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A Review Paper on Properties and Applications of Nanofluids

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Abstract. A nanofluid is a liquid that contains nanometer-sized particles. Nanofluids are obtained by dispersing nanometer-sized particles in conventional base fluids such as water, oil, ethylene glycol, etc. Nanoparticles of materials such as metallic oxides (Al2O3, CuO), nitride ceramics (AlN, SiN), carbide ceramics (SiC, TiC), metals (Cu, Ag, Au), semiconductors (TiO2, SiC), single, double or multi-walled carbon nanotubes, alloyed nanoparticles (Al70, Cu30), etc., were used to prepare the nanofluids. This paper presents a procedure for preparing Nanofluids, the properties of Nanofluids, and their applications in various fields, including energy, mechanics, and biomedicine. Then it defines the parameter that challenges the use of Nanofluids in different applications and finally suggests directions for future research on Nanofluids. The thermal conductivity of the Nanofluids is improved at a very low (< 0.1%) percentage of suspended particles. Nowadays, Nanofluids are used efficiently in non-traditional energy resources in absorbing solar energy to increase the temperature.

Keywords: Nanoparticles, Nanomaterials, Base Fluids, Temperature.

1. Introduction

A fluid created from tiny solid particles with a minimum size of 100 nm is also known as Nanofluid. This name was thought up by Dr. Choi at Argonne National Laboratory [1]. In synthesizing Nanofluids, metal oxides and metals are suspended in a liquid form that typically contains less than 4% solid volume [2]. Materials included in the term nanomaterials, such as Nano crystalline materials, Nano composites, and carbon nanotubes, are all classified as nanomaterials. Nanomaterials have unique structures that give them enhanced properties. These unique properties include mechanical, thermal, chemical, and physical strength. They also help with processes like chemical transformation and electricity generation [3]. Nanomaterials come in four different forms. One is metal-based, like aluminum oxides and dendrites, another is carbon-based, like carbon nanotubes, and another is made of micro polymers called parahydrox 2 [4]. Composites are also a type of nanomaterial; they are base materials mixed with other micro-sized particles [5]. Adding a liquid to the base material helps these tiny particles better transfer heat by improving their thermal conductivity. In 1995, scientists at the Argonne National Laboratory mixed 1-100nm Nano particles with a fluid [6] and [7]. Nanofluids have better thermal properties than other liquids because sedimentation and clogging cause high-pressure drops, and friction leads to irregular paths through the liquid.

Nanofluids are a newer form of heat transfer fluid. They can transfer heat better than smaller-sized particles like microspheres [8]. Many people do not even realize they are using Nanofluids in their everyday lives. They are used for automotive cooling, air conditioning and plant cooling, solar power, and defence and space. People also use Nanofluids to improve diesel engines' efficiency, reducing the temperature of transformer oil and increasing the efficiency of nuclear reactors and defence systems. This was reported by Xiang and Arun [9].

Nanofluids are liquid alternatives to traditional heat-removing methods for microelectronic devices. Nanofluids can be used in devices that need to maintain functionality in low-volume sizes since they can remove excess heat from the device. Car engines use Nanofluids to reduce the energy produced by the fuel combustion process [10, 11]. Nanofluids outperform conventional fluids in many heat-transfer manufacturing processes thanks to their ability to absorb excess energy produced by friction between pistons and bearings [12]. This makes them an ideal replacement for conventional fluids in heat-transfer manufacturing processes. By understanding the mechanisms involved, researchers can better understand the properties and characteristics of Nanofluids. This is because improving fluid heat transfer performance involves adding Nano phase particles to the fluid that is being heated or cooled. These reasons are listed as follows [3]:

1. Particles suspended in the liquid increase its heat capacity and surface area.
2. Suspended nanoparticles increase the apparent thermal conductivity of the fluid by increasing its effective thermal conductivity.
3. Extensive fluid and particle entanglements occur regarding the passage edge.
4. Increases in turbulence and mixing lead to an increase in the amount of fluid in a mixture.
5. The decrease in temperature across the width of the fluid due to nanoparticles' dispersion causes a diminution in the shear stress.

The objective of this paper is to know the physical properties of nanofluids as well as the applications and Stability of nanofluids.

2. Properties of Nanofluids

Adding small solid particles to a liquid increases the liquid's thermal conductivity. This idea - called thermal due-levelling has been used for a long time and is based on the properties of nanofluids, such as viscosity, specific heat, thermal conductivity, and stability. Here are the necessary basic properties that must be discussed below.

2.1. Viscosity

Comparatively, little literature exists on the subject of heat convection in Nanofluids compared to thermal conduction. Nonetheless, many approaches and results exist due to the wide diversity of the field [13]. Because understanding these issues requires knowledge of Nano fluids' viscosity, understanding first how Newtonian or shear thinning their flow is important. Furthermore, this relates to the importance of analysing whether Nanofluids are shear thinning or Newtonian. Pak and Cho discovered Newtonian flow in Nanofluids in 1998 [14]. They reported that water contained 13nm and 27nm particles ofγAl2O3 and TiO2. When these tiny particles were suspended in water, Pak and Cho found that the fluids exhibited Newtonian flow. However, as the volume fraction of these particles increased, the fluids displayed shear thinning behaviour [15]. On the other hand, TiO2-based Nanofluids show Newtonian behaviour up to 10% volume fraction, while Pak and Cho discovered shear thinning with Al2O3 Nanofluids at a 3% volume fraction. The same year, Lee et al. reported similar findings regarding increased viscosity for both water and ethylene glycol-based Nanofluids with Al2O3 particles [16]. Different researchers in 2003 came to the same conclusion as Das et al. regarding Nano fluid behaviour. They found no evidence of Nanofluids shearing or thinning, despite the other findings by other scientists. This contrasts with the observations of other researchers who noticed Newtonian behaviour with larger water Nanofluid particles. Calculating the viscosity of a liquid involves using the measured value of pure water. But many calculated viscosities measured for Nanofluids are higher than pure water. This data helps offset the increased heat transfer observed in Nanofluids. Adding more carbon nanotubes to a mixture makes the resulting substance behave non-Newtonian when it comes to its viscosity [13]. According to Ding et al., water nanotubes in 2006 caused Nanofluids to thin in a linear fashion at lower shear rates. However, other reports claim that Nanofluids have non-linear shear-thinning properties [17]. As part of an effort to reconcile these differences, Chen and associates performed both scientific and theoretical research in 2007 [18]. The research team analysed Newtonian values for shear viscosity in their surrounding environment. They tested oils with TiO2 nanoparticles at 0.5%, 1%, 2%, 3%, 4%, 5%, 6%, and 8% by weight at a temperature range between 20 and 600 degrees Celsius. Krieger-Dougherty's equation predicted the shear viscosity of a base liquid to be a function of nanoparticle size. However, this correlation became less accurate as the size of nanoparticles increased. Additionally, temperature greatly influenced this formula, making it random and nonlinear [19]. Some studies report that fluids exhibit unusual shear-thinning properties. This is allegedly due to the presence of small particles within the base fluid. The claim made by Chen et al. is that some researchers may disagree about this phenomenon in the literature. They argue that this might be due to scientific disagreements over why these observed results are the case. The high shear viscosity remains constant regardless of temperature. This is because the Brownian motion in high shear flows prevents the viscosity from decreasing. The shear rate also shows a significant temperature dependence. This is why Nano fluids thinning processes change their behaviour in different temperatures.

2.2. Specific Heat

To determine how much heat a Nanofluid can withstand, an investigator first tested their base fluid. Then, they compared the results to the specific heat of their Nanofluid of interest. This was achieved by conducting a DSC test that adheres to DIN 51007 standards. The sequence for this particular test is as follows: performing an isotherm for 5 minutes at 25 ºC, then transitioning to a heating segment from 25 ºC to 95 ºC at 10 ºC/min. After this, the temperature was returned to 25 ºC for another isotherm. Finally, two isotherms were performed at 95 ºC and then 25 ºC. Namburu [20] reported in 2009 that several Nano fluids made with ethylene glycol had lower specific heat than their base fluids. Studies by Vajjha and Das [21] show that adding nanoparticles to Nanofluids increases their heat conductivity. In a 60:40 mixture of ethylene glycol and water, they added 2 to 10% of Al2O3, SiO2, and ZnO. These two researchers found that adding nanoparticles decreased the specific heat of the fluids and increased their thermal conductivity by up to 40%. Similarly, Bergman [22] found that Nanofluids with higher Al2O3, SiO2, and ZnO percentages have lower specific heat than regular fluids. The results of Puliti et al. [23] appear to contradict other studies. One of those reports states that no anomalous specific heat was observed in one case [24]. A classic theory can predict the Nanofluid density with only a 10% deviation and its specific heat with a small error. Nelson, et al. [25] reported that adding exfoliated graphite nanoparticles to a polyalphaolefin increased its specific heat by 50%. Another study found that adding silica nanoparticles increased the specific heat of a molten salt by 26%. Adding these particles to the Nanofluid increases its density by about 2% and increases its specific heat by about 26%. Zhou and Ni found that adding AlO2-W to the Nanofluid reduced its specific heat by between 40% and 50%. Adding more than 1% by weight of silica nanoparticles reduced specific heat even further; up to 50% was lost [26]. Both Banerjee and Shin and Banerjee and Shin published a comment about their findings. Alumina nanoparticles tend to stick together, decreasing the thermal properties of the Nanofluid [6]. Additionally, the statement made no mention of whether alumina nanoparticles were evenly dispersed throughout the water solution. In fact, if agglomerated alumina nanoparticles precipitate out of the water solution, that can ruin its thermal properties. Adding 20-30 nm silica nanoparticles to 1% chloride salt eutectic increased the specific heat of the mix by 14.5%. However, no mention is made of any particle dispersion in the research findings. The researchers considered three possible thermal transport mechanisms to explain the unusual increase in specific heat they observed. By scanning electron microscopy, Shin and Banerjee [27] confirmed the particles dispersion behaviour:

Mode 1: Since the surface atoms of nanoparticles have a higher specific surface energy than the bulk material, the specific heat is increased. This is because the vibrations applied to the outermost layer of the nanoparticles are more pronounced and low in frequency.

Mode 2: Nanoparticles have a high specific surface area, which causes them to store additional thermal energy through interfacial interactions with liquid molecules. This energy is stored through virtual spring-mass systems that the molecules create due to interactions at the particle-molecule interface.

Mode 3: Regarding the thermal conductivity improvements already mentioned, another possible explanation is the creation of fluid layers. These are likely to improve specific heat by shortening

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the intermolecular mean free path. This is because both solids and liquids have intermolecular bonds that hinder heat transmission.

More research is needed on the thermal properties of Nanofluids, as specific heat is a key property in many engineering applications [28].

It is possible to investigate the effect of increased specific heat capacity on fluid adsorption on a nanoparticle's surface further. This is due to the increased volume concentration of nanoparticles with increased liquid adsorption [29].

2.3. Thermal Conductivity of Nanofluids

To accurately measure thermal conductivity, a Decagon Devices Inc. KD2 Pro thermometer uses the transient hot wire technique. This commercial device measures thermal conductivity by measuring the heat transfer abilities of Nanofluids. Compared to conventional fluids, Nanofluids have superior heat transfer properties. The increased thermal conductivity of suspended particles helps increase the fluid's overall heat transmission. It is almost impossible to accurately determine the thermal conductivity of Nanoliquids. However, some theoretical equations have been developed that yield a rough estimation of the apparent thermal conductivity of two-phase mixtures. Additionally, the percentage and size of nanoparticles in a mixture can have an effect on its thermal conductivity. Based on the definition of effective thermal conductivity for a two-component mixture, the following theory was developed.

$$k_{eff} = \frac{k_p\,\alpha_p\left(dT/dx\right)p + k_f\,\alpha_f\,(dT/dx)f}{\alpha_p\left(dT/dx\right)p + \alpha_f\,(dT/dx)f} \tag{1}$$

Hamilton and Crosser suggested a theory for mixtures of solids and liquids where the ratio of the conductivity of the two phases is greater than 100- that is, higher than 100%,

$$\frac{k_{eff}}{k_f} = \frac{k_p + (n-1)k_f - (n-1)\alpha(k_f - k_p)}{k_p + (n-1)k_f + \alpha(k_f - k_p)} \tag{2}$$

Where <paraphrase> k_p is the thermal conductivity of the discontinuous particle phase, k_f is the thermal conductivity of the fluid, n is the volume fraction of particles, and n is the empirical shape factor, calculated as:

$$n = \frac{3}{\varphi} \tag{3}$$

For spherical particles, their research showed a satisfactory coincidence between theoretical expectations and the data for their size. The ratio φ is the amount of surface area of a sphere compared to the volume of the same size particle. It is defined as the ratio of the two areas, and it can be from 0.5 to 6.0. Calculations show that other shapes had similar predictions when n ranged from 0.5 to 6.0.

Wasp came up with a new way to calculate the elective thermal conductivity of solids mixed with liquids [30].

$$\frac{k_{eff}}{k_f} = \frac{k_p + 2k_f - 2\alpha(k_f - k_p)}{k_p + 2k_f - 2\alpha(k_f - k_p)} \tag{4}$$

The portion of the particle's volume that is occupied by the particle's particles

$$\alpha = \frac{V_P}{V_F - V_P} = m\frac{\pi}{6}d^3 p \tag{5}$$

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When calculating the particle density, take into account m, the average size of a particle. Additionally, dp refers to the average diameter of the particles. Although Wasp also recognizes this relationship, he opts to treat it as a special case due to his preference for either Hamilton and Crosser's model or 1.0 sphericity.
Finding formulas that can accurately predict the thermal conductivity of Nanofluids can be difficult. However, these formulas are useful for calculating the thermal conductivity of Nanofluids when no formula is available. These formulas take into consideration two-phase Nano fluid mixtures with micrometer to millimeter-sized powders.
The thermal conductivity of nano-alumina particles is estimated by applying Hamilton and Crosser's model. This is shown in Figure 2, which φ affects the k_{eff} value. The results of applying this model to a water-based alumina dispersion are shown in comparison to experimental data by Eastman et al. (1997) in Figure 2. Increasing the volume of an alumina nanoparticle decreases its sphericity. Doing so increases the thermal conductivity of Nanofluids. This happens because larger particles have a higher effective thermal conductivity than smaller ones when they have the same shape. When Alumina nanoparticles have a sphericity of 0.3, a noticeable increase in thermal conductivity is expected at 1.2 to 1.5 if between 2% and 5% of their volume is solid. Additionally, thermal conductivity can be increased by decreasing the sphericity of particles with a given shape, although this only works with specific shapes. When increasing the particle volume fraction to 5%, certain properties of nanoparticles, such as size, shape, and specific mass, cause them to have an overbearing thermal conductivity effect on the fluid. This can be seen with a 1.2x increase in thermal conductivity at a particle sphericity of 1 and a 1.5x increase at a 0.3 sphericity particle. Increasing the size of particles increases the base fluids' thermal conductivity. This prediction is shown through these results [31].

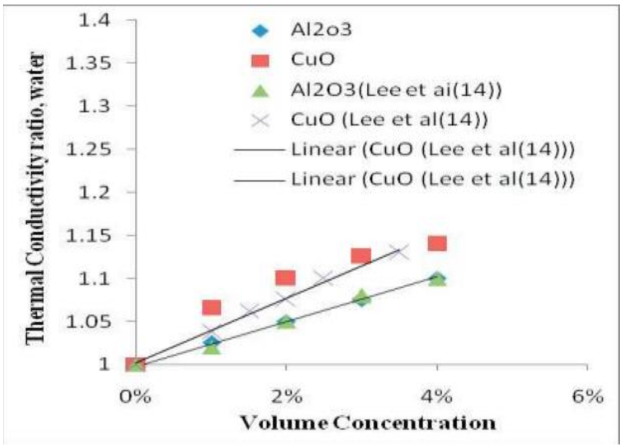

Figure 1. The thermal conductivity of Cu-water Nanofluid is greater than that of water.[31]

2.4. Stability of Nanofluids
A Turbiscan Lab Expert (Formulation SA, France) analysed Nano fluids regarding their stability. These fluids were tested using a laser light to see how much light was reflected back to the source. Multiple light scattering theories were used to gather data for measurements. This equipment uses a near-infrared light source and a light detector to observe the light reflected back [32]. For each Nano fluid sample, multiple measurements were taken at different time intervals. These measurements were conducted up to 48 hours in duration and focused on the Nano fluids' stability. Special equipment is needed to determine the variation of particle size or concentration in sediment Nano fluids [13]. A camera can be used to observe the sedimentation of test tubes filled with Nanofluids. Nanofluids are considered stable when their concentration or particle size remains consistent [13]. A camera can easily observe the sedimentation process of Nanofluids in test tubes. A special apparatus called a particle size analyser can measure the variation of particle size or concentration of Nanofluids in sediments [13]. This measurement indicates the stable nature of Nanofluids, which can be confirmed by observing constant Nano fluids conditions in test tubes. Zhu et al. determined the graphite suspension stability using a

sedimentation balance. They used this method to measure the weight of suspended particles while they mixed the mixture [33]. In order to determine the stability of Nanofluids, a centrifugation method was created. Long periods of observation for sedimentation methods are a significant defect. As a result, graphite nanoparticles' suspension fraction can be calculated. As a stabilizing agent, PVP prevents agglomeration of the nanoparticles and inhibits their growth [34]. This allows for the silver Nano fluids created via microwave synthesis to maintain stability for more than one month. Additionally, these fluids can remain stable for up to 10 hours when spun at 3,000 rpm without sedimentation. This is due to the protective nature of PVP. The authors of this work applied the centrifugation method to observe the stability of these fluids. Li used centrifugation to test the stability of aqueous polyaniline colloids [35]. The electrostatic repulsion between Nano fibers maintains the colloids' long-term stability. The longer the ultrasonication time, the longer the stability period would be for all samples. SiO2 nanoparticles in a Nanofluid help increase its stability. SiO2nanofluid was determined to be the most stable of all the fluids tested, while Al2O3lowest instability. With regards to the hybrid samples, stability increases with a higher volume concentration of SiO2 nanoparticles [36].

3. METHODS FOR PREPARATION OF NANOFLUIDS

To alter heat transfer performance, first, use Nano phase particles. Doing so requires preparing Nanofluids, which don not merely contain a liquid and solid mixture. Additional steps are necessary to prepare the Nanofluids properly, such as maintaining even suspension, resisting instability and long-term use, and not chemically changing the fluid. Adding surface activators or dispersants can improve suspensions' preparation. Also, using ultrasonic vibrations can be useful when creating new formulas. This is due to the fact that most formulas require both changes. The following Techniques are discussed below:

3.1. Two-Step Method Two-step method

Concentrated Nano materials are prepared through the use of a process called dry milling. This method mixes Nanofibers or powders into a liquid by using mixing methods like ultrasonic, magnetic, high-shear, magnetic agitation, and ball milling. Some other mixing methods include chemical and physical mixing. Surfactants help create Nano fluids that are more stable when suspended in solutions. This makes two-step synthesis the most cost-effective way to produce large quantities of Nanopowders. Synthesizing nanoparticles is already expensive, so manufacturers have to scale up their techniques to industrial levels. Creating Nanofluids can be difficult because of the difficulty in creating stable two-step Nano solutions. In order to solve this problem, many people have developed advanced methods for creating one-step Nanofluids, such as the one-step method. Figure 3 details the most common Two-Step process. One-Step is a more convenient, in-depth method that requires no additional steps.

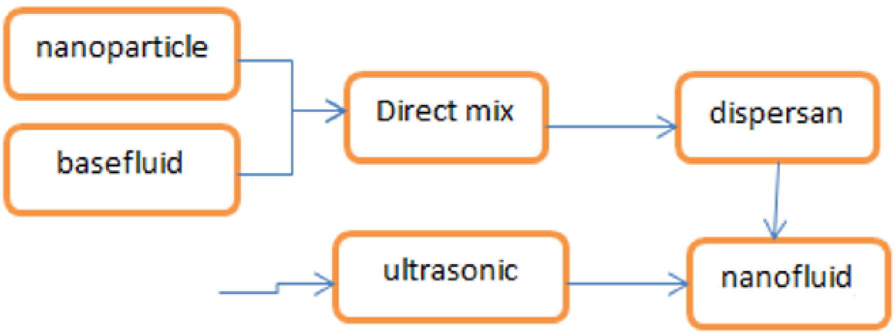

Figure 2. The two-stage preparation procedure of Nanofluid

3.2. One–Step Method

The one-step process developed by Eastman et al. eliminates the transportation, storage, and drying of particles. Instead, they create fluids by mixing particles with ethylene glycol in one step [37]. This reduces the probability of particles clumping together and increases the stability of liquids [13]. Alternating dielectric liquids produce various results; these are often seen via the resulting particles' shapes. Vacuum-SANSS, or one-step Nano particle creation, is another method that uses dielectric liquids with high thermal conductivity. By using this method, large and uniformly sized nanoparticles can be formed in a stable state within the base fluid. Although the resultant nanoparticles form various shapes, such as needles, squares, circles, and polygons, they do not form agglomerated aggregates. However, creating Nanofluids in large quantities costs a significant amount of money. Consequently, research into chemical synthesis methods is rapidly evolving. Zhu and his colleagues developed a one-step chemical method that produces Nanofluids with copper in a stable form [38]. They used ethylene glycol, NaH2PO2·H2O and CuSO4·5H2O under microwave radiation to create Nano fluids [39]. Copper Nanofluids created with this method had well-dispersed mineral oil particles, and stable suspension of silver nanoparticles was also possible. Silver nanoparticles can be stabilized using Korantin, which is an oxygen-containing alcohol that provides a dense layer around the particles. For about one month, these suspensions were stable. It is possible to create ethanol-based Nanofluids containing silver nanoparticles via a one-step microwave process. Colloidal silver is a thin liquid that works as an antibacterial and antimicrobial agent. It also acts as a reducing agent when combined with polyvinyl pyrrolidone, or PVP, which stabilizes the colloidal silver and reduces its solubility. ODA, an anionic surfactant, phase-transfers to silver to form colloids [40]. ODA molecules chemically interact with silver nanoparticles via coordination bond formation or weak covalent bonding. This results in nanoparticles being coupled with ODA molecules in the organic phase.

4. ADVANTAGES OF NANOFLUIDS

Nanofluids provide the following advantages for use in various applications.

- Minimizing particle size, material, and shape will increase the efficiency of solar energy absorption.
- In tiny suspended particles, the increased heat capacity and surface area result from the small size of 1.5 nm.
- Adding Nanoparticles to a substance allows for better heat transfer efficiency thanks to the increased thermal conductivity.
- Surfaces lose heat to the surrounding environment, while the fluid within maintains a consistent temperature. This allows the material's overall temperature to be pushed away from the skin, making it more comfortable.
- Mixing and turbulent motion of the fluid increase.
- Nanoparticles decrease the transverse temperature gradient in the fluid.
- High concentrations of nanoparticles can change a material ability to be used in different ways.
- Using solar thermal applications with Nanofluids increases the temperature.

5. APPLICATIONS OF NANOFLUIDS

Using Nanofluids in engineering applications improves heat transfer and energy efficiency by an enormous amount.

5.1. Transportation

Nanofluids have great potential to improve the cooling rates of heavy-duty automobile engines, Increase efficiency, reduce weight, and reduce thermal management complexity systems. The improved cooling rates of car and truck engines can be used to remove more heat from higher horsepower engines is about the same as the cooling system. It is useful for designing a more compact cooling system with smaller, lighter radiators. And she, in turn, High performance and high fuel economy benefit the car and truck. Based on ethylene glycol, Nanofluids have attracted much interest as an engine coolant [41] because of their lower pressure process compared to a 50/50 mixture of ethylene glycol and water, which is approximately used as general car coolant.

5.2. Industrial Cooling Applications

Nanofluids increase energy efficiency and reduce greenhouse gas emissions in industrial processes [48]. US industrial processes that use Nanofluids can save over 1 trillion Btu per year, enough energy to power approximately 50,000 to 150,000 homes. The replacement of cooling and heating water with Nanofluids can reduce energy costs by up to 48 billion Btu per year-equivalent to the cost savings of replacing 1 trillion Btu of heating and cooling water each year. The associated reductions in emissions are approximately 5.6 million metric tons of carbon dioxide, 8,600 metric tons of nitrogen oxides, and 21,000 metric tons of sulfur dioxide [42]. This was discovered through experiments performed on a flow loop system using materials such as exfoliated graphite nanoparticles and polyalphaolefins [41]. The specific heat of the polyalphaolefin material was reported to be 50% higher than the Nanofluid. Additionally, it was discovered that Nano fluids increased in temperature with each additional added Nanofluid. Nanofluids have a thermal diffusivity four times higher than regular ones. This increase in heat flow is due to increased convective heat transfer by 10%.

5.3. Heating Building and Reducing Pollution

Kulkarni et al. studied how certain fluids perform as heating transfer fluids in buildings with heating systems [43]. The common practice in cold regions is to mix propylene glycol or ethylene glycol with water to apply as a heat transfer fluid. Calculating the power that needs to be pumped per unit volume or weight resulted in 60:40 ethylene glycol/water as the base fluid. Nanofluids require smaller heating systems. This makes them more affordable than larger heating systems because they use the same amount of thermal energy as more expensive systems but take up less space. Their initial equipment costs excluding nano fluid costs, are lower than other systems. Less material and liquid are needed by end-of-life heat transfer units because they process their waste less. This reduces environmental pollution from heating units since smaller units take less energy to run.

5.4. Solar Absorption

Some nanoparticles have unique antibacterial or drug-delivery properties. This means the Nanofluids containing these particles have special properties.

Solar energy is one of the best renewable energy sources with minimal environmental impact. The conventional direct absorption solar collector is a well-established technology, and it has been proposed for a variety of applications such as water heating; however, the efficiency of these collectors is limited by the absorption properties of the working fluid, which is very poor for typical fluids used in solar collectors. Recently, this technology has been combined with the emerging technologies of nanofluids and liquid-nanoparticle suspensions to create a new class of nanofluid-based solar collectors. Otanicar et al. reported the experimental results on solar collectors based on nanofluids made from a variety of nanoparticles (CNTs, graphite, and silver) [44].

The efficiency improvement was up to 5% in solar thermal collectors through the use of nanofluids such as absorption media. In addition, they compared the experimental data with a numerical model of solar energy collector with direct adsorption nanofluids. Experimental and numerical results are shown as an initial rapid increase in efficiency with a volume fraction, followed by a levelling off in efficiency, such as the volume portion continuing to increase. Theoretical investigation into the feasibility of using a direct absorption non-concentrating solar collector showed that the presence of nanoparticles increased. The absorption of the incoming radiation is more than nine times that of pure water [45]. Under Similar operating conditions, the efficiency of a nanofluid solar absorber such as it is found that the working fluid is up to 10% higher (on an absolute basis) than the flat plate fluid.

5.5. Antibacterial Activity

Metal oxides, such as zinc oxide, have antibacterial properties that make them popular among scientists. Organic antibacterial materials often break down or lose effectiveness when exposed to high temperatures or pressures. This is why many prefer inorganic metal oxides like zinc oxide to organic antibacterial materials for use in harsh process conditions. ZnO Nanofluids have proven to be bacteriostatic against bacteria [46]. ZnO nanoparticles can kill bacteria if they come into contact with the bacteria membrane. Jalal et al. created these nanoparticles by a green method. They used this process to treat Escherichia coli (E. coli) with a suspension of ZnO nanoparticles. The antibacterial activity of ZnO was tested by measuring the ratio of reduction in bacteria treated with ZnO against untreated E. coli. ZnO nanoparticles have antibacterial properties. Research has shown that their antimicrobial effects are more effective the longer bacteria are exposed to ZnO Nanofluids and light. Further testing determined that bacterial survival rates decrease with increasing ZnO Nano concentrations [47]. Zinc oxide nanoparticles have shown antibacterial properties. They can break down E. coli O157:H7, one of the most common food-borne pathogens. Zinc oxide particles have more effect the higher the concentration of them in a solution. Zinc oxide is an antibacterial agent that can protect agricultural and food safety. It can even destroy bacteria's cell membrane and break down components in cells. Zinc oxide can change the cell membrane by changing fats and proteins inside cells. This change can even cause bacteria to lose their cell components and die. Because of its potential, zinc oxide is a promising technology for future use [48].

5.6. Nano Drug Delivery

Many new medical applications have been created thanks to the multifunctional and solubility-improving properties of nanoparticles. These small particles can be made to specifically interact with cellular functions, which hadn't been possible before. This is because, over the last few decades, colloidal drug delivery systems have been developed. These systems help improve the efficiency and specificity of a drug's effects [49]. Gold nanoparticles have many uses as nontoxic carriers for delivering drugs and genes to specific locations in the body. Their high stability combined with a monolayer coating allows them to be used for creating hydrophobic and lipophobic surfaces [50]. Gold nanoparticles also have the ability to interact with thiol groups, which allows them to selectively release certain substances into cells. Nakano and his team presented a nonmagnetic fluid delivery system that could transport and focus pharmaceuticals [51]. They figured out how to use magnetic nanoparticles in a Ferro fluid cluster thanks to the biochemistry they could add to the particles, as well as their drug-loading function. A new alternative to using animal-based cargo is using carbon nanotubes, which can transport both types of molecules. CNTs can be modified with other materials, including drugs and protein molecules [52]. This gives them the ability to deliver cargo to cells and organs. CNTs are low-toxic and non-immunizing, which makes them a great option for use in the field of Nano biotechnology and nanomedicine. A recent strategy for functionalizing CNTs was created by Pastoring et al. They used 1,3-dipolar cycloaddition of azomethine ylides to create two different functionalized CNTs [53]. The research of Liu et al. found that CNTs can capture and hold certain molecules. These findings suggest that CNTs can be mixed with other materials to create a forest-like state. This allows the formation of highly effective drug delivery formulas that can hold high concentrations of doxorubicin mixed with CNTs. This mixed material is referred to as a "forest scrub" because it resembles an environment where plants grow in between trees. The mixed material also incorporates PEG, which makes the formula more soluble and easier for the aromatic molecules to occupy CNTs' slots. [54].

6. CONCLUSION

This paper covers the topic of Nano Fluid, providing an overview of the subject. It also provides information on how to prepare Nano Fluid, its properties, and methods for testing its stability. Additionally, it details potential applications of Nanofluids in heat transfer, mass transfer, energy fields, and mechanical fields. Plus, it explains why Nano Fluid is more cost-effective and easier to produce than other fluids. Some of the unique applications are explained in this paper, along with the benefits and drawbacks of using Nano Fluid in these situations. Currently, much research and development are required to fully understand Nano fluids' abilities. Additionally, finding the most important factors when it comes to Nanofluid efficiency needs to be further studied. Because of these hindrances to commercialization, finding a way to overcome them should remain an ongoing priority. The ongoing lack of consensus among various research teams leads to a need for the study of key factors. These could include the accurate mappings of suspension structures that account for discrepancies in data. Also, adding Nanofluids to suspensions increases pumping power and decreases flow rate due to increased viscosity. Strongly increasing the ability of two separate phases to interact with each other through modifying the interface properties of both phases is one possible solution to improving Nano fluids' compatibility. A third possible solution may be to use shape-dependent additives in Nanofluids, which could be an interesting area of research. Some applications for Nanofluids with low viscosity and high conductivity contain promising results, and these results might be improved by new approaches to making Nanofluids with controllable structures. High-temperature energy storage and solar energy absorption are two possible future applications of Nanofluids that haven't been researched yet. The lack of stability in practical applications means that stabilizing Nanofluids is also a priority for both research and practical purposes. Additionally, the stability of Nanofluids at low temperatures is also important because it affects practical uses and long-term stability. Making sure these stability traits don not deteriorate over time is also critical to the fluid long-term viability. In addition to high temperature, increasing the surfactants' degradation rate can cause more foams thanks to increased oil degradation. This can be problematic when considering these factors. Additionally, the dispersion properties of Nanofluids are heavily reliant on the inclusion of an additive. Even today, many practical applications in engineering and science still utilize Nano fluids due to their complex nature. Although a wide range of heat transfer mechanisms has been explained, this still remains a critical necessity due to sedimentation formation and blockages in flow paths.

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