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Recent Advances and Applications in Graphene Nanofluids: A Comprehensive Study

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Abstract: ***Nanofluids are fluids containing suspensions of nanoparticles that display significant property enhancement even at low concentrations of nanoparticle. Many of the articles on nanofluids aim to improve our understanding of their performance so that in applications like nuclear reactors, transportation, electronics, biomedicine, and food it can be used. This paper goes over the fundamentals that facilitate heat transmission by introducing nanoparticles. Graphene nanofluids and their properties, as well as current developments in their production, evaluation methodologies, and approaches to improve graphene nanofluid stability, is explored, as well as possible applications in a range of energy domains. Various researchers' reports on the thermophysical, optical, and thermodynamic properties of graphene nanofluids, as well as their heat transmission performance, are discussed. Using graphene nanofluids in real-world applications also comes with a number of challenges. This article is intended to serve as a handy reference guide in order to fully understand graphene nanofluid heat transfer mechanisms, in addition to the most crucial components that determine graphene nanofluids' predicted thermal performance.***

Keywords: Graphene, Nanofluids, Stability, Thermophysical Properties, Thermal conductivity, Viscosity

1. Introduction

Finned heat exchangers to enhance heat exchange surfaces have been introduced to help increase heat transmission rate by reducing heat exchange time and increasing energy efficiency, which increases heat exchanger weight and volume. [1]. This resulted in the formation of nanofluids, which are generated by suspending nanosized particles in base fluids to maximize heat transmission capabilities of the base fluid. According to a large body of literature [2-4], the insertion of a specific amount of nanoparticles to traditional fluids enhances thermal conductivity and, as a consequence, heat transfer system thermal performance. Other parameters that influence convective heat transmissions, such as specific heat and viscosity, are influenced by nanoparticle dispersion in base fluid [3], [5]. Nanoparticles another component that could affect the thermo physical properties of nanofluid are concentration, purity level, nanomaterial morphology, shape of nanomaterials, and the manufacturing process. Metal oxides [6-8], nanomaterials of carbon [9-10], ceramics [11], and several different nanomaterials are used to create nanofluids, but none of them have the same excellent thermal and physical properties as carbon. graphene and carbon nanotubes. When it comes to thermal characteristics, carbon materials, which come in a range of allotropes, have a distinct place. At ambient temperature, the thermal conductivity (K) of various allotropes of carbon varies by more than five orders of magnitude, ranging after 0.01 percent W/mK in unstructured carbon to over 2, 000 W/mK in diamond or else graphene. Heat energy stands transmitted by phonons in solid materials, in a crystal lattice, these are ion-core vibrations, and electrons, resulting in $K = Kp + Ke$, where phonons and electrons taking part in thermal conductivity are given by Kp and Ke respectively. Ke plays because of the enormous concentrations of free carriers in metals, plays a major role. In carbon materials, phonons frequently dominate heat conduction, even in graphite, which has metal-like characteristics. As peran analysis by Balandin et al. [12], the graphene's in-plane thermal conduction can extend to5200 W/mK, proving its lead over carbon nanotubes. The excellent heat transfer via lattice vibrations is explained by the strong covalent sp2 bonding. Ke, on the contrary, can have a big impact in doped materials. There's also a lot of potential in studying hybrid nanofluids' thermophysical properties using various graphene-based nanomaterials and varying effective parameters under diverse heat and flow regimes, such as concentration of nanoparticles, size, aspect ratio, temperature, and host fluids. In addition, identifying the critical parameters that influence graphene-based nanomaterials and hybrid nanofluids' thermo-physical characteristics might be the subject of research. [13]. Sarsam et al. [14] used triethanolamine-treated graphene nanoplatelets to make a nanofluid and after that, the contact angle on a glass surface was determined. The angle of contact for the nano - fluids was lowered from 50.7° for nearly clean water 47.1°–47.9° for nanofluids. The wettability of the surface increases as the contact angle is reduced, which can improve heat transfer. Baby and Ramaprabhu [15] examined experimentally, graphene water nanofluids with better convective heat transfer. They discovered that a 0.05 percent concentration increased thermal conductivity by 16 percent and 75 percent at 250 and 500 degrees Celsius, respectively. Furthermore, the Nusselt number improved more than the thermal conductivity, according to their findings.

2. Preparation Method

Carbon-based nanofluids are One-step or two-step procedures are often used [16]. Carbon nanomaterials production and nanofluids preparation at the same time is part of the one-step method, the two-step technique contains the creation of carbon nanomaterials as dry followed by distribution in traditional fluid [17]. The second approach is not costly and more appropriate to mass manufacturing. The hydrophobic nature of nanoparticles, and long-term stability, on the contrary, is a serious worry. Physical and chemical treatments are utilized to address this matter. Graphene (Gr) has arisen as a developing material from a sea of nanoparticles. The key motivators for such intense interest were the extraordinary physical, optical, mechanical, electrical thermal and chemical properties. Gr which is a two-dimensional carbon allotrope is made up of a single carbon atom arranged in a one-atom-thick layer. Figure 1 displays the numerous forms of Gr derivatives. Separating one layer thickness from graphite is a common way to make Gr, which is a three-dimensional 3D allotrope of carbon. Gr can be made using chemical vapour deposition, mechanical, chemical, and exfoliation by electrochemical process, epitaxial development on SiC, and a variety of more modern processes.

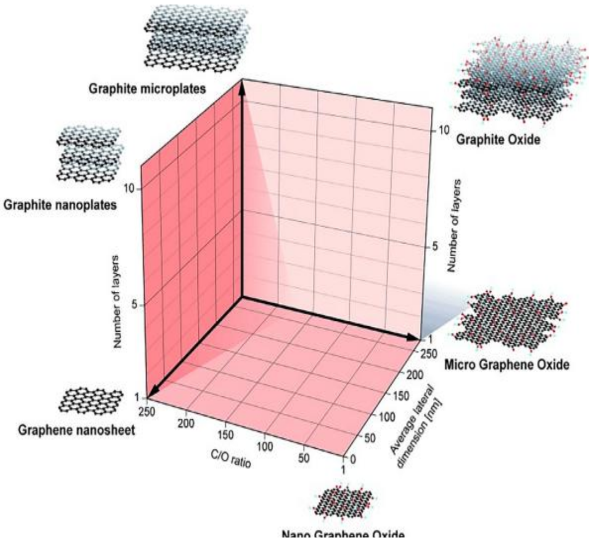

Figure 1: Graphene and its derivatives in various forms source (Reference: Khaled Elsaid et al.[22])

The significance of graphene nanoparticles, as well as their advantages over other nanoparticles, has been studied, the following are some of the advantages of graphene nanoparticles: 1. It's simple to make and keep for a long period (Extra stable) 2. Having a better surface-to-volume proportion (Greater by1000 times) 3. Thermodynamic conduction has significantly improved. 4. Corrosion, clogging, and erosion are less likely to occur. 5. The amount of energy used for pumping is lowered. A variety of nanofluids have been produced for a variety of applications for technical purposes, including automobiles, refrigerators in the home, coolants, solar appliances, makeups, anddrug distribution. Figure 2 depicts graphene nanofluid applications in graphic form.

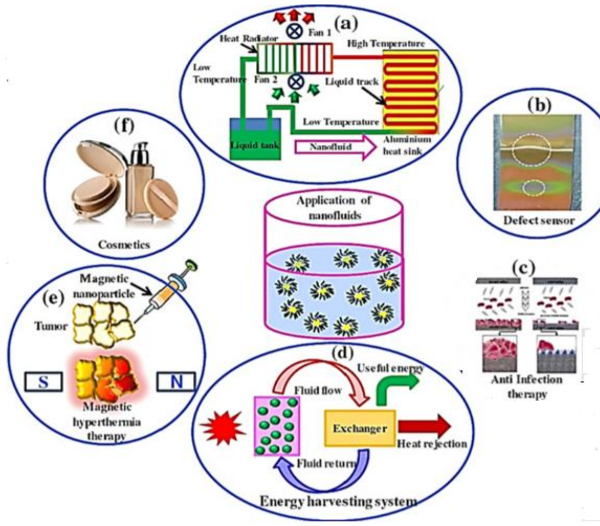

Figure 2: Nanofluids are being used in (a) heat transfer applications (b) defect identifying sensors, (c) therapy for infection (d) energy garnering systems, (e) magnetic therapy (f) makeups. (Reference: Emad Sadeghinezhad et al. [28])

3. Stability of Nanofluids

Nanofluid preparations pose a significant difficulty in terms of producing a homogeneous and stable nanofluid. The speed, with which nanoparticles held in a heat transferring liquid aggregate, that is determined by the rate of collisions and the possibility of cohesiveness as a consequence of collisions, is proven as the nanofluids' stability mechanism. A nanofluid's stability is determined by the characteristics of scattered nanoparticles and basic heat transfer fluids. The sedimentation velocity (Vsed) as defined by Stokes' law from Eq. 1 is

$$\text{Vsed} = \frac{r^2(\rho_{np} - \rho_{bf})\,g}{9\mu} \qquad \text{Eq (1)}$$

The radius of the dispersed particle is r, the nanoparticles and the underlying fluid densities are np and bf, the gravitational acceleration is g, and the dynamic viscosity of the nanofluid isμ.Vsed drops when the nanoparticles size and the nanoparticle and host heat transfer fluid density difference diminishes, and the host heat transfer fluid viscosity rises, as shown in Eq. 1. At bigger sizes, nanoparticles can bind together and form aggregates, as a result, sedimentation, and agglomeration occur.

According to Derjaguin, Landau, Verway, and Overbeek's theories, (DLVO) [18], the consistency of each element in liquid is determined by means of total attractive Van der Waals forces and double-layer electrical forces of repulsion that arise when nanoparticles come close to one other as a outcome of Brownian motion. When the Van der Waals' attractive forces outweigh the forces of repulsion, particles combine and sink, forming a non-stable colloid. In contrast, if the net electrical force of repulsion among the particles is high enough to avoid agglomeration, we have a stable colloid. To enhance the behaviour of dispersion of nanofluids and prevent particle aggregation, researchers employ three typical methodologies: pH control, surfactant addition, and ultrasonic agitation (vibration). Gum Arabic, for example, is a surfactant (GA). Sodiumdodecyl sulphate (SDS), Hexadecyltrimethylammonium bromide (CTAB), Sodium octanoate (SOCT), Dodecyl trimethylammonium bromide (DTAB), Hexadecyltrimethylammo dibromide (HCTAB), Polyvinylpyrrolidone (PVP), Oleic acid are also used as surfactants. As per the force of repulsion characteristics, scattered nanoparticles stabilization is done by either steric repulsive, electrostatic (charge), or electro-steric forces of repulsion, as shown in Figure. 3 [19]. During steric stabilisation, polymers are straightforwardly supplied to the colloid structure and attached on to the particle surface, resulting in an extra steric force of repulsion. Mechanisms such as electrostatic stabilisation generate the charges that are present on the nanoparticle's surface. 1) Preferential ion adsorption 2) The development of new species as a consequence surface separation. 3) Ions with substituent's that are isomorphic 4) Surface electron depletion or build-up 5) Physical holding of charged species on the surface.

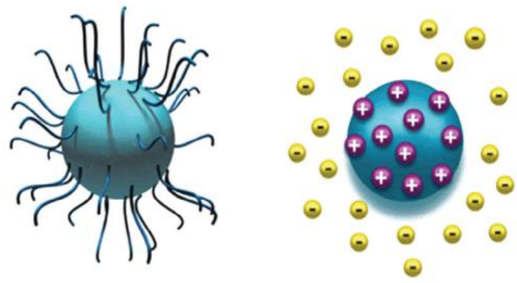

Figure 3: Stabilization methods
(Reference Source: Mehdi Bahiraei et al. [28])

Stability is also a concern with graphene-based nanofluids. In actuality, graphene is aquaphobic and cannot stay distributed for extended periods of spell for most liquids, and it rapidly agglomerates. Several efforts have been made to improve graphene particles' stability in wide range of host liquids, using covalent as well as non-covalent approaches. Carbon atoms have permanent bonds and other organic molecules are formed during covalent functionalization procedures. The non-covalent approach, which isolates particles using polymers or surfactants, is another way to progress the endurance of graphene particles in solutions.

The surface and edges of a graphene sheet can be folded, coiled, or corrugated, and despite the fact that these features can have a major influence on energy transmission processes, minute consideration has been devoted to this issue in the works. Furthermore, it stays widely recognized that coating graphene layers by way of metal otherwise metal oxide nanoparticles reduces graphene aggregation and eliminates the requirement for surfactants in base fluids to maintain graphene nanomaterials, While the downsides and benefits of such a critical problem should be thoroughly examined. Metal or metal oxide nanoparticles inhibit graphene platelets from stacking and increase overall surface area, as a result, nanofluid stability is improved while heat transmission is increased. The introduction of functional groups to such nanoparticles upon graphene shuns graphene aggregation and removes the need for base fluid wetting agent to maintain graphene nanomaterials. Furthermore, a graphene/metal oxide hybrid can greatly increase the qualities of base fluids in terms of heat transfer. This is because while both graphene and metal oxides may enhance thermal characteristics on their own, the rise is higher when the two particles are mixed. Because of its favourable properties, such as chemical inertness, SiO2 nanoparticles are commonly employed as covering nanomaterials [20].

4. Nanofluid Thermophysical Properties

The thermophysical characteristics of the resulting nanofluid are determined by the thermal characteristics of nanoparticles (NPS) and base fluid (BF), as well as their interaction (NFs). Table1 illustrates the thermal and physical characteristics of familiar NPSplusBFs. The thermal conductivities of typical heat transfer fluids are lower than those of ethylene glycol, water, and silicone oil which are, 0.255 0.607 & 0.156 W/mK respectively resulting in poor heat transfer performance. Alternatively, the thermal conductivity of silver and copper, are 429 and 389 W/m.K, respectively. These metallic elements, however, do not arise innately and must be harvested using energy-intensive technologies, which leads to greater prices and negative environmental repercussions. There are a variety of metallic as well non-metallic oxides, with silica, or else sand, being the highly prevalent. The thermal conduction of magnesium MgO is around 55 W/m.K, while that of silica SiO2 is just 1.4 W/m.K. Carbonaceous material's thermal conductivity with a value of about 6 W/m.K, such as graphite and a variety of others, have also been widely explored owing to their abundant availability, small cost, and environmentally friendly compounds, as they can result from a variety of garbage, including agricultural waste. Because of its unusually high heat conductivity of up and about to 5, 000 W/m-K and other profile-focussed properties of existing as a single-layer of carbon atoms, graphene has gotten a lot of interest among all carbon-based materials. Gr also has a lower density and a greater capacity for specific heat than the other materials in the table, which are both desired attributes for NFs. Brownian movement, molecular stacking at the particle/ liquid boundary, spontaneous heat transmission amid liquid and particle, NPS crowding effect are all examples of how the NPS increases the thermal conductivity of the material host fluid.[20-21].

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Table 1: Common nano particles and base fluids thermophysical properties

	Thermal conductivity, W/m.K	Specific heat, kJ/kg.K	Density, kg/m^3	Viscosity, 10^{-3} Pa.S
Objective	*Increase*	*Increase*	*Decrease*	*Decrease*
		Common base fluids		
Distilled water (DI)	0.607	4.18	998	0.855
Ethylene glycol-water (1:1 vol.)	0.380	3.28	1,073	3.94
Ethylene glycol (EG)	0.255	2.35	1,111	15.5
Silicone oil (SO)	0.156	1.51	930	11
Engine oil (EO)	0.145	1.88	880	84
		Common nanoparticles materials		
Silver Ag	429	0.234	10,400	-
Copper Cu	398	0.385	8,933	-
Aluminum Al	237	0.877	2,700	-
Magnesia MgO	55	0.955	3,560	-
Alumina Al_2O_3	36–40	0.775	3,970	-
Copper oxide CuO	32.9	0.525	6,500	-
Titania TiO_2	8.4	0.692–0.711	4,000	-
Silica SiO_2	1.38	0.680–0.745	2,220	-
Graphene[*]	6–5,000	0.643–2.100	2,000–2,500	-

4.1Thermal Conductivity

The improved thermal conductivity of NFs is their most essential property, attained by adding extreme thermal conductive NPS to host fluid. The ratio of NFs to host fluid thermal conductivity, Knf/Kbf, must be larger, the better the NFs, the greater the ratio. However owing to the basic suppositions of perfect round elements, absence of two-way interaction between NPs and BF and uniform particle size, experimental results drastically differ from the correlations presented below in Eq. 2. The thermal conduction fraction for several types of Gr besides other distinctive metal oxides in familiar host fluid is presented in Figure 4. Graph shows the huge surge in thermal conductivity generated by adding up Gr, indicating that even a small volume fraction may cause a considerable rise in thermal conduction. A substantial increase in thermal conduction in the case of Gr-centred NFs remains owing to the extreme thermal conduction of Gr, which is expected to exist up to 3, 000 W/m.K (in plane to the Gr plane) to a minimum of 6 W/m.K (at right angle to the Gr plane) [22].

$$\frac{Knf}{Kbf} = \frac{Knp + 2Kbf + 2\varphi(Knp - Kbf}{Knp + 2Kbf - \varphi(Knp - Kbf} \qquad \text{Eq (2)}$$

Where nf stands for nanofluid, bf stands for base or host fluid, np stands for nanoparticle, and $\varphi$is the volume fraction.According to a literature study; nanofluid's thermal conductivity is affected by nanoparticle dimension, temperature, dilution, particle movement, and other parameters. A couple of these criteria have been discussed in this section.

4.1.1Morphology

The analysis of the shape, texture, size and phase distribution of physical things is known as morphology in material science. Some studies looked at the impact of nanoparticle dimensions on thermal conductivity. They observed that the nanoparticle's dimension has a substantial impact on the nanofluid's thermal conductivity. Specific surface area (SSA), which impacts nanofluid thermal conduction that can be computed using Eq. (3), is a feature of nanoparticles that researchers should consider during manufacture.

$$SSA = \frac{Particle\ \ surface\ \ area}{Particle\ \ volume} \qquad \text{Eq (3)}$$

4.1.2. Temperature

Temperature and thermal conductivity have a direct link meaning that as the temperature rises, so do nanofluids conductivity of heat according to new study.

4.1.3 Concentration

The nanoparticles concentration in the underlying liquid is another key aspect that can alter the nanofluid's thermal conductivity. Concentration has been given in both volume and weight % form in various papers.

4.1.4. Motion

Thermophoretic movement (movement generated by a temperature variation), Brownian motion (power), and osmophoretic movement (movement due to concentration change) have all been thoroughly addressed in the literature.

4.1.5 Nanoparticle thermal conductivity

The particle's thermal conduction aimed at a given host fluid has a significant impact on the thermal transfer of one sample when related to another when each samples' base fluids are the same. In this situation, increased particle thermal conduction is predicted to result in superior nanofluid thermal conduction. Numerous research and experimental examinations have proven this.

4.1.6. Base-fluid thermal conductivity

As previously noted particle motion, particularly Brownian motion can impact the nanofluids thermal conductivity. Base fluid viscosity is one differentiating property that has a direct link with particle mobility. The influence of an electric dual coating enclosing nanoparticles might stand regarded as crucial component impacting nanofluid thermal conductivity depending on the base fluid.

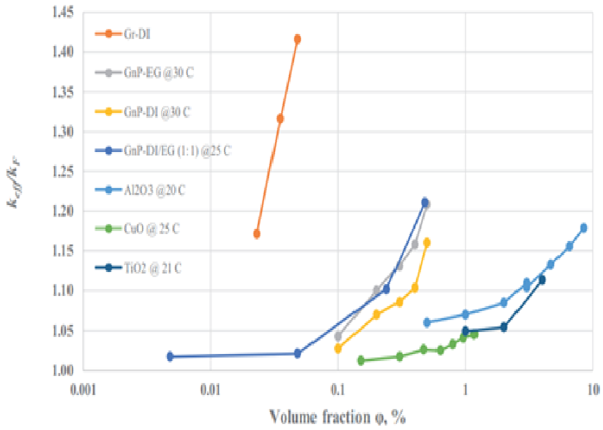

Figure 4: Ratio of Thermal Conduction augmentation for Graphene and other Nanofluids Gr: Graphene, Gnp: Graphene nanoplatelets, EG: Ethylene glycol, DI: Deionized water source (Reference Source: Khaled Elsaid et al. [22])

4.2 Specific heat capacity

The power involved to rise temperature of a unit quantity of material by one degree Celsius, written in metric units as J/g.K, is the specific heat capacity. NFs have a high specific heat capacity as a typical heat transfer fluid (HTF), which is simply the product of the flow velocity of liquid and specific heat capacity in J/k, is used to assess the fluid's heating/cooling capacity per unit increase/decrease in temperature. The greater the heat capacity, the improved the HTF. Consequently, the superior the specific heat capacity the better, for a given heating/cooling activity, the less fluid flow is required, resulting in reduced pumping power. The heat capacity of NF is reduced when NPs are added to BF.

As demonstrated in Table 1, BFs have a considerably higher specific heat capacity than NPs, with 4.18 KJ/Kg.K for water and 2.35 KJ/Kg.K for ethylene glycol, respectively. Even while graphene has the most powerful specific heat capacities among NPs (0.642-2.10 J/g.K), it still falls short of the BF [23, 24].

NF-specific heat capacity may be connected to NPs and BF specific heat capacities, and to the volume ratio, using a simple correlation, as shown in Eq (4)and the heat capacity of a Gr-water NF dropped by 3.75 percent, according to Liu et al.[26], from 3.915 J/g.K for pure water at 20 °C to 3.875, 3.834, and 3.768 J/g.K for 0.2, 0.4, and 0.8 wt. percent, respectively.

$$C\text{pnf} = (1-\varphi)C\text{pbf} + \varphi\text{Cp, np} \qquad \text{Eq (4)}$$

4.3 Density

NFs have a higher density than BF, as seen in Table 1 and according to Eq. 5. This is a result of the addition of solid NPs with a greater density. Because Gr is porous by nature, it is possible to differentiating between actual and bulk density in this circumstance. Gr has a real density of 2.00 - 2.50 Kg/lts, that is equivalent to graphite, however porous Gr structures have a bulk density of 0.2-0.4 g/ml, which is substantially lower.

The higher density of NFs, along with their increased viscosity, causes a substantial surge in pressure drop and, as a result, increased pumping power needs. In pure water, the density of Gr/DI NF rose by about 1.3 percent, from 0.9805Kg/lts to 0.9934 Kg/lts at 0.8 wt% [24]. The difference in density between BF and NPs is another essential component in NF stability; the higher the NPs density, the faster the NPs settling or velocity of sedimentation.

$$\rho nf = (1-\varphi)\rho bf + \varphi\rho np \qquad \text{Eq (5)}$$

$$\mu\text{nf} = (1+2.5\varphi+6.25\varphi^2) \qquad \text{Eq (6)}$$

4.4 Viscosity

Viscosity is the solution's opposition to movement as a consequence of inter-layer or liquid / surface interaction. Viscosity, like density, has two adverse impacts on pressure drop and the pumping power required. Because of NPs/surface impacts and other inter-layer friction and interfacial dynamics, the existence of NPs in the BF, i.e., creating the NFs, rises resistance at the fluid/surface interface. The NF viscosity is greater than the BF because of these resistances at interface.

In Eq. (6), the viscosity of NFs is given by a simple correlation. Figure 5 demonstrates that Gr-based NFs have a substantially larger rise in viscosity at lower concentrations, reaching roughly 40-50 percent in certain cases at 0.1 percent, which is significantly higher than oxide-based NFs at even higher concentrations of 1%.

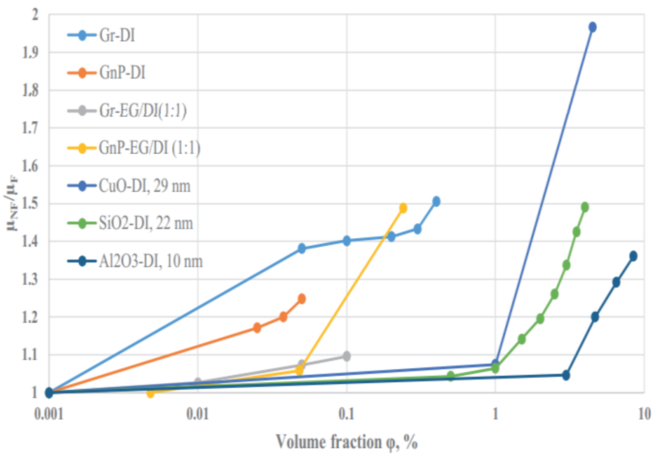

Figure 5: The difference in viscosity between graphene-based nanofluid and other nanofluid with respect to base fluid (Reference source: Khaled Elsaid et al. [22])

5. Reported Developments

The majority of sectors are seeking for fluids that can better conduct heat. Nanofluids are more efficient in transferring heat than traditional fluids. Smaller cooling systems, improved dependability, reduced pumping-power needs, fewer pollutants, and increased energy and fuel-saving are all nanofluids advantages. As a result, this study focuses on the thermal characteristics and uses of graphene nanofluids. Nevertheless, additional study is needed to properly comprehend graphene nanofluids so that practical challenges connected with their usage in heat transmission applications may be resolved.

1) The longstanding stability of nanoparticle dispersion along the host fluid as discovered by Saidur et al. [25]

2) As the Nanofluid flows, the pressure drop and friction increase.

3) The rise in viscosity of the working fluid.

According to Eastman et al. [26], freshly generated nanofluids have better thermal characteristics than nanofluids that have been prepared for a long while. It's tough to maintain particle dispersion stability alongside the base fluid since contact forces between nanoparticles tend to produce particle clusters over time. The creation of these clusters can diminish the fluid's thermal conductivity.

According to Mehdi Bahiraeia and Saeed Heshmatian's [27] research, surfactants are nonconductive, so they obstruct heat transmission and function as a barrier, diminishing thermal conductivity. Using too many surfactants to promote stability might impair the nanofluid’s thermal conductivity. An inorganic film can be adorned on graphene platelets instead of wetting agent to advance the stability of graphene particles in host fluids without affecting the nanofluid’s thermal conductivity.

Furthermore, metal or else metal oxide nanoparticles covering graphene layers inhibit clustering and remove the necessity for wetting agent to maintain graphene nanomaterial stability in host solutions. While a good review research should cover the advantages and problems of such a big issue, the relevant literature lacks such a study. Because graphene nanomaterials vary from other nanoparticles in nature, it's critical to comprehend the factors that cause the stimulation of thermal and hydrodynamical characteristics of graphene-group nanofluids.

The presence of physical flaws, reloading, and multifilm thickness may all have an impact on the characteristics and surface space of large graphene particles and ought to be considered. Although the surface and edges of a graphene sheet can be folded, coiled, or corrugated, minute consideration has stood devoted to this issue in the works, despite the fact that these features can have a substantial influence on energy transmission processes.

According to Emad Sadeghinezhad et al. [28], authors have mostly concentrated on nanofluids comprising a solitary nanoparticle, with just a limited research concentrating on hybrid graphene nanofluids. As a consequence, future study may focus on merging diverse kinds of nanoparticles (hybrid nanofluids) and discovering the important factors that influence the thermophysical characteristics of graphene nanofluids. Furthermore, models established for one type of nanoparticle may not be able to predict real-world processes in other types of nanoparticles. As a result, new models for forecasting the thermal and physical characteristics of nanofluids based on graphene should be created. The research of nanofluids' thermal characteristics makes commercial uses of this material particularly interesting. Many problems, however, continue to stymie the widespread use of these fluids, and these concerns have been recognized as future research priorities.

6. Conclusions

- Nanofluids are high-efficiency new heat transmission liquids with remarkable thermophysical characteristics. To improve the thermal characteristics of routinely used fluids, a variety of nanostructures, notable nanoparticles, are created. Graphene (Gr), which has roughly 5000 W/m.K of thermal conduction value, is the material having a lot of potential as are sourceful NF. As a result, Gr-founded NFs have been studied and tested in an extensive range of fluids. When compared to high thermal conduction metals and metal oxides for instance Ag, Cu, Al_2O_3, and SiO_2, Gr-centred NFs show a 40 to50 percent growth in thermal conductivity at 0.1 weight percent. The density viscosity and specific heat capacity of Gr-centred NF, on the contrary, are lower than, commonly used nanofluids. Consequently, the volume fraction must be optimized well to obtain better thermal conduction while keeping a tolerable density and viscosity rise in order to decrease pressure fall and pumping power needs. The graphene family of nanofluids was studied in depth in this study. Material type, preparation techniques, stability, surfactant kinds, and convective heat transfer are all taken into account. According to the study, these nanofluids offer exceptional capabilities to be used in a number of thermal applications. The following are the most vital inferences from this review study.
- Single-layer graphene sheets have larger thermal conductivity than multi-film graphene sheets.
- Because the resultant compounds are simpler to deal with, non-covalent ways of functionalizing are more promising than covalent approaches..
- The use of metal otherwise metal oxide nanoparticles to adorn graphene layers inhibits aggregation and removes the necessity for wetting agent to maintain graphene nanomaterials stable in the base liquid.
- Graphene-based nanofluids have improved convective heat removal than GO-based nanofluids. The application of nanomaterials involving the graphene group in nanofluids can make the thermal characteristics better and energy efficiency of heat transmission device while also reducing the size of devices like heat exchangers, resulting in greater reliability, decreased pollution, and increased efficiency.
- The specific heat of nanofluids is poorer than that of basic fluids, according to Namburuet al.[29]. Nanofluids are less appropriate for applications involving the storing of heat in a fluid, such as heat storage units, as a consequence of this behavior.
- Using a grapheme / metal oxide hybrid, the heat transference behaviour of the underlying fluids may be greatly enhanced. This is because both graphene and metal oxides may enhance thermal characteristics alone, but when the two structures are joined, the rise is larger.

7. Scope for Further Work

Theoretical studies attempting to describe the physical mechanisms responsible for improving the thermal properties of nanofluids still have many discrepancies, in addition to the technical challenges associated with their use. Due to a lack of agreement between experimental results from different studies, as well as incorrect characterization of nanofluids, it's difficult to formulate general mechanisms that occur under general conditions, which would allow for a better understanding of nanofluid thermal behaviour. Fluids with a higher specific heat must be investigated, as well as the possibility of hybrid nanofluids. Density differences cause particle sedimentation, which must be addressed.

Further to the technological obstacles connected with their utilization, theoretical research with the goal of elucidating the physical mechanics accountable for rise in the thermal characteristics of nanofluids still have significant differences. It's difficult to establish generic mechanisms that occur under general settings, which would allow for a better understanding of nanofluid thermal behaviour, due to a lack of consistency between experimental data from diverse research, and erroneous characterisation of nanofluids. Fluids with a greater specific heat, in addition the potential of hybrid nanofluids, must be researched. Particle sedimentation caused by density differences must also be studied.

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