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.

Keywords: Nanofluids, Preparation Methods, Thermophysical Properties, Stability Evaluation.

Introduction:

Nanofluids are a special kind of fluids manufactured by suspending nanometer-sized materials (nanoparticles, nanofibers, nanotubes, nanowires, nanorods, nanosheets) in base fluids. Nanofluids have better and remarkable thermophysical properties and signify great potential applications in many fields due to which nanofluids can also be known as, 'next generation heat transfer fluid'. The term nanofluid designates a colloidal suspension containing nanoscale particles 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 based on dispersing nanorange particles of average particle size of less than 100 nm into conventional heat transfer fluids, named, "nanofluids". As the nanofluids exhibit magnificent fundamental characteristics, they are able to enhance the system performance as well as capability of the equipments [2].

Some of the advantages possesses by the nanofluids comparing to conventional solid-liquid suspensions are: 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 fabrication 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.

Experimental:

Method of Preparation:

It is essential to synthesize the nanofluids with uniformly dispersed nanoparticles into the base fluid. However, special care is required so that particles agglomeration can be avoided. To achieve long-term suspension performance and enhanced thermophysical properties, the nanofluid to be prepared must be stable and durable.

Therefore, many combinations of material can be used for special applications, namely: nanoparticles of metals, metal oxides, nitrides, 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 single-step method and the two-step method [5-7].

Single-Step Method:

The single-step method is the process of forming and dispersing the particles together in a fluid. This includes 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 is increased.

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, the single-step method has some disadvantages, which cannot synthesize nanofluids on large scale, the cost is also high and its applicability to low vapor pressure base fluids only [8,-12].

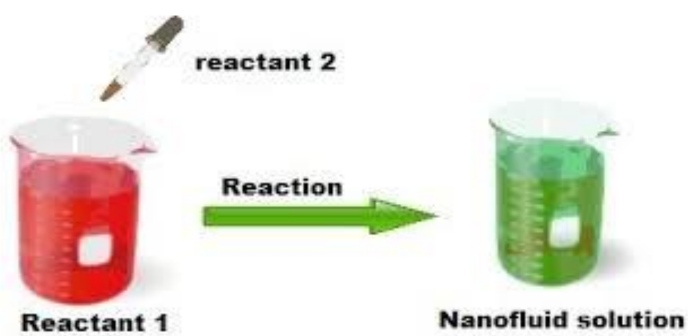

Fig.1: Single-step preparation method

Two-Step Method:

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

The important advantage of using the two-step method is higher production capacity with lower cost. The two-step method synthesizes almost all types of nanofluids but is more preferable for making metal oxide nanofluids. Additionally, the stability and thermal conductivity of the produced nanofluids doesn't seem to be optimal [10-13].

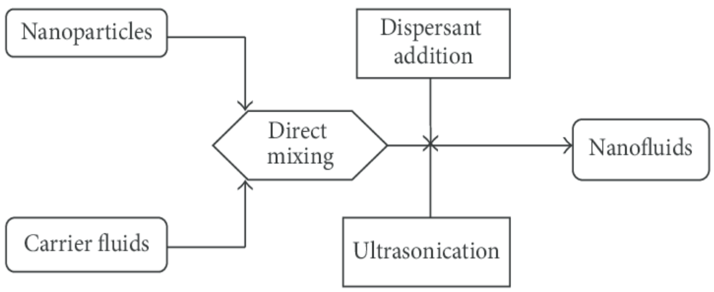

Fig.2: *Two-step preparation method*

Thermo-Physical Properties of Nanofluids:

For predicting heat transfer behavior, thermophysical properties of the nanofluids are quite essential and they are also helpful in regulating the industrial and energy saving approaches. Nanoparticles have great potential to improve the heat transfer properties compared to conventional particles fluids suspension, millimeter, and micrometer sized particles. The four vital thermophysical properties, namely, thermal conductivity, viscosity, density, and specific heat, changes their values when nanoparticles are added to the base fluid [3,5].

Thermal Conductivity:

The enhancement of thermal conductivity is the main source behind the concept of nanofluids, which also has a positive effect on the fluid convective heat transfer. Addition of nanoparticles to the basefluid increases its thermal conductivity. The thermal conductivity of nanofluids can be affected by many parameters such as particle volume fraction, particle material, particle size, particle shape, base fluid material, and temperature. Quantity and quality of additives used and the acidity of the nanofluid also plays an important role in enhancing the 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].

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 increment in effective viscosity leads to higher pressure losses due to which the pumping power demands also increases. The factors affecting the effective viscosity of nanofluids are the basefluid viscosity, nanoparticles concentration, particle shape, particle diameter, particles type, temperature, pressure, pH value, and shear rate [4,11,14].

Density:

An increase in nanoparticle concentration leads to an increase in the effective density of nanofluids. Increasing the density increases the volume of nanofluid, due to which the heat capacity of nanofluid per unit volume also increases. As the effective density of a nanofluid is considered to be a combined property of both basefluid and nanoparticles, it can be calculated theoretically using its basefluid density and nanoparticle density. The effective density of nanofluid depends on the particle size and shape, nanofluid temperature, added surfactant, and the nanolayer between the particles and basefluid effect [14,15].

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. Since the specific heat of solids is lower than that of liquids, the addition of solid nanoparticles to the base fluid reduces the specific heat. 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].

Stability of Nanofluids:

Stability Evaluation Methods for Nanofluids:

Long-term nanofluid stability is essential as it prolongs the shelf-life of the product while preserving its thermophysical properties. The following sections are various approaches acclimate to analyze nanofluid stability.

Sedimentation Method:

The easiest method to analyze the stability of nanofluids is sedimentation. In sedimentation method, the amount of the agglomerated nanoparticles in a nanofluid are observed under an external force. The process can be done by placing a sample of the prepared nanofluid in a transparent glass vial; the formation of sediments is then observed by capturing photographs of the vial at equal intervals using a camera. The comparison between captured images is done to evaluate the stability of nanofluids. Thus, the typical nanofluid is considered to be stable when the particles size and its dispersity remain constant over time (i.e., no sedimentation occurs) [8,10].

Zeta Potential Analysis:

In zeta potential analysis, the electrical potential also called as zeta potential is measured between the dispersion medium and the steady fluid layer to determine the stability of nanofluids and it indicates the degree of repulsion between charged particles dispersed in the fluid. Generally, nanofluids having higher value (positive or negative) of zeta potential are considered to be electrically stable, but those with lower value will suffer nanoparticle clustering and sedimentation. Nanofluids with zeta potentials between 40-60 mv are considered stable while with zeta potentials greater than 60 mv have magnificent stability [10].

Spectral Absorbency Analysis:

The spectral absorbency or UV-vis spectral analysis is a reliable method to determine the stability of nanofluids if the nanomaterials suspended in basefluid have characteristic absorption bands between the wavelength 190nm to 1100 nm. The nanoparticle size distribution in nanofluid is characterized via absorbed spectrum due to the optical properties of the nanoparticles depending on their morphology (i.e., shape and size) are responsible for the size distribution of nanoparticles in nanofluid which are characterized via absorption spectrum. Alternatively, the absorption intensity and the concentration of nanoparticles present in nanofluid varies linearly [16].

Electron Microscopy Method:

Electron microscopy method uses transmission electron microscopy (TEM) or scanning electron microscopy (SEM) devices which measures the size distribution of nanoparticles to evaluate the stability of nanofluids. These are very high-resolution microscopes that captures the digital image, designated as the electron micrograph, which is approximately 0.1 nm in size and these micrographs were studied to find the stability of nanofluids [6].

Stability Enhancement Methods for Nanofluids:

Addition of Surfactants:

It is one of the simple and economical method to raise the stability of nanofluids. This lowers the surface tension of the base fluid and improves nanoparticle dispersion because the surfactants has a hydrophobic tail portion (e.g., long-chain hydrocarbons) and a hydrophilic polar head group that enhances the hydrophilic behavior between the base fluid and the nanoparticles [16].

Surface Modification Techniques:

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. In order to obtain a self-stabilized nanofluid, the functionalized nanoparticle is introduced, generally, 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].

Ultrasonic Agitation:

It is a physical method that relies on employing ultrasonic waves through the fluid that ruptures the force of attraction of nanoparticles within the sediments to improve the stability. This approach is mostly used by nanofluids which are synthesized by the two-step method [10,16].

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].

Electrostatic stabilization:

As the major source behind the kinetic stability is an electric charge that exists on the surfaces of particles, hence electrostatic stabilization occurs by adsorption of ions to the electrophilic metal surface. Adsorption forms an electrical double or multi-layer resulting in a Columbic repulsion force between the nanoclusters. Also, it is a pH sensitive method and has limited use [16,18].

Steric stabilization:

In order to obtain stability by means of steric stabilization, there is an addition of macromolecules such as polymers or surfactants to the surfaces of the particles. The stabilization is because of the large adsorbents that provide steric barrier which helps in preventing the particles coming close to each other [16,18].

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.

In industrial cooling, the use of nanofluids will result in huge energy savings and emissions reduction. 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. To remove ultrahigh heat flux, nanofluids can be used in combination with microchannel heat sink and has the potential to work as next generation cooling device [1].

Every mechanical industry, from manufacturing companies to railways, have to deal with wear and tear, life and reliability of moving parts. Nanoparticles provides amazing load-bearing capacity and are able to handle high pressure in order to minimize the wear and tear in moving parts of machines [19]. Fabrication of engines using the cooling properties of nanofluids are capable to run at more optimal temperatures, leading to increased power output. Engines which are constructed using nanofluids have considerably smaller and weigh less components that provides better gas mileage, consumers money saver, and also results in lower 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 up to nine times more than that of 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. Nanofluids can be used to cool machinery, sensors operating at high temperature and high friction during the extraction of geothermal energy from the earth's core. Also the revolutionary improvements using new methods of cooling and lubricating rock by nanofluids will reduce production costs [20].

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

Conclusion:

The paper presents a review about recent study of nanofluids that involves preparation methods, thermophysical properties, the stability evaluation methods as well as stability enhancement methods, the stability mechanisms, and some 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 method have higher production capacity than that of the single-step method. Also, the two-step mechanism is more convenient in preparation of nanofluids containing oxide nanoparticles, whereas it is less successful towards the nanofluids containing metallic nanoparticles than the single-step method. The thermophysical properties of nanofluids are affected by the volume concentration, temperature, and flow rate. However, further research is needed to study more about the effect of nanoparticle's shape, size, and surface chemistry on the properties of nanofluids.

The stability of nanofluids is one of the major challenges hindering the widespread practical application of nanofluids. Studies have shown 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 need to focus on preparing the nanofluids that are more stable and durable by using appropriate techniques. However nanofluids have displayed highly exciting potential applications for commercialization.

Conflict of Interest:

The author declared that they have no conflict of interest.

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