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Enhancing Thermal Conductivity and Heat Transfer using Graphene Nanofluid

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ABSTRACT
Due to their low density and inherent thermal conductivity in compared to metals or metal oxides, carbon nanostructures among other nanoparticles exhibit better thermal conductivity. The ability of graphene Nano fluids to transmit heat has been studied in this work through a review of the findings of several studies. The current techniques for making graphene nanofluids have been summarized, along with several characteristics including viscosity, concentration, particle size, and temperature that have an impact on thermal conductivity. The convective heat transfer capabilities of graphene nanofluids have also been subjected to a careful analysis. The study shown that employing graphene nanofluids as a working fluid through a tube channel can improve heat transfer with considerable results. There hasn't been any research on the effects of graphene Nano fluids on facing steps and corrugated surfaces, according to the literature.

INTRODUCTION

Numerous attempts have been made to find novel ways to improve the rates of heat transfer due to the quick growth of science and the growing demands of industries for high heat transfer rates. Even while a variety of strategies, including introducing electric or magnetic fields, altering the geometry, and increasing the heat transfer surface, have been employed successfully, they have not been able to meet the current demands for heat flux dissipation and heat transmission. It is possible to define nanofluid as a component of nanoparticles included within a common working liquid, such as water or ethylene glycol, which is produced to form an efficient alternative working fluid intended to improve heat transmission [1]. However, there is a major issue with any technology that uses small size and high power, and that issue is the removal and management of heat. Therefore, bringing these challenges to light through the use of nanofluids has caught the interest of the scientists working in this area. Nanofluid can be designed to meet a variety of needs, and because of its flexibility in meeting those needs, it can serve as a flexible cooling solution. In general, nanofluids have the potential to be the world's most versatile coolant because, in a variety of circumstances, they can serve as a flexible cooling method because they can be created to address a specific problem; as a result, they have the flexibility to adapt to the requirements of a particular system [2,3]. To increase the fluid heat transfer coefficient, several efforts have been made to improve surface characteristics such roughness, shape, and extension as well as the heat transfer fluid and fluid motion whether laminar or turbulent. Numerous studies have been conducted recently to look into the creation of nanofluids using carbon-based nanostructures [4]. Graphene [4], which is a sheet of hexagonally arranged, sp2-bonded carbon atoms that is one atom thick, is one of the materials that has been investigated most lately. Since Novoselov et al. discovered graphene,[5] its remarkable electrical properties as well as its high transfer or mobility have drawn scientists' interest. A common configuration for other sp2 carbon bonded nanostructure materials is for the carbon atoms to be placed in a two sp2 orbitals bonded, ordered hexagonal form at the atomic scale [6]. Due to its important properties (such as optical, electrical, thermal, mechanical, etc.), graphene has been the subject of numerous investigations in recent years [7]. Characterization of graphene is a crucial component of graphene research and involves measurements based on a number of spectroscopic and microscopic techniques [8]. Studies have also looked at the importance of graphene nanoparticles and how they differ from other nanoparticles in terms of advantages. According to these research, graphene nanoparticles have a number of advantages including improved stability, reduced corrosion, a greater surface area to volume ratio, reduced erosion and clogging, a reduced need for pumping power, a higher thermal conductivity, and significant energy savings. In order to gain a general understanding of the enhanced tribology and thermal conductivity (k) of graphene and oxide graphene nanofluids, this study covers some experiments that have been conducted. The main difficulties and improvements relating to synthesis, characteristics, and characterisation have also been explored. Additionally, a critical analysis of the findings from previous research on thermal conductivity measurements and the convective heat transfer capabilities of graphene nanofluids is given. Tribology and viscosity have been identified as the two key variables that affect k. Inconsistencies in

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earlier research findings were found, and suggestions for further studies were made.heattransfer efficiency of Al2O3 and TiO2 Numerous attempts have been made to find novel ways to improve the rates of heat transfer due to the quick growth of science and the growing demands of industries for high heat transfer rates. Even while a variety of strategies, including introducing electric or magnetic fields, altering the geometry, and increasing the heat transfer surface, have been employed successfully, they have not been able to meet the current demands for heat flux dissipation and heat transmission. It is possible to define nanofluid as a component of nanoparticles included within a common working liquid, such as water or ethylene glycol, which is produced to form an efficient alternative working fluid intended to improve heat transmission [1]. However, there is a major issue with any technology that uses small size and high power, and that issue is the removal and management of heat. Therefore, bringing these challenges to light through the use of nanofluids has caught the interest of the scientists working in this area. Nanofluid can be designed to meet a variety of needs, and because of its flexibility in meeting those needs, it can serve as a flexible cooling solution. In general, nanofluids have the potential to be the world's most versatile coolant because, in a variety of circumstances, they can serve as a flexible cooling method because they can be created to address a specific problem; as a result, they have the flexibility to adapt to the requirements of a particular system [2,3]. To increase the fluid heat transfer coefficient, several efforts have been made to improve surface characteristics such roughness, shape, and extension as well as the heat transfer fluid and fluid motion whether laminar or turbulent. Numerous studies have been conducted recently to look into the creation of nanofluids using carbon-based nanostructures [4]. Graphene [4], which is a sheet of hexagonally arranged, sp2-bonded carbon atoms that is one atom thick, is one of the materials that has been investigated most lately. Since Novoselov et al. discovered graphene,[5] its remarkable electrical properties as well as its high transfer or mobility have drawn scientists' interest. A common configuration for other sp2 carbon bonded nanostructure materials is for the carbon atoms to be placed in a two sp2 orbitals bonded, ordered hexagonal form at the atomic scale [6]. Due to its important properties (such as optical, electrical, thermal, mechanical, etc.), graphene has been the subject of numerous investigations in recent years [7]. Characterization of graphene is a crucial component of graphene research and involves measurements based on a number of spectroscopic and microscopic techniques [8]. Studies have also looked at the importance of graphene nanoparticles and how they differ from other nanoparticles in terms of advantages. According to these research, graphene nanoparticles have a number of advantages including improved stability, reduced corrosion, a greater surface area to volume ratio, reduced erosion and clogging, a reduced need for pumping power, a higher thermal conductivity, and significant energy savings. In order to gain a general understanding of the enhanced tribology and thermal conductivity (k) of graphene and oxide graphene nanofluids, this study covers some experiments that have been conducted. The main difficulties and improvements relating to synthesis, characteristics, and characterisation have also been explored. Additionally, a critical analysis of the findings from previous research on thermal conductivity measurements and the convective heat transfer capabilities of graphene nanofluids is given. Tribology and viscosity have been identified as the two key variables that affect k. Inconsistencies in earlier research findings were found, and suggestions for further studies were made

NANOFLUID SYNTHESIS

When it comes to experimental research on nanofluids, the preparation method is the most important component. It must take into account two factors: the first is that there should be no agglomeration, and the second should be that there should be little sedimentation over a long period of time in practical applications. When a base fluid and a nanoparticle are combined, the result is a complex mixture of liquid and solid known as a nanofluid. However, for other types, the primary requirements for nanofluids include little agglomeration of nanoparticles, a robust, stable suspension, and no chemical alteration of the base fluid. The Nanofluids are produced by adding nanoparticles to the basic fluid, which contains oil, water, and ethylene glycol (EG). This procedure can be created using a one- or two-step preparation approach, such as graphene oxide for a one-step method and graphene nanoplatelets (GNP) nanofluid for a two-step method [9]. Both of these approaches have benefits and drawbacks, and the choice of approach depends on the production measure as well as the nature and function of the groups required for stable diffusion into the desired base fluid. Graphene can be found in single layers or many layers. By micromechanical cleavage, "highly ordered pyrolytic graphite" (HOPG) is often converted into single-layer graphene [5]. Using glue and scotch tape on a silicon substrate, a layer must be removed from the HOPG crystal in order to obtain graphene using this method. Furthermore, single-layer graphene oxide spreading in dimethlyformamide (DMF) can be reduced by hydrazine hydrate to produce graphene using chemical techniques [10]. The graphene nanofluid is created by a number of methods. The first method involves treating the graphene chlorine salt in methanol with potassium suffocate salt. The result of the first step is dialyzed in the following step. The third step, centrifuging the substance after it has been dissolved, comes after this. The solvent-free graphene nanofluid is obtained by discarding the insoluble particles, collecting, and drying the liquid supernatant. By hydro-thermally heating pure graphene oxide in a Teflon coated autoclave with NH3, Mehrali et al[11] .'s creation of nitrogen doped graphene with pristine graphene oxide. Wang et al. [12] also suggested very stable graphene-based nanofluids. This resulted from the separation of graphene oxide (GO) powder into distilled water (DW) with the use of hydrazine hydrate and the addition of ultrasonication to the mixture. The procedure produced a solid product, which was exsiccated in a vacuum oven for 24 hours at 60°C to remove the remaining solvent after being rinsed with ethanol and distilled water. Furthermore, studies to create grapheme nanosheets have been carried out by Park et al. [13] and Ghozatloo [14]. In order to accomplish this,

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they attempted to enhance the graphene nanosheet on copper foil using catalytic putrefaction in a system using quarts tubes as a furnace. The technique used for this was chemical vapour deposition (CVD). The graphene was then functionalized using a potassium per sulphate and reflux system before being combined with deionized water (DI). The product was then prepped for the graphene nanofluid by putting it in the ultrasonic bath for an hour.

STABILITY

Creating a stable and uniform nanofluid is one of the biggest hurdles in nanofluid preparation. The strong van der Waals interaction between the nanoparticles gives them the potential to agglomerate. In general, the researchers employ a variety of methods, such as physical or chemical treatment, to improve the dispersion of the nanofluid and to lessen the agglomeration of particles that hinder long-term stability. However, it has been noted that aggregation and collection are characteristics that aid in increasing the thermal conductivity of nanofluids. Therefore, if a compromise is to be struck between the stability of a nanofluid and thermal conductivity, these difficulties must be taken into account throughout the preparation [26,27]. There are several different forms of surfactants, including "Sodium dodecyl sulphate (SDS), Oleic acid, Hexadecyltrimethylammonium bromide (CTAB), Gum Arabic (GA), Sodium octanoate (SOCT), Polyvinylpyrrolidone (PVP), Dodecyl trimethylammonium bromide (DTAB), Hexadecyl-trimethylammoniumbrom These kinds might help to modify hydrophobic substances so that they can disperse in an aqueous solution. Otherwise, it would cause aggregation, clogging, and sedimentation, which would reduce the properties of nanofluids such thermal conductivity and viscosity and increase specific heat [11, 28, 29].

THERMAL PROPERTIES

Due to its significance in the applications of heat transfer, k is the subject of one of the most important studies of nanofluids. Different base fluids used in coolants have weak thermal conductivity, so their thermal characteristics must be significantly improved. The deepest thermal conductivity of carbon-based nanofluids, in particular carbon nanotubes (CNT) nanofluids, was shown to surpass that of metallic and metal oxide nanofluids. Although graphene has a theoretical thermal conductivity of 5000 Wm 1 K 1, this is still regarded to be less than that of CNT [36]. Additionally, each material's real state and physical makeup serve as the foundation for its k value, which is one of the material's key thermal characteristics and plays a crucial role in a variety of design-related problems. As a result, extensive effort has been made in the past [28,29] to describe and measure thermal conductivity. For a very long time, determining the physical characteristics of thermoses was challenging since different procedures and methods produced contradictory results. In order to minimise the measurement error as much as feasible, the approach meant for adaptation would be adopted. Thermal comparator, steady-state parallel plate, cylindrical cell, thermal constants analyzer, transient hot-wire, and laser flash methods are only a few of the techniques used to assess thermal conductivity.

VOLUME CONCENTRATION'S EFFECT ON THERMAL CONDUCTIVITY

In comparison to oil and other high-viscous fluids, ethylene glycol and water are frequently utilised as a base fluid in investigations. With increasing concentration, an increase in kwas observed in both graphene [37,38] and grapheme oxide [9,39], which is quite similar to the metal-oxide and metallic nanofluids [40,41]. For the purpose of exploring chronological order, Yu et al. [39] proposed in 2010 that the GO can increase the thermal conductivity of DW, propyl glycol, and fluid paraffin nanofluids by 30.2%, 62.3%, and 76.8%, respectively, using 5.0vol%. As opposed to this, Ahammed et al.'s[24] experimental investigation has shown an improvement in the kof of 37.2% for 0.15% volume concentration of graphene at 50°C in comparison to the same of the water at similar temperature. Volume concentration enhances the kof graphene-water nanofluid [24] Another interesting finding from this study is that the percentage of the average kimprovement with an increase in volume concentration from 0.05% to 0.15% is discovered to be 3.3% greater than that of the average improvement with a temperature rise from 10 to 50°C. For a constant average temperature of 30°C, the percentage improvement in differences of the kof graphene-water nanofluid for volume concentration. It is clear that the percentage improvement in the Kof graphene water nanofluid directly increases with volume concentration. In other words, the second increases in tandem with the first.

HOW GRAPHEME SIZE AFFECTS THERMAL CONDUCTIVITY

According to reports, the size and shape of the nanoparticles play a significant role in how well the kof nanoparticle suspensions work because they strongly rely on them [34] and [42]. According to Esfahani et al.,[43], the thermal conductivity of graphene oxide nanofluids is two times higher than average. It can be shown that as the concentration of graphene oxide increases, so does the average particle size of GO nanofluids. The rise in volume concentration from 0.01 weight percent to 0.1 weight percent causes an abnormal aggregate size increase from 600 nm to 1200 nm. According to

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recent research by Park et al.,[44] graphene oxide with tiny average particle diameter can offer improved properties in contrast to other graphene nanofluids. The fabrication of uniformly sized graphene sheets is still a difficult task for scientists. Any more research that could assist this field advance could offer a useful opportunity to learn more about the role that size plays in this situation.

HOW TEMPERATURE AFFECTS THERMAL CONDUCTIVITY

According to kinetic theory, as the temperature rises, the energy of the particles and the molecules of the base liquid also rises. The random motion of the particles would make it possible to transfer the rising energy from one location to another. Temperature is related to the anomalous improvement of nanofluids since it depends on it, as Das et al. [45] found in 2003. When temperature is raised, improvements are seen in the most metallic, metal oxide, and CNT-based nanofluids [45,46]. The effect of temperature and GO nanofluid concentration on thek was examined by Hajjar et al. [47]. The study's findings indicated that for volume concentrations of 0.25 weight percent, the improvement ratio can reach 31.0 at 10°C and 47.5 at 40°C. Consequently, it can be claimed that an improvement ratios increase in the thermal conductivity by increasing temperature, which agrees with the findings of other studies [9,45]. Ahammed et al. conducted another study[24] to investigate how temperature affects the kof graphene-water nanofluids. These investigations have found that increasing the temperature and volume concentration of the nanoparticles causes an increase in the kof nanofluid. Additionally, it was shown that the kof improved by 37.2% for 0.15% volume concentration of graphene compared to that of pure water at 50°C temperature. It is noteworthy that while using various nanofluids, the aforementioned research [24,47] almost got the same results for thermal conductivity enhancement of 0.8 W/m.K (0.15 wt% and 40°C) by applying the same conditions (graphene oxide and graphene).

In addition to the fact that both the pressure drop and the consequent ofpumping power largely depend on viscosity, viscosity plays an important part in the creation of dynamic systems for the uses of nanofluids' heat transfer [2]. Compared to studies on the thermal conductivity of graphene nanofluids, fewer studies have discussed the rheological behaviour and given graphene nanofluids close attention. Numerous research projects on the apparent viscosity of nanofluids found that when temperature rises, the apparent viscosity decreases. However, a number of common models, including the law model, the power Bingham plastic model, and the Herschel-Bulkley model are used to examine the flow behaviour of liquids [48].

VISCOSITY OF GRAPHENE NANOSHEETS

A study on the viscosity of graphene nanosheets was conducted by Dhar et al. in 8781, and a comparison between the study's findings and those of CNT was made. Additionally, the effects of Alumina nanoparticles on the viscosity of graphene nanosheets at different volume concentrations (0.01-0.50 vol%) and temperatures (25-70°C) were studied experimentally and numerically. The findings have shown that the viscosity of the graphene nanofluid and Einstein's formulation are similar [49]. The viscosity of the graphene M-5 and M-15 nanofluids at room temperature was studied by Park and Kim [44]. The research demonstrated that the nanofluid graphene M-5 has a lower rate of viscosity growth than the nanofluid graphene M-15. Additionally, a 15.65% rise in viscosity at 0.01 vol% was seen in the graphene M-15 nanofluid. Akhavan-Zanjani et al. [50] also conducted a study to look at the viscosity of a graphene-water nanofluid. The outcome showed that at 0.02% volume concentration and 25°C temperature, the viscosity increases by a maximum of roughly 4.90%. However, a study on the viscosity of graphene oxide (GO) and graphene nanoplatelet (GNP) nanofluid was undertaken by Kazi et al. [51]. In comparison to individual graphene oxide solutions, the viscosity was shown to rise tenfold at low shear as a result of colloidal contact. However, there haven't been many investigations done to look at the direct connection between k and the viscosity of graphene nanofluids. More research is required to have a better understanding of the viscosity of graphene nanofluids due to the fact that viscosity has a substantial impact on the stability and heat transfer characteristics of nanofluid.

GRAPHENE NANOFLUID CONVECTIVE HEAT TRANSFER PERFORMANCE

Convective heat transfer (h) of nanofluids experimental results are typically presented as a function of Reynolds number using a plot of Nusselt number (Nu) (Re). Sadeghinezhad et al. [17] investigated the impact of pumping power. The outcomes demonstrated a negligible impact of the GNP nanofluid on the pumping power penalty. Graphene nanofluids based on water have been examined by Ghozatloo et al. [52] who measured their hcoefficients in laminar circumstances in the entrance area. Additionally, the study covered how temperature and volume concentration affect the hcoefficients of graphene nanofluids. The hcoefficient of graphene nanofluids at 38°C increased up to 35.6% at a concentration of 0.1 wt% in compared to pure water. Additionally, sadeghinezhad et al.,[53] discovered a factor of 1.77 for the thermal performance. Both Sadeghinezhad et al. [53] and Mehrali et al. [54] researched the entropy generation study of nanofluids, which is useful for the heat exchangers to analyse the thermal design. Akhavan-Zanjani et al. [50] offered an alternative method of hcoefficient stability. They investigated the stability of the graphene-water nanofluids using UV-Vis

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spectroscopy. Additionally, they looked at the graphene water nanofluid twice; the first time was one week before the trials, and the second time was one week after, and it was discovered that both were almost stable, with the exception of a small sedimentation. Mehrali et al. [54] carried out another study on the stability of nanofluids by defining the deposition with centrifuge. The heat transport characteristics of GNP have been studied by sadeghinezhad et al. [55] using both experimental and computational methods. They studied nanofluids from both a numerical and an experimental perspective, and after conducting an experiment, they employed a sedimentation snapshot capturing technique to assess the stability of the nanofluid. The experiments covered here demonstrate how experimental heat transfer led to turbulent and laminar flow for different types of graphene nanofluids.

NANOFLUIDS OF GRAPHENE VIA A TUBE CHANNEL

In recent years, it has been discovered that nanofluids have the power to dramatically improve the k, stability, and heat transfer coefficient as well as to lower costs and lost energy [52]. Due to the decreased energy usage, these advantages have increased the trend to use nanofluids in various types of heat exchangers. In a study by Akhavan-Zanjani et al.,[16] the convective heat transfer coefficient of graphene water nanofluid in a laminar flow through a circular tube with uniform wall heat flux was experimentally investigated. Maximum improvements were found at 0.02% concentration. At Reof 1850, these improvements in thermal conductivity and heat transfer coefficient are 10.3% and 14.2%, respectively. Mehrali et al.[18] also employed a circle tube with nitrogen-doped graphene (NDG) nanofluids to study the thermophysical characteristics of laminar flow. The study's findings demonstrated that the NDG nanofluids' kis improved between 36.78% and 22.15% when compared to the base liquid, and that their heat transfer coefficient increased by 7–50%. Ghozatloo et al. [52] employed laminar flow over a shell and tube heat exchanger while using graphene nanofluids. It was discovered that adding 0.075% of graphene to the base liquid improves both the heat transfer coefficient, which depends on the flow conditions, and the kup to 31.83% at saturation volume concentration of graphene. Sadeghinezhad et al.[17] carried out an experimental study to examine the thermal performance of a sintered wick heat pipe utilising aqueous GNP nanofluids. According to the study's findings, the heat pipe's highest efficiency gains are 23.4, 29.8, 37.2, and 28.3%, respectively, as compared to a horizontal position (=°0), for heat input rates of 20, 40, 60, and 80W at a tilt angle of 60°. However, Yarmand et al., examined the same nanofluid[61]by a square pipe at a constant heat flux, and the findings revealed that the improvement % is a function of temperature and the weight concentration of nanoparticles. With a 9.22% rise in friction factor and a weight concentration of 0.1% at a Reof 17,500, the overall heat transfer coefficient has increased by the maximum amount (19.68%) as compared to the data from the base fluid. In an experiment, Zhou et al. [62] investigated the effectiveness of heat transfer of oscillating heat pipes (OHPs) using grapheme nanoplatelet GNP nanofluids. The filling ratios used in the aforementioned trials were 45%, 55%, 62%, 70%, and 90%. When the working fluid and an OHP with deionized water were compared, it was discovered that employing GNP nanofluids improves the heattransfer performance of OHPs (DI). The most effective range of GNP nanofluid concentrations was found to be 2.0-13.8 vol% at acceptable filling ratios (55%, 62%, and 70%). It is clear from the literature reviewed above that several research have been conducted employing various nanofluids in corrugated or facing step channels to analyse and evaluate the influence of nanofluids inside the channel as working fluid. However, only a few studies have been done to look at graphene nanofluids in such a channel; therefore, greater research on the graphene nanofluid may help us learn more about its characteristics and influence on the improvement of heat transmission.

CONCLUDING REMARKS

The review of the literature demonstrates that the thermal conductivity enhancement and heat transfer are significantly impacted by graphene nanofluids. For the creation of nanofluids, it is crucial to have a firm grasp of the fundamentals of heat transfer for a variety of heat transfer applications in order to be adaptable in varied heat transfer applications. There have been significant advancements made in studying heat transfer using graphene nanofluids, though. To understand the fluid flow behaviour and heat transmission of nanofluids, additional experimental and theoretical studies of particle movement are necessary. The experimental results demonstrated that graphene nanofluid has a considerable impact on the heat transfer and thermal conductivity augmentation, which is one of the key findings in this review paper. Additionally, the factors that affect thermal conductivity, such as viscosity, particle size, concentration, and temperature, have been researched and have a significant impact on the improvement of thermal conductivity. Another important conclusion is that the majority of studies showed that the rate of growth in thermal conductivity is larger than the rate of rise in convective heat transfer coefficient. ii. Several studies have been conducted on the use of graphene nanofluid in various tube shapes, and they all demonstrate a notable improvement in heat transmission. Graphene nanofluid's impact on facing steps or corrugated channels, however, has only been the subject of a few number of investigations, according to the literature. The majority of graphene nanofluid research were conducted at room temperature. To close the knowledge gap and gain a better understanding of the behaviour and heat transmission of graphene nanofluids, more experiments on the properties of graphene nanofluid in high temperatures must be conducted.

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