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DYNAMICS AND HYDRODYNAMICS OF NANOFLUIDS

Ajay Kumar Singh
Research Scholar
University Department Of Physics (L.N.M.U) Darbhanga

Dr. Shree Narayan Yadav
H.O.D. Physics , R.K College Madhubani
(L.N.M.U Darbhanga)

Abstract:

Nanofluids, colloidal suspensions of nanoparticles in base fluids, have attracted significant attention in recent years due to their enhanced thermal and fluidic properties. This research paper provides a comprehensive review of the dynamics and hydrodynamics of nanofluids. It explores the fundamental principles governing the behavior of nanofluids, investigates their unique characteristics, and examines the underlying mechanisms responsible for their improved thermal and flow-related performance. The paper also discusses the applications of nanofluids in various industries and outlines the challenges and opportunities for future research and development in this promising field.

INTRODUCTION:

Nanofluids, colloidal suspensions containing nanoparticles in base fluids, have emerged as a promising class of advanced materials with remarkable thermal and fluidic properties. The field of nanofluids has attracted extensive research interest and has found applications in various industrial sectors, including electronics cooling, thermal management, solar thermal systems, and heat exchangers. These nanoscale suspensions exhibit enhanced thermal conductivity and heat transfer characteristics compared to traditional fluids, opening up new possibilities for more efficient and effective heat transfer and cooling technologies.

The concept of nanofluids was first introduced in the early 1990s, and since then, it has been the subject of intensive investigation. The idea of dispersing nanoparticles into conventional fluids to enhance their thermal properties was motivated by the potential to address the limitations of conventional heat transfer fluids, such as water, oils, and refrigerants. Various types of nanoparticles, including metallic, non-metallic, and hybrid materials, have been studied for their potential to improve the thermal conductivity and heat transfer efficiency of base fluids. Additionally, nanofluids have shown unique rheological behaviors that can influence their flow characteristics and convective heat transfer.

Objectives of the Study:

The primary objectives of this research paper are to:

1. Provide a comprehensive review of the dynamics and hydrodynamics of nanofluids.
2. Investigate the fundamental principles governing the behavior of nanofluids.
3. Examine the thermal conductivity, viscosity, and rheological properties of nanofluids.
4. Scope and Structure of the Paper: This research paper covers a wide range of topics related to nanofluids, starting with an introduction to the background and significance of nanofluids. It proceeds to explore the fundamental principles underlying nanofluid behavior, including nanoparticle selection, nanoparticle-fluid interaction, and thermal conductivity enhancement. The theoretical models for understanding nanofluid dynamics, such as Brownian motion, thermophoresis, and buoyancy-driven convection, will be discussed.

The paper will also delve into the experimental techniques and measurements used for the characterization of nanofluids, including thermal and rheological properties. Furthermore, it will examine the heat transfer enhancement potential of nanofluids in various heat transfer scenarios, such as convection, boiling, and two-phase flows.

The applications of nanofluids in different industries and their potential impact on electronics cooling, solar thermal systems, and heat exchangers will be explored. Finally, the paper will address the challenges faced in the field of nanofluids and outline potential avenues for future research and development.

NANOFLUID SYNTHESIS AND PROPERTIES

Nanofluids are colloidal suspensions comprised of nanoparticles dispersed in a base fluid. The synthesis of nanofluids involves several critical steps to achieve stable and well-dispersed nanoparticles in the chosen base fluid. The properties of nanofluids, such as thermal conductivity and viscosity, are greatly influenced by the choice of nanoparticles and base fluids, as well as their interactions and stability within the suspension.

1. Nanoparticle Types and Characteristics: Nanoparticles used in nanofluids can be metallic, non-metallic, or hybrid materials. Common metallic nanoparticles include copper, aluminum, silver, and gold, while non-metallic nanoparticles may comprise oxides, carbides, nitrides, or carbon-based materials like graphene and carbon nanotubes. The choice of nanoparticle material depends on the desired properties and applications of the nanofluid. For instance, metal nanoparticles are known for their excellent thermal conductivity enhancement, while oxides offer stability and dielectric properties. The characteristics of nanoparticles, such as size, shape, and surface chemistry, play a crucial role in determining the stability and performance of nanofluids. Smaller nanoparticles generally provide higher thermal conductivity enhancement due to increased surface area, but they may also lead to higher agglomeration tendencies, affecting the fluid's stability.
2. Base Fluid Selection and Properties: The base fluid is the continuous phase in which nanoparticles are dispersed. Common base fluids include water, ethylene glycol, engine oils, and refrigerants, depending on the intended application and thermal properties required. Water-based nanofluids are widely studied due to their environmental friendliness and low cost, while oil-based nanofluids are used in industrial applications for their compatibility with existing systems. The properties of the base fluid, such as viscosity, density, and specific heat, directly influence the flow and heat transfer behavior of nanofluids. Proper base fluid selection is crucial to achieving the desired thermal performance and stability of the nanofluid.
3. Nanoparticle-Fluid Interaction and Stability: One of the critical challenges in nanofluid synthesis is achieving stable suspensions with well-dispersed nanoparticles. Nanoparticles have a natural tendency to agglomerate due to van der Waals forces and electrostatic interactions. Surface modification techniques, such as functionalization and surfactant coating, are employed to enhance the stability of nanofluids by reducing agglomeration tendencies. The stability of nanofluids is vital for long-term applications, as sedimentation and agglomeration can lead to clogging and reduced thermal performance. Understanding the nanoparticle-fluid interaction and factors influencing stability is essential for producing reliable and functional nanofluids.
4. Thermal Conductivity of Nanofluids: One of the most significant advantages of nanofluids is their improved thermal conductivity compared to base fluids. The addition of nanoparticles, with higher thermal conductivities than the base fluid, enhances the overall thermal performance of the nanofluid. The effective thermal conductivity of nanofluids is influenced by factors such as nanoparticle concentration, size, shape, and temperature. Several theoretical models, such as the Maxwell model and the Hamilton-Crosser model, have been proposed to predict the effective thermal conductivity of nanofluids. Experimental studies are also essential to validate these models and understand the underlying mechanisms of heat conduction in nanofluids.
5. Viscosity and Rheological Behavior: The addition of nanoparticles can significantly alter the rheological behavior of the base fluid. Nanofluids often exhibit non-Newtonian behavior, where the viscosity is dependent on the shear rate. The increase in viscosity can affect the pumping power and pressure drop in nanofluid flow systems.

Understanding the rheological behavior is crucial for designing heat exchangers and other heat transfer devices that employ nanofluids. Various models, such as the Krieger-Dougherty and the Shear-Induced Structure model, have been proposed to predict the viscosity of nanofluids based on nanoparticle concentration and size.

nanofluid synthesis and properties play a crucial role in determining the effectiveness and stability of nanofluids in various heat transfer and cooling applications. The choice of nanoparticle material, base fluid, and the understanding of their interaction and stability are essential considerations for developing functional nanofluids with enhanced thermal properties. Additionally, characterizing the thermal conductivity and viscosity of nanofluids helps in optimizing their performance in different industrial scenarios.

THEORETICAL MODELS FOR NANOFLUID DYNAMICS

Brownian Motion and Diffusion: Brownian motion is the random movement of particles suspended in a fluid due to collisions with the fluid molecules. In nanofluids, nanoparticles experience Brownian motion, which contributes to their dispersion and stability. The Brownian motion is influenced by the size of nanoparticles, temperature, and fluid properties. Smaller nanoparticles exhibit more significant Brownian motion due to their higher collision frequency with fluid molecules.

Diffusion is the net movement of particles from regions of higher concentration to regions of lower concentration. In nanofluids, diffusion plays a crucial role in nanoparticle dispersion and uniformity. The rate of diffusion is influenced by nanoparticle size, temperature, and the concentration gradient within the nanofluid.

Thermophoresis and Soret Effect: Thermophoresis refers to the migration of nanoparticles in a temperature gradient. When a nanofluid experiences a temperature gradient, the nanoparticles tend to move from regions of higher temperature to regions of lower temperature. This phenomenon occurs due to a combination of thermal and concentration gradient-driven forces. Thermophoresis can lead to particle accumulation or depletion in certain regions of the nanofluid, affecting the overall thermal conductivity enhancement.

The Soret effect is a thermophoretic phenomenon specific to multicomponent mixtures, including nanofluids. It refers to the separation of nanoparticles based on their thermophoretic mobility when exposed to a temperature gradient. The Soret effect can lead to compositional variations within the nanofluid, influencing its properties and performance.

Buoyancy-Driven Convection: Buoyancy-driven convection, also known as natural convection, occurs when density variations in the fluid cause fluid motion in response to a temperature gradient. In nanofluids, the presence of nanoparticles can alter the fluid's density and, consequently, affect the buoyancy-driven convection. This phenomenon plays a significant role in heat transfer enhancement, especially in applications where natural convection is dominant, such as in cooling systems and solar thermal collectors.

Nanoparticle Agglomeration and Sedimentation: Nanoparticle agglomeration refers to the process of nanoparticles forming clusters or aggregates due to attractive forces, such as van der Waals forces and electrostatic interactions. Agglomeration can lead to reduced stability and altered properties of nanofluids, impacting their thermal performance. Various stabilization techniques, such as surface modification and surfactant coating, are employed to minimize nanoparticle agglomeration and ensure long-term stability.

Sedimentation occurs when nanoparticles settle at the bottom of the container due to gravity. Sedimentation is a common challenge in nanofluid applications, as it can lead to uneven distribution of nanoparticles and reduced heat transfer efficiency. Understanding the factors influencing nanoparticle agglomeration and sedimentation is essential for designing stable and high-performance nanofluids.

Two-Phase Flow Models: Two-phase flow models are used to study the behavior of nanofluids in flow systems where both the liquid phase (base fluid) and the solid phase (nanoparticles) coexist. Two-phase flow models are relevant in scenarios such as flow boiling, flow condensation, and flow through heat exchangers. The flow behavior of nanofluids in such applications is influenced by interfacial forces, phase change phenomena, and particle distribution.

Various modeling approaches, such as two-fluid models, Eulerian-Lagrangian models, and population balance models, are used to describe the interactions between the fluid and solid phases in two-phase flow systems. These models help in understanding the heat transfer characteristics and pressure drop behavior of nanofluids in complex flow regimes. theoretical models for nanofluid dynamics play a crucial role in understanding the behavior of nanofluids under different conditions and applications. Brownian motion, diffusion, thermophoresis, and buoyancy-driven convection influence the nanoparticle dispersion, heat transfer, and fluid flow characteristics. Additionally, understanding nanoparticle agglomeration and sedimentation is vital for ensuring the stability and efficiency of nanofluids in practical applications. Two-phase flow models are employed to study nanofluid behavior in complex flow scenarios, helping optimize their performance in various heat transfer and cooling systems.

EXPERIMENTAL TECHNIQUES AND MEASUREMENT

Characterization of Nanoparticles: Characterizing nanoparticles is essential to understand their size, shape, morphology, and surface chemistry, as these properties significantly impact their behavior in nanofluids. Techniques such as Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), and Atomic Force Microscopy (AFM) are used to visualize and measure nanoparticle size and shape. X-ray Diffraction (XRD) and Energy-Dispersive X-ray Spectroscopy (EDS) are employed to identify the crystal structure and elemental composition of nanoparticles. Surface area analyzers, such as the Brunauer-Emmett-Teller (BET) method, are used to determine the specific surface area and porosity of nanoparticles.

Nanofluid Preparation and Stability: Preparing stable nanofluids with well-dispersed nanoparticles is crucial for accurate and reliable experimental results. Several methods are used to prepare nanofluids, including one-step and two-step methods. One-step methods involve directly dispersing nanoparticles into the base fluid, while two-step methods involve synthesizing nanoparticles separately and then dispersing them in the base fluid. Ultrasonication and mechanical agitation are commonly employed to achieve uniform nanoparticle dispersion in the base fluid.

The stability of nanofluids is evaluated through various techniques, such as zeta potential measurements and dynamic light scattering (DLS). Zeta potential provides information about the surface charge of nanoparticles and the stability of the nanofluid by evaluating the repulsive forces between nanoparticles. DLS measures the size distribution of nanoparticles in suspension and is used to monitor changes in stability over time.

Thermal and Rheological Characterization: To evaluate the thermal properties of nanofluids, measurements of thermal conductivity and heat capacity are conducted. The Hot Disk method, Transient Plane Source (TPS) method, and Differential Scanning Calorimetry (DSC) are some of the techniques used for thermal characterization. These methods provide information about the effective thermal conductivity and specific heat capacity of nanofluids as a function of nanoparticle concentration and temperature.

Rheological characterization involves measuring the viscosity and flow behavior of nanofluids. Rheometers and viscometers are used to determine the viscosity of nanofluids under different shear rates and temperatures. Non-Newtonian behavior, which is common in nanofluids, is characterized using models like the Power Law model and Herschel-Bulkley model.

Flow Visualization and Particle Tracking: Flow visualization techniques are employed to observe the flow patterns and behavior of nanofluids in different geometries. Optical methods, such as Particle Image Velocimetry (PIV) and Laser Doppler Anemometry (LDA), are used to visualize fluid flow and measure velocity fields in the presence of nanoparticles.

Particle tracking methods involve seeding nanoparticles with tracers and tracking their motion within the nanofluid flow. This allows researchers to study the particle trajectories, dispersion patterns, and settling behavior. Techniques like Particle Tracking Velocimetry (PTV) and Particle Tracking Microrheology (PTM) are commonly used for particle tracking in nanofluids. experimental techniques for nanofluids involve the characterization of nanoparticles to understand their properties, nanofluid preparation, and stability evaluation. Thermal and rheological measurements help assess the heat transfer and flow behavior of nanofluids. Additionally, flow visualization and particle tracking techniques provide valuable insights into nanofluid behavior in different flow scenarios, aiding in the optimization of nanofluid applications.

HEAT TRANSFER ENHANCEMENT WITH NANOFLUIDS

Nanofluids have gained significant interest for their ability to enhance heat transfer compared to traditional heat transfer fluids. The unique properties of nanoparticles, such as high thermal conductivity and increased surface area, contribute to the improved heat transfer performance of nanofluids. Various heat transfer scenarios, including convective heat transfer, pool boiling, flow boiling, and thermal management using heat pipes, benefit from the application of nanofluids.

1. Convective Heat Transfer: Convective heat transfer involves the transfer of heat between a solid surface and a fluid through forced convection. Nanofluids, when used as the working fluid in convective heat transfer applications, can significantly enhance the heat transfer coefficient. The nanoparticles dispersed in the base fluid facilitate increased heat transfer rates due to their higher thermal conductivity. As a result, nanofluids have been used in heat exchangers, radiators, and other cooling systems to improve their efficiency and reduce the overall size and weight of heat transfer equipment.
2. Pool Boiling and Critical Heat Flux: Pool boiling is a phase change heat transfer process where a heated surface interacts directly with a liquid. Nanofluids have been found to promote nucleate boiling, leading to enhanced boiling heat transfer and critical heat flux (CHF) improvement. The presence of nanoparticles on the heating surface provides active sites for bubble nucleation, promoting the growth of nucleation sites and preventing critical heat flux deterioration. This phenomenon is particularly advantageous for applications like electronics cooling and thermal management, where maintaining stable boiling conditions is crucial.
3. Flow Boiling and Two-Phase Heat Transfer: Flow boiling involves the simultaneous flow of liquid and vapor phases in heat transfer systems, such as evaporators in refrigeration and air conditioning systems. The presence of nanoparticles in the liquid phase of nanofluids enhances the boiling heat transfer coefficient and critical heat flux. Nanofluids have shown promising results in flow boiling heat transfer applications, as they help to delay the onset of critical heat flux and enhance the overall heat transfer performance.
4. Heat Pipes and Thermal Management: Heat pipes are efficient heat transfer devices used for thermal management in various applications. The incorporation of nanofluids as the working fluid in heat pipes enhances their thermal performance due to increased thermal conductivity. The presence of nanoparticles in the working fluid reduces the thermal resistance within the heat pipe, leading to improved heat transfer rates. As a result, nanofluid-filled heat pipes offer higher thermal conductance and better heat dissipation capabilities, making them suitable for advanced thermal management in electronics, aerospace, and other industries.

nanofluids have demonstrated their potential to significantly enhance heat transfer in various scenarios, including convective heat transfer, pool boiling, flow boiling, and thermal management using heat pipes. The improved thermal conductivity and heat transfer coefficients of nanofluids make them attractive candidates for more efficient and compact heat transfer equipment and systems. As research continues in this area, nanofluids are expected to find broader applications in numerous industrial and technological fields where enhanced heat transfer is crucial.

FLOW BEHAVIOR AND HYDRODYNAMICS OF NANOFLUIDS

Single-Phase Flow Behavior:

Single-phase flow behavior refers to the behavior of nanofluids when they flow as a single-phase fluid without undergoing phase changes (i.e., no boiling or condensation). The flow behavior of nanofluids can differ from that of the base fluid due to the presence of nanoparticles, which can alter the fluid's viscosity and rheological properties. Depending on the nanoparticle concentration, size, and shape, nanofluids can exhibit Newtonian or non-Newtonian behavior. In Newtonian nanofluids, the viscosity remains constant with shear rate, similar to traditional fluids. Non-Newtonian nanofluids, on the other hand, show a viscosity that varies with shear rate, and their behavior can be described by models like the Power Law model or the Herschel-Bulkley model. Understanding the single-phase flow behavior of nanofluids is crucial for designing efficient heat exchangers, cooling systems, and other fluid flow applications.

Two-Phase Flow Behavior:

Two-phase flow behavior involves the simultaneous flow of two phases: liquid and vapor. In the context of nanofluids, this typically refers to flow boiling or flow condensation scenarios. Nanofluids can influence two-phase flow behavior due to changes in boiling or condensation heat transfer characteristics, as well as the interaction between nanoparticles and phase change processes. Nanoparticles can enhance nucleate boiling, promote bubble departure, and alter the dynamics of bubble growth and condensation. These effects can lead to improved heat transfer rates and more efficient phase change heat transfer in two-phase systems.

Turbulence and Mixing Characteristics:

Turbulence and mixing characteristics of nanofluids are critical in many industrial applications where efficient heat transfer is desired. Turbulence enhances the convective heat transfer coefficient by increasing the fluid mixing and promoting contact between the heated surface and the cooler fluid. The presence of nanoparticles in nanofluids can influence turbulence through changes in viscosity and fluid properties. Experimental and numerical studies have shown that nanofluids can exhibit altered turbulence characteristics compared to base fluids. The behavior of nanofluids under turbulent conditions is influenced by nanoparticle concentration, size, and shape, as well as the Reynolds number of the flow.

Pressure Drop and Frictional Losses:

Pressure drop and frictional losses refer to the energy loss experienced by a fluid as it flows through a conduit or pipe. Nanofluids can exhibit different pressure drop behavior compared to the base fluid due to changes in viscosity and fluid properties. The addition of nanoparticles can increase the pressure drop, especially in non-Newtonian nanofluids.

Understanding the pressure drop behavior is crucial for designing and optimizing fluid flow systems that employ nanofluids. While nanofluids can offer enhanced heat transfer capabilities, the increased pressure drop may affect the pumping power required for fluid circulation, and it must be taken into consideration during system design. the flow behavior and hydrodynamics of nanofluids play a crucial role in their performance in various applications. Understanding how nanofluids behave in single-phase and two-phase flow scenarios, their influence on turbulence and mixing, and the impact on pressure drop and frictional losses is essential for effectively utilizing nanofluids for enhanced heat transfer and fluid flow applications. Research in this area continues to uncover new insights and optimize nanofluid-based systems for efficient heat transfer and cooling.

APPLICATIONS OF NANOFLUIDS

Electronics Cooling and Thermal Management:

Nanofluids have shown great potential in the field of electronics cooling and thermal management. The continuous miniaturization and increasing power density of electronic devices, such as microprocessors and integrated circuits, generate significant heat that needs to be efficiently dissipated to ensure optimal performance and prevent overheating. Nanofluids offer improved thermal conductivity compared to traditional cooling fluids, making them ideal for enhancing heat transfer in electronic cooling systems. By using nanofluids as the cooling medium, electronic devices can operate at lower temperatures, reducing the risk of thermal failures and extending their lifespan. Additionally, nanofluids' superior thermal properties enable the design of compact and efficient cooling solutions, making them particularly beneficial in modern electronics and data centers.

Solar Thermal Systems:

Solar thermal systems harness solar energy to generate heat, which is then utilized for various applications, including water heating, space heating, and electricity generation through steam-driven turbines. The efficiency of solar thermal systems largely depends on the ability to capture, store, and transfer solar heat effectively. Nanofluids have emerged as a promising heat transfer fluid in solar thermal applications due to their enhanced thermal properties. By using nanofluids in solar collectors, the absorption and transfer of solar energy can be significantly improved, leading to higher system efficiency and reduced energy consumption. The use of nanofluids in solar thermal systems contributes to the promotion of renewable energy and helps in reducing greenhouse gas emissions.

Heat Exchangers and Cooling Systems:

Heat exchangers are essential components in many industrial processes, including power generation, chemical processing, and HVAC systems. The efficiency of heat exchangers depends on the heat transfer rate between the hot and cold fluids. Nanofluids offer a significant advantage in heat exchangers by enhancing the overall heat transfer coefficient. By using nanofluids as the working fluid, heat exchangers can achieve improved thermal performance, allowing for more efficient heat exchange and reduced energy consumption. The integration of nanofluids in heat exchangers is particularly valuable in applications where compact design and high heat transfer rates are crucial.

Automotive and Aerospace Industries:

In the automotive and aerospace industries, effective thermal management is critical for the performance and reliability of vehicles and aircraft. Nanofluids find applications in engine cooling, transmission systems, and aircraft cooling systems. By utilizing nanofluids in automotive and aerospace cooling systems, heat dissipation can be significantly improved, leading to better engine efficiency and reduced fuel consumption. Moreover, nanofluids' high thermal conductivity enables the design of compact and lightweight cooling systems, which is particularly advantageous in space- and weight-constrained applications. In the aerospace industry, nanofluids can be used for thermal management in spacecraft and satellites, where temperature control is vital to ensuring proper functioning of onboard electronic systems.

CHALLENGES AND FUTURE PERSPECTIVES

Nanoparticle Dispersion and Agglomeration: One of the main challenges in working with nanofluids is achieving and maintaining a stable dispersion of nanoparticles in the base fluid. Nanoparticles have a natural tendency to agglomerate, leading to reduced stability and altered thermal properties of nanofluids. Overcoming this challenge requires developing effective techniques for ensuring uniform nanoparticle dispersion and preventing agglomeration during nanofluid preparation and storage. Future research should focus on improving nanoparticle surface modifications and understanding the underlying mechanisms governing nanoparticle dispersion and agglomeration. Innovative approaches, such as using surfactants or functionalizing nanoparticles, may play a crucial role in achieving long-term stability and enhancing the performance of nanofluids.

CONCLUSION

the study of nanofluids and their dynamics and hydrodynamics has provided valuable insights into the behavior of these innovative fluid systems. Nanofluids, which are colloidal suspensions of nanoparticles in a base fluid, exhibit fascinating properties that distinguish them from traditional fluids. The addition of nanoparticles to the base fluid alters various thermophysical and rheological properties, such as thermal conductivity, viscosity, and convective heat transfer. Through experimental investigations and numerical simulations, researchers have elucidated the mechanisms responsible for the enhanced heat transfer capabilities of nanofluids. The Brownian motion and thermophoresis of nanoparticles, along with the increased surface area for heat transfer, contribute significantly to the augmented thermal conductivity observed in nanofluids. Additionally, the agglomeration and dispersion of nanoparticles can affect the overall heat transfer performance. studies on the hydrodynamics of nanofluids have shed light on their flow behavior in different geometries and under various flow conditions. The presence of nanoparticles alters the fluid flow patterns and pressure drop characteristics, leading to both beneficial and adverse effects depending on the specific application. Nanofluids have shown promise in diverse applications, such as cooling systems, heat exchangers, and renewable energy technologies. However, challenges related to nanoparticle stability, aggregation, and long-term performance sustainability remain areas of ongoing research. In conclusion, nanofluids are a promising avenue for enhancing heat transfer efficiency and fluid flow behavior in numerous engineering applications. Continued research and development in this field hold the potential for significant advancements in thermal and fluid sciences.

REFERENCES

1. Choi, S. U. S. (1995). Enhancing Thermal Conductivity of Fluids with Nanoparticles. ASME International Mechanical Engineering Congress and Exposition, 66, 99-105.
2. Xie, H., Wang, J., Xi, T., & Liu, Y. (2002). Thermal Conductivity of Suspensions Containing Nanosized SiC Particles. International Journal of Thermophysics, 23(2), 571-580.
3. Das, S. K., Putra, N., Thiesen, P., & Roetzel, W. (2003). Temperature Dependence of Thermal Conductivity Enhancement for Nanofluids. Journal of Heat Transfer, 125(4), 567-574.
4. Buongiorno, J., Venerus, D. C., Prabhat, N., McKrell, T., Townsend, J., Christianson, R., ... & Hu, L. W. (2009). A benchmark study on the thermal conductivity of nanofluids. Journal of Applied Physics, 106(9), 094312.
5. Keblinski, P., Phillpot, S. R., Choi, S. U. S., & Eastman, J. A. (2002). Mechanisms of heat flow in suspensions of nano-sized particles (nanofluids). International Journal of Heat and Mass Transfer, 45(4), 855-863.
6. Murshed, S. M. S., Leong, K. C., & Yang, C. (2008). Thermophysical and electrokinetic properties of nanofluids—a critical review. Applied Thermal Engineering, 28(17-18), 2109-2125.
7. Bhattacharya, P., & Saha, S. K. (2015). Heat transfer enhancement using nanofluids—an overview. Renewable and Sustainable Energy Reviews, 48, 540-551.
8. Wang, X., Xu, X., & Choi, S. U. S. (1999). Thermal conductivity of nanoparticle-fluid mixture. Journal of Thermophysics and Heat Transfer, 13(4), 474-480.
9. Turgut, A., & Tavman, İ. H. (2009). Viscosity measurements of water-based Al2O3 nanofluids. International Journal of Thermal Sciences, 48(11), 2169-2178.
10. Peng, H., Ding, G., & Takata, Y. (2010). Experimental research on the laminar convective heat transfer of alumina–water nanofluid flowing through a circular tube. International Journal of Heat and Mass Transfer, 53(1-3), 508-515.