Preparation, Properties, Stability and Applications of Nanofluids: A Review

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Abstract

A nanofluid is a fluid containing nanometer-sized particles, typically made of metals, oxides, carbides, or carbon nanotubes. All methods of preparation can be categorized into two types, viz., single-step method and two-step method. The thermophysical properties such as thermal conductivity, specific heat, viscosity, and density play a vital role in the heat transfer behaviour of nanofluids. Nanofluids have a broad range of current and future applications in different fields. Though nanofluids have a wide range of applications, it has to suffer by some challenges, and limitations like to maintain the stability and operational performance. In this paper, we are going to deal with all the above aspects of nanofluids.

1. Introduction:

Nanofluids are a new kind of fluids engineered by suspending nanometer-sized materials (nanoparticles, nanofibers, nanotubes, nanowires, nanorods, nanosheets, or droplets) in base fluids. Nanofluids have enhanced thermophysical properties and signify great potential applications in many fields. The term nanofluid designates a colloidal suspension containing nanoscale particles of average size less than 100 nm with any base fluid that doesn't dissolve the particles hosted by it [1].

Choi, in 1995, developed a novel class of heat transfer fluids that depends on suspending nanoscale particles of average particle size of less than 100 nm into conventional heat transfer fluids, named, "nanofluids". The nanofluids exhibit enhanced thermal conductivity, increasing the volumetric fraction of nanoparticles [2].

Compared to conventional solid-liquid suspensions, nanofluids possess the subsequent advantages: High specific surface area, High dispersion stability, Reduced pumping power as compared to pure liquid, Reduced particle clogging as compared to conventional slurries, Adjustable properties, etc. [3].

The unique features of nanofluids are stated as: Abnormal enhancement of thermal conductivity, Stability, Small concentration and Newtonian behavior, Particles size dependence

While selecting the nanomaterial for the preparation of nanofluids, the factors to be assumed are,

(i) chemical stability, (ii) thermophysical properties, (iii) toxicity,

(iv) availability, (v) compatibility with the base fluid, and (vi) cost.

2. Method of Preparation:

It is very important to synthesize the nanofluids with uniformly dispersed nanoparticles into the base fluid. However, special care is needed to avoid particles agglomeration. In order to obtain the enhanced thermal properties, the nanofluid to be prepared should be stable and durable.

Therefore, many combinations of material might be used for particular applications, namely: nanoparticles of metals, oxides, nitrides, metal carbides, and other non-metals with or without surfactant molecules which may be dispersed into fluids like water, ethylene glycol, or oils. There are mainly two approaches used to synthesize nanofluids, namely, the bottom-up approach or the single-step method and the top-down approach or the two-step method [5-7].

2.1. Single-Step Method:

The single-step method is the process of simultaneously making and dispersing the particles in the fluid. It consists of direct evaporation and condensation, the submerged-arc nanoparticle synthesis system (SANSS), and laser ablation. This method eliminates the stages of drying, storage, transportation, and dispersion of nanoparticles, so that aggromeration of nanoparticle is minimized, and the stability of fluids increases.

A main advantage of using the single-step method is that parameters affecting the synthesis process can be varied, and desired micro-structures can be targeted. However, there are some disadvantages to the single-step method which are, it cannot synthesize nanofluids on large scale, the cost is also high and its applicability to low vapor pressure base fluids only [8,-12].
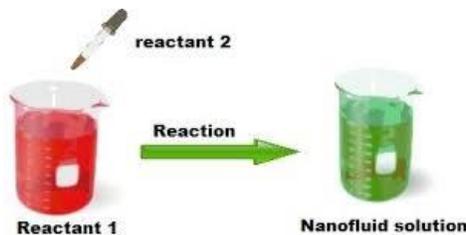

Fig.1 Single-step preparation method

2.2. Two-Step Method:

The two-step method is a widely used method for preparing nanofluids. Nanoparticles employed in this method are first produced as dry powders by chemical or physical methods. Then, the nanosized powder will be dispersed into a fluid within the second processing step with the help of intensive magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenizing, and ball milling, clustering, and high surface energy

The main advantage of the two-step method is higher production capacity with lower cost. The two-step method can be used to synthesize almost any kind of nanofluids but it is more preferable for forming nanofluids containing oxide nanoparticles, while it is less effective toward metallic nanoparticles. Additionally, the stability and thermal conductivity of the produced nanofluids doesn't seem to be optimal [10-13].
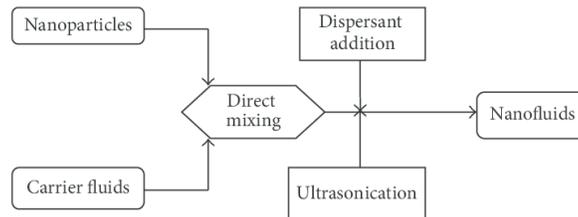

Fig.2 Two-step preparation method

3. Thermo-Physical Properties of Nanofluids:

Thermophysical properties of the nanofluids are quite essential to predict their heat transfer behavior and also in the control of the industrial and energy saving perspectives. Nanoparticles have great potential to improve the heat transfer properties compared to conventional particles fluids suspension, millimeter, and micrometer sized particles. There are four major thermophysical properties that change their values due to nanoparticle addition to the base fluid which are thermal conductivity, viscosity, density, and specific heat. [3,5].

3.1. Thermal Conductivity:

One of the main source behind the concept of nanofluids is the enhancement of the thermal conductivity compared to conventional fluids, which has a positive effect on the fluid convective heat transfer. Adding nanoparticles to a conventional fluid improves its thermal conductivity if the added nanoparticles had a higher thermal conductivity than its base fluid. The thermal conductivity of nanofluids depends on many factors such as particle volume fraction, particle material, particle size, particle shape, base fluid material, and temperature. Amount and types of additives and the acidity of the nanofluid also plays important role in enhancement of thermal conductivity. The increase of the thermal conductivity with an increase in the temperature is an interesting phenomenon that could be potentially used for the efficiency enhancement of thermal systems under higher operating temperatures [2,4,14].

3.2. Viscosity:

Nanofluid viscosity is a measure of the tendency of the suspension to resist the flow. It can also be defined as the ratio of the shear stress to the shear rate. The viscosity of nanofluids mainly increases by increasing nanoparticles concentration and decreases by increasing temperature. Comparing to

conventional fluid nanofluids has higher viscosity. The rise in effective viscosity leads to higher pressure losses and hence elevates the pumping power demands. The factors affecting the effective viscosity are the basefluid viscosity, nanoparticles concentration, particle shape, particle diameter, particles type, temperature, pressure, pH value, and shear rate [4,11,14].

3.3. Density:

The increase in concentration of nanoparticles leads to increase in density of nanofluids. The increase in density increases the volume of nanofluid which tend to increase the heat capacity of nanofluid per unit volume. The effective density of a nanofluid can be theoretically calculated through its basefluid density and nanoparticle density because it is assumed to be a mixed property of both, basefluid and nanoparticles. The parameters affecting the effective density of nanofluids are the particle size and shape, nanofluid temperature, added surfactant, and the nanolayer between the particles and basefluid effect [14,15].

3.4. Specific Heat:

Specific heat can simply be defined as the heat required to raise the temperature of 1 g of a substance by 1 °C. As the specific heat of solids is less than that of liquids, the specific heat decreases with the addition of solid nanoparticles to the base fluid. However, to remove more heat, a higher value of specific heat is required and nanofluids have slightly higher specific heat compared to conventional fluid. It is a very important property that affects the heat transfer rate of a nanofluid. The two important models suggested for calculating the effective specific heat of nanofluids, the first one based on volume fraction while other one based on heat capacity concept. [14-16].

4. Stability of Nanofluids:

4.1 Stability Evaluation Methods for Nanofluids:

Long-term nanofluid stability is necessary as it extends the shelf-life of the product while conserving its thermophysical properties. The following sections are various techniques used to evaluate nanofluid stability.

4.1.1. Sedimentation Method:

This method is one of the simplest method to measure the stability of nanofluids. In this method, the volume of the agglomerated nanoparticles in a nanofluid is observed under an external force. This is done by placing a sample of the prepared nanofluid in a transparent glass vial; then the formation of sediments

is observed via capturing photographs of the vial at equal intervals of time using a camera. The captured images are then compared to each other to analyze the stability of the nanofluid. Thus, the characterized nanofluid is considered to be stable when the particles size and its dispersity remain constant with time (i.e., no sedimentation occurs) [8,10].

4.1.2. Zeta Potential Analysis:

The stability of a nanofluid can be determined by measuring the electrical potential known as zeta potential between the dispersion medium and the stationary fluid layer attached to the particle and it indicates the degree of repulsion between charged particles dispersed in the fluid. Nanofluids with high zeta potentials (negative or positive) are considered to be electrically stable and with low potentials will undergo nanoparticle clustering and sedimentation. Nanofluids with zeta potentials between 40 and 60 mv are considered stable while with zeta potentials greater than 60 mv have excellent stability [10].

4.1.3. Spectral Absorbency Analysis:

The spectral absorbency or UV-vis spectral analysis is a reliable method to evaluate the stability of nanofluids if the nanomaterials suspended in basefluid have characteristic absorption bands in the wavelength 190–1100 nm. The nanoparticle size distribution in nanofluid is characterized via absorbed spectrum due to the optical properties of the particles, which depend on their morphology (i.e., shape and size,. In other words, there is a linear relation between the absorption intensity and the concentration of nanoparticles in a nanofluid [16].

4.1.4. Electron Microscopy Method:

Particles size distribution can be measured to determine the nanofluid stability using transmission electron microscopy (TEM) or scanning electron microscopy (SEM) devices. These very high-resolution microscopes tend to capture the digital image, known as the electron micrograph, of approximately 0.1 nm in size and these images were compared to find the stability of nanofluids [6].

4.2. Stability Enhancement Methods for Nanofluids:

4.2.1. Addition of Surfactants:

The addition of surfactants is a simple and economical method to improve the stability of nanofluids. It reduces the surface tension of the base fluid and improves the immersion of nanoparticles as the surfactants consist of a hydrophobic tail portion (e.g., long-chain hydrocarbons) and a hydrophilic polar

head group that tends to increase the hydrophilic behavior between the base fluid and the nanoparticles [16].

4.2.2. Surface Modification Techniques:

By modifying the surface of the nanoparticles (via surface functionalization) is a very surfactant-free approach that can deliver long-term nanofluid stability without the problems normally associated with surfactants. This is done by introducing functionalized nanoparticles into the base fluid in order to obtain a self-stabilized nanofluid. Usually, suitable functional organic groups are selected as they tend to attach to the surface of the atoms, enabling the nanoparticles to self-organize and avoid agglomeration [17].

4.2.3. Ultrasonic Agitation:

It is a physical method which depends on employing ultrasonic waves through the fluid that ruptures the nanoparticles' attractional force within the sediments to enhance the stability. This technique is widely used in the nanofluids prepared by the two-step method [10,16].

4.3. Stability Mechanism:

Stability which is the most critical issue can be hampered by particle aggregation. Therefore, by preventing the aggregation of particles, stability can be ensured. This can be done by two mechanisms: electrostatic stabilization and steric stabilization [16,18].

4.3.1. Electrostatic stabilization:

Existence of an electric charge on the surfaces of particles is a major source of kinetic stability. Electrostatic stabilization occurs by adsorption of ions to the electrophilic metal surface. Adsorption creates an electrical double/multi-layer which results in a Columbic repulsion force between the nanoclusters. Electrostatic stabilization is a pH sensitive method and of limited use [16,18].

4.3.2. Steric stabilization:

Steric stabilization of nanoparticles is achieved by attaching macromolecules such as polymers or surfactants to the surfaces of the particles. The stabilization is due to the large adsorbents which provide steric barrier to prevent particles coming close to each other [16,18].

5. Applications of Nanofluids:

Now-a-days nanofluids are nearly used in all the sectors or industries like automobile sector, energy industry, in medical sector, etc. Some of the applications include cooling in electrical, electronic and, mechanical devices, efficient heat transfer in energy generation and process industries, cooling and heating of buildings, thermal storage, solar energy systems, desalination, refrigeration, space and defense, and lubrication in moving parts of machines and biomedical equipment.

The application of nanofluids in industrial cooling will result in great energy savings and emissions reductions. For the US industry, the replacement of cooling and heating water with nanofluids has the potential to conserve 1 trillion Btu of energy [11]. Nanofluids could also increase the heat transfer coefficient by increasing the thermal conductivity of a coolant by reducing both the thermal resistance and the temperature difference between the heated microchannel wall and the coolant. A combined microchannel heat sink with nanofluids had the potential as the next-generation cooling device for removing ultrahigh heat flux [1].

The major concern of any mechanical industry ranging from manufacturing companies to railways is wear and tear, life, and reliability of moving parts. Nanoparticles have excellent load-bearing capabilities and can withstand high pressures, thereby reducing wear and tear in moving parts of machines [19].

Engines that are designed using nanofluids' cooling properties would be able to run at more optimal temperatures allowing for increased power output. With a nanofluids engine, components would be smaller and weigh less allowing for better gas mileage, saving consumers money, and resulting in fewer emissions for a cleaner environment [16]. In case of fuel containing nanofluids, as the aluminum nanoparticles are allowed for increased decomposition of hydrogen from water during the combustion process, the combustion of diesel fuel mixed with aqueous aluminum nanofluid increases the total combustion heat and decreases the amount of nitrous oxide and smoke in the exhaust emission from the diesel engine [20].

The presence of nanoparticles in absorption solar collectors increases the absorption of incident radiation nine times higher than pure water. In other words, the efficiency of an absorption solar collector using nanofluid compared to working fluid is about 10% higher than the flat plate collector. Nanofluids are also utilized during the extraction of geothermal energy. While extracting energy from the earth's core, nanofluids can be used to cool machinery, sensors working at high temperature and high friction. Also the revolutionary improvements utilizing new methods of rock penetration cooled and lubricated by nanofluids will lower production costs [20].

In biomedical field, nanofluids containing nanoparticles having antibacterial activities or drug-delivery properties will exhibit some relevant properties. The various biomedical applications that involve nanofluids are magnetic cell separation, drug delivery, hyperthermia, contrast enhancement in magnetic resonance imaging, etc. [18,20].

6. Conclusion and Discussion:

The paper presents a review of recent developments in the study of nanofluids, including preparation methods, thermophysical properties, the evaluation methods for their stability, the ways to enhance their stability, the stability mechanisms, and their potential applications. Nanofluid stability and its production cost are major factors in using nanofluids. So that they may be applied as more efficient and compact heat transfer systems, maintaining a cleaner and healthier environment and unique applications.

Among the two common preparation methods reported to synthesize nanofluids, the two-step technique works well for oxide nanoparticles, while it is less successful with metallic particles as compared to the single-step method. It is important to mention that thermophysical properties vary with the volume concentration, temperature, and flow rate. However, more research is required to study the effect of nanoparticle's shape, size, and surface chemistry on the properties of nanofluids.

The stability of nanofluids is one of the key challenges hindering the widespread practical application of nanofluids. Studies showed that stability depends on pH, sonication time, different types of shapes and sizes of nanoparticles with different base fluids, nanofluid preparation methods, volume fraction, and surfactants. Therefore researchers had concentrated on preparing stable nanofluids by using different techniques. Although nanofluids have displayed enormously exciting potential applications for commercialization.

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