide (CuO) is a brilliant nanoparticle scheme for examining the phase stability and structural transformations. It has particularly attracted concern due to its simplest family member of copper and displays valuable physical characteristics. It is a semiconducting material with monoclinic symmetry. As a significant semiconductor (p-type specimen), copper oxide has created numerous useful applications in batteries, gas sensors, solar energy conversion, superconductors, thermoelectric materials, field emission emitters, catalysis, and magnetic storage media, ceramics resistors and so on.

3 Synthesis and Characterization of Nanoparticles

Nanoparticles for nanofluids can be produced from several processes which can be categorized into five general synthesis methods. These five methods are as below:

1. Transition metal salt reduction process
2. Photochemical /Thermal decomposition process
3. Metal vapor preparation / synthesis
4. Ligand reduction and displacement from organometallics
5. Electrochemical synthesis

The transition metal salt reduction (wet chemical) method of nanoparticle synthesis is a relatively easy and cheap procedure that provides better control over the properties of nanoparticles to be synthesized. Thermal decomposition (combustion synthesis) is also an outstanding method for synthesizing high-temperature specimens due to its lower cost, capability to attain high purity, and higher production of single/multiphase complex oxide powders. In this method, input heat needs only to attain ignition temperature so that an exothermic, self-sustaining response takes place between oxidizers and reducers. As a result, the auto-ignition method together with the self-propagating high-temperature preparation process has developed as simple, safer, and more economic that produces powders (high purity) with fine particle sizes and outstanding uniformity. The combustion synthesis technique has several benefits as compared to conventional synthesis techniques. It could be utilised to yield novel phases along with unique features in specimens due to higher thermal gradient and fast cooling rate. Agglomerates could degenerate throughout the method. The subsequent product is very fine particulates of friable agglomerates that could be easily ground to attain a more fine particle size [36]. Al_2O_3 and CuO have widely used nanoparticles for the preparation of nanofluids for heat transfer applications.

Al_2O_3 nanoparticles can be developed/prepared through numerous methods: the sol–gel process [37], pyrolysis synthesis process [38], hydrothermal synthesis process [39], laser-ablation process [40], solution combustion process [41], plasma synthesis process [42], freeze-drying of sulfate solutions process [43], well-control hydrolysis process of metal alkoxide [44] aerosol synthesis process [45] and so on. It has also been described as the finding of dense nanocrystalline nature of the Al_2O_3 yields, moreover, the phase transformation of γ to α or nanocrystalline α-Al_2O_3 powders has to be utilized [46] [47]. The group of Fatemeh et al. [48] determined the influence of the stirring time on the preparation of nano α-Al_2O_3 elements. Al_2O_3 nanoparticles have been prepared through the sol–gel process and it is established that the different stirring times might affect the particle size. Al_2O_3 in the γ phase, having a typical particle size of 6 nm—12 nm with a wall thickness of about 2–3 nm has been synthesized [49]. Crystalline α Al_2O_3 has been prepared by utilizing of solution combustion technique [50]. Mostly, the combustion process is an outstanding method for synthesizing high-temperature specimens due to its low cost, capability to attain higher purity of single/multi-phase complex oxide powders and higher production. Table 1 lists a summary of numerous methods used for the development/preparation of Al_2O_3 nanoparticles and their characterization results.

The CuO nanoparticles have been prepared through the numerous technique as sonochemical [56], sol–gel [57], solid-state [58], electrochemical method [59], thermal decomposition [60], wet chemical route [61], alkoxide based synthesis [62], hydrothermal [63] and solid-state [64]. The research group of Rejith et al. [65] developed CuO nanoparticles through a microwave-used thermal process with urea and copper acetate as precursors specimens. In this process, a single-phase of monoclinic symmetry, 10–14 nm particle size with spherical morphology nature has been obtained.

The development of CuO nanoparticles through several solvents by the sol–gel process has also been stated [66]. Its XRD examination specifies that the crystallite strain and size are greater for CuO nanoparticles prepared through the propanol as a solvent specimen. The group of Swarnkar et al. [67] developed copper-oxide nanoparticles through the laser ablation of copper metal in an aqueous solution of sodium dodecyl sulfate. The influence of preparation/synthesis factors, the quantities of copper salts, and the reaction time have been investigated. The copper acetate concentration and reaction time influence the nanoparticle's size. Table 2 lists a summary of numerous methods used for the development/preparation of CuO nanoparticles and their characterization results.

4 Nanofluids for Heat Transfer Applications

Thermophysical features of the nanofluids have attracted engineers and are most significant in very cold and hot countries [70]. The thermophysical characteristics are all material features that affect the transfer as well as heat storage capacity. It varies with the state parameters of temperature, composition, pressure, and other factors, without varying the material's chemical identity. These characteristics consist of thermal conductivity, thermal resistivity, thermal diffusivity, thermal expansion, and thermal radiative features. The transfer of energy between two adjacent components of the materials is generally dependent on its thermal conductivity. The information on the thermal conductivity of the materials is essential for further computation of heat flow in any thermal system.

Several transient techniques are available for thermal conductivity measurement viz. transient hot-wire process

Table 1 Summary of work on synthesis and characterization of Al_2O_3 nanoparticles

Preparation method	Main objectives	Observed results	References
Sol–Gel	To evaluate the influence on stirring time of the nano α Al_2O_3 powder production	Size decrease with increasing stirrer time up to a threshold	[48]
Composite Electrode Sputtering	To synthesise the hollow nanoparticles of γ Al_2O_3	Typical particle size is 6 nm—12 nm and a wall thickness of 2 nm—3 nm	[49]
Solution Combustion	The preparation and further characterization of the α Al_2O_3 platelet nanoparticle	Crystalline α Al_2O_3 nanoparticles	[50]
Laser Ablation	To estimate the influences of laser energy on the production of Al_2O_3 nanoparticles	Particle size increased with increasing laser energy	[51]
Polymeric Precursor	Structural symmetry characterization of phase transition of Al_2O_3 nanopowders	γ to α Al_2O_3 phase transition with an increase in temperature	[52]
Flame Synthesis	Phase transition characteristics of γ Al_2O_3 nanoparticles with heat treatment	γ to α Al_2O_3 phase transition with an increase in temperature	[53]
Flame Spray Pyrolysis	Synthesis of nanostructured Al_2O_3 powders through the aerosol process	Production of γ Al_2O_3	[54]
Evaporation	Photoluminescence of Al_2O_3 nanopowders of different phases	Change in luminescent behavior with temperature due to phase change	[55]

Table 2 Summary of work on the synthesis and characterization of CuO nanoparticles

Method	Objective	Results	References
Gel Combustion	Size-dependent features of CuO nanoparticles	Single phase CuO nanoparticles	[68]
Precipitation Pyrolysis	Size-dependent optical and magnetic features of CuO nanoparticles	Significant variation in properties with size	[69]
Microwave	Microwave synthesis of CuO nanoparticles	Single-phase of monoclinic symmetry, 10–14 nm particles size with spherical morphology nature	[65]
Sol–Gel	Structural, microstructural and optical absorption studied of the CuO nanoparticles	Crystallite strain and size are higher for CuO nanoparticles prepared through propanol as a solvent	[66]
Laser Ablation	Synthesis of CuO nanoparticles	Spherical nanoparticles have an average diameter of 4 nm -5 nm	[67]

[71], and transient probe process [72]. Buongiorno et al. [73] analyzed a variety of experimental approaches for thermal conductivity measurement including steady-state, and Transient Hot Wire (referred to as THW) methods using aqueous metal oxide nanofluids. Yoo et al. [74] utilized the THW technique to estimate the thermal conductivity of Al_2O_3 nanofluids and observed a major enhancement in thermal conductivity as compared to the base fluid. Teng et al. [75] also used the THW process to estimate the thermal conductivity of Al_2O_3 water nanofluids produced through the direct synthesis process. They investigated the influence of particle size, temperature and weight fraction on the thermal conductivity ratio of the nanofluid and base fluid. Modifications have also been tried in the typical THW method for better results. For example, Zhang et al. [76] used a short hot wire that accounts for effects of boundaries. Ali et al. [77] used a laser beam displacement process with the THW method to separate the detector and heater to escape interference. The thermal conductivity of nanofluids is a subject to the influence of many factors.

Many research groups have examined the influence of these factors on the thermal conductivity of nanofluids. Kole and Dey [78] reported several suspensions based on Al_2O_3 nanoparticles (< 50 nm) for the car engine coolant. They investigated the thermal conductivity of the nanofluids associated with the concentration of Al_2O_3 nanoparticles and with the temperature function between 10 °C and 80 °C. The fluid temperature shows a significant character in improving the effective thermal conductivity of the nanofluids [79]. Liu e*t al.* [80] examined the influence of temperature on the effective thermal conductivity of nanofluids. Thermal conductivity is observed to have an inverse dependence [81] on nanoparticle size [82] and a quasi-linear reliance on temperature [83]. Lin et al. [84] displayed that a rise in operating temperature causes the rise in thermal conductivity of Al_2O_3 nanofluids. Yiamsawasd et al. [85] displayed that the thermal conductivity of nanofluids increases further with the base fluid and increases with the rising of concentration and temperature.

Khedkar et al. [86] reported, that the volume fraction of the nanoparticles in suspension increases, and the thermal conductivity (effective) of the nanofluid also increases. Patel et al. [87] achieved an experimental analysis that shows the enhancement of thermal conductivity of oxide nanofluids. It shows that the thermal conductivity of nanoparticle suspension is quite greater at lower volume fractions, thus giving a non-linear reliance on the particle volume fraction. Mintsa et al. [88] measured, the thermal conductivity of Al_2O_3 water nanofluids (29 nm) with their volume concentration increasing up to 9% in the range of temperature from 20–40 °C. It detected that the thermal conductivity increases through the rise of volume concentration as well as particle size decreases. They also delivered a novel thermal conductivity expression for Al_2O_3 water nanofluids of particle sizes about 47 nm, 36 nm, and 29 nm by fitting the curve of their internal data. The group of Sundar et al. [89] measured thermal conductivity of the water through ethylene glycol using mixed Al_2O_3 nanofluids for particle concentration up to 0.8 volume percent with an intermediate range of temperature from 15–50 °C. An additional relationship has also been developed through them for the measurement of thermal conductivity of the nanofluids, established on experimental records. The research group of Beck et al. [90] deliberate thermal conductivity of the Al_2O_3 nanoparticles dispersed in ethylene glycol and demonstrated the influence of the volume/mass fraction of the nanoparticles on nanofluids' thermal conductivity. Zamzamian et al. [91] demonstrated the improved heat transfer features of Al_2O_3 ethylene glycol nanofluids.

Xie et al. [92] detected a growth trend followed by a decreasing trend in thermal conductivity nature for many suspensions containing Al_2O_3 nanoparticles utilizing particular surface zones (5 m^2 g^{-1} – 124 m^2 g^{-1}). Patel et al. [93] displayed an inverse dependency of the particle size on thermal conductivity improvement by allowing for three sizes of Al_2O_3 nanoparticles suspended in water. Beck et al. [94] described that the magnitude of thermal conductivity will rise with a decrease in nanoparticle diameters. The group of Kulkarni et al. [95] utilized Al_2O_3 nanofluid as a form of coolant in a diesel-electric generator. The specific heat analysis of Al_2O_3 nanofluid through several particle concentrations has already been measured and displays that the nanofluids lead to a reduction of cogeneration efficiency. It is the decrease in specific heat that affects the waste heat recovery from the engine. It has been established that the efficiency of the waste heat recovery in heat exchanger improves for nanofluid because of its superior convective heat transfer coefficient. Table 3 summarizes the outcomes of various experimental analyses on thermal conductivity improvement through Al_2O_3 nanofluids.

The group of Zhu et al. [101] developed CuO nanofluid through transforming of unstable $Cu(OH)_2$ precursor to CuO water in ultrasonic vibration through microwave irradiation. Haitao et al. [102] utilized a wet chemical technique to prepare stable CuO nanofluids. The thermal conductivity enhances 31.6% with a 1% volume fraction of 8 nm CuO in water and 54% improvement with CuO ethylene glycol suspension has been observed by Karthikeyan et al. [103]. The nanofluids prepared through CuO particles of 10–30 nm in size and ethylene glycol have been investigated for further improvement/boosts of the thermal conductivity value [104]. The thermal conductivity analysis shows that the substantial improvement in thermal conductivity through particle concentration is achievable only when the concentration of the particles is under the dilute limit. Nemade/Waghuley [105] described the improvements in thermal conductivity of CuO water nanofluids and have shown that probe sonication time grows the thermal conductivity of nanofluids. Table 4 summarizes the outcomes of various analyses (experimental)

Table 3 Work summary on Al_2O_3-based nanofluids applications in the form of their thermal conductivity improvement

Main objectives	Key results	References
To analyze the influence of particle size on the thermal conductivity of alumina nanofluids	The enhancement of thermal conductivity values decreases as the particle size decreases under 50 nm	[94]
The modification of thermal conductivity on liquid through dispersing ultra-fine particles	Nanofluids produce enhanced thermal conductivity up to 30% at a particular volume fractions less than 4.3%	[96]
To measure the thermal conductivity of the fluids having oxide nanoparticles	The thermal conductivity value is enhanced at a particular ratio of 20% for Al_2O_3 ethylene glycol/water nanofluids at a 4% volume fraction	[97]
To measure the thermal conductivity of a nanoparticle-fluid mixture	The thermal conductivity increases 12% for a particular diameter around 28 nm Al_2O_3 water nanofluids with a 3% volume fraction	[15]
To investigate temperature/volume fraction deviations on their effective thermal conductivity of the nanoparticle suspensions	Provides expressions of thermal conductivity in terms of temperature/volume fraction for Al_2O_3 water nanofluids	[11]
To determine the combined model influences for an effective thermal conductivity of nanofluids	The value of thermal conductivity increase 20% for 4% Al_2O_3-water nanofluids	[98]
The experimental studies on thermal conductivity of the Al_2O_3 and water nanofluids at lower concentrations	The thermal conductivity enhances at lower concentrations	[99]
The studies of Al_2O_3 used nanofluids through 43 nm diameter of the particle at different volume concentrations	Displays a linear growth in conductivity values with a rise in volume concentration	[100]
To analyze temperature dependency of thermal conductivity improvement for nanofluids	The dramatic growth in the conductivity values is observed and takes place with temperature	[79]

Table 4 Work summary on CuO nanofluids applications in thermal conductivity improvement

Objective	Results	References
To study the thermal conductivity of the nanoparticle-fluid mixture	The thermal conductivity increase 12% for 23 nm CuO water nanofluids with a volume fraction of 3%	[15]
The experimental thermal conductivity of ethylene glycol and water mixture used a lower volume concentration of CuO nanofluids	Enhancement in thermal conductivity 8–15.6% for CuO has been achieved in the volume concentration from 0.2–0.8% of nanoparticles loading in the base fluid at a particular temperature of 15 °C	[89]
The thermal conductivity of CuO nanofluid dispersed in ethylene glycol	Substantial improvement in thermal conductivity with particle concentration is achievable only when the particle concentration is under the dilute limit	[107]
Enhancement of thermal conductivity with CuO for nanofluids	CuO water nanofluid with a 5% volume fraction of particles has shown a 22.4% increase in thermal conductivity	[80]

on thermal conductivity improvement utilizing CuO nanofluids. Esfe et al. [106] performed a sensitivity investigation to assess the sensitivity of nanofluids' thermal conductivity of the growth particle filling at different temperatures. Their results showed that at a specified concentration, the thermal conductivity sensitivity to the particle filling rises with the further growth of temperature.

5 Conclusions

Nanofluids at low-volume fractions enhance the thermal conductivity above base fluid standards. Therefore, it has potential importance for the use of advanced cooling thermal systems. Standard experiments are required utilizing different nanofluids themes under different experimental conditions. These results might confirm the reproducibility of experimental outcomes. It would be needed to deliberate not only a single probable mechanism but a set of numerous combined mechanisms, the comparison of predictive outcomes to new standard experimental data sets is also required.

Significant research for experimental analysis on nanofluids' thermal conductivity has been conducted. Though, the systematic studies on the influence of several base fluids, thermal conductivity concentration and temperature are uncommon and state outcomes displaying a lack of consistency. The Al_2O_3 nanofluids that have been examined broadly still lack comprehensive study [108]. For more research on the Al_2O_3 nanofluids, scientists have utilized commercially available Al_2O_3 nanoparticles that are budget ineffective. The present investigation has already sketched further analysis on said nanofluids, the comprehensive representation/analysis in a single work is limited [109]. Lomascolo et al. [110] established that large inconsistencies are observed in the reported outcomes. Numerous significant problems are required to be solved for further uses of nanofluids in engineering, viz.:

- While several sets of the nanofluid schemes have been developed, the nanofluid schemes of having special features, which could come across the applied engineering that has not been established. E.g., nanofluids having higher thermal conductivity, dielectric property, and long-term stability that are potentially appropriate for innovative vehicles, do not exist currently and are required to be explored.
- The long-range strength of the nanofluids is a crucial problem for practical and scientific utility. Up to now, the long-range strength of extreme deliberate nanofluids is not established and additional work is essentially required for refining the strength /stability of nanofluids.
- Lots of key issues manipulating the improvement of thermal conductivity of nanofluids are required to be further studied logically.
- A Uniform standard has not been offered for the experimental investigation of nanofluids with the development of nanofluids.
- The ultimate understanding of the mechanisms that create exciting and promising characteristics is limited. Consequently, further research is required, which would help to develop a better understanding of nanofluid heat transfer features.

6 Future Work

The quantitative and fundamental understanding of changes in nanofluids' thermal conductivity is in the initial phase. Following are the key suggestions where this research can be extended further:

- Design of structural simulations that could explain the thermal conductivity of nanofluids.
- Moreover, the particle size, particle motion made through interparticle, and other forces could be important at the nanometer scale and could point to additional features as motions might expressively contribute to an energy transport at this scale.
- Analyzing the motions through microscopic nanofluids and understanding their influence on energy transport. The need for nanoscale and atomic level is required to understand further heat transfer behavior in the nanofluids.
- Other thermophysical properties viz. rheology of nanofluids is significant as the form of thermal conductivity and could be explored.
- The Robust process for the huge production of stable nanofluids is desirable.
- The present research focuses on the increment of thermal conductivity but the inverse effect *i.e.* decrease in thermal conductivity can also be explored for various applications viz. localized heating to treat cancer cells.
- The use of soft computing processes/methods for predictive analysis is in infancy and can be extended for low-cost solutions.

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