Principle, Fabrication and Applications of Micro-Nano Fluid Dynamics

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Abstract. A new generation of efficient heat transfer and cooling technologies has been studied by researchers since the 1990s due to the rise of nanotechnology. In 1995, Professor S.U.S. The idea of 'nanofluids' was first proposed by Choi from the Aragon National Laboratory in the United States, which combines nanotechnology with traditional thermal engineering in an innovative way. Enhanced heat transfer is a field where nanofluid technology has broad application prospects and potential significant economic value, and is known as the 'future cooling and heat dissipation technology'. The theme of this article is the principles, preparation processes, and application fields of micro-nano fluids. The research on nanofluids still needs to be carried out. Due to their unique thermal conductivity properties, they can theoretically be widely used in fields such as industry, energy, aerospace, automobiles, air conditioning and refrigeration, electronics, etc. The aim of this study is to examine the heat conduction principle of nanofluids, the basic preparation process, and some applications of nanofluids in the field of enhanced heat conduction.

Keywords: Principle, fabrication, application, Micro-nano, fluid dynamic.

1. Introduction

In 1959, Nobel laureate Richard Feynrnan proposed the concept of miniatures. Since then, miniaturization has become a major trend in technology today. And about 40 years later, another Nobel laureate H. Rohrer mentioned the challenges and opportunities of the "nano age". The steady trend towards miniaturization has progressed from the millimeter scale in the mid-20th century to the atomic scale today. Trends in miniaturization and nanotechnology have a direct bearing on the development of nanofluids [1]. In the 25 years before 2018, the problems and prospects of microfluidics have inspired researchers to devote themselves to deep research in microfluidics applications and so on. Small, low-cost, and handheld devices face many difficulties throughout the process of actuation, manipulation, and integration into the final practical device. The goal is to replace each step in each macro-scale process with a micro-scale, and then seamlessly connect these parts without compromising the advantages to form an integrated device that can be used by non-experts. Sackmann and others raised a question in 2014: 'Why hasn't microfluidics been widely adopted?' Becker pointed out in 2009 that the success of any new technology depends on "killer applications", and microfluidics lacks such application [2]. Since then, more and more applications of nanofluids have emerged and developed. Such as graphene nanofluid, molten salt nanofluid and so on. Talking about the research significance of nanofluids, promoting the development of new materials is not the only thing it can do, but also promote the development of new structures and processes along with the discovery of new working fluids. At the same time, nanofluids can promote the progress of more related researches based on it being an interdisciplinary research object [3].

Many predecessors have done a lot of related research, such as graphene nanofluid, heat transfer properties of nanofluids, stability of nanofluid, etc. When it comes to graphene fluid, this study will definitely think of the six-membered ring benzene-like structure of graphene at the first moment. The high thermal conductivity of graphene, the current research includes thermal conductivity theory, stable dispersion, basic thermodynamic properties and thermal conductivity influencing factors. However, there is still a lack of extensive research on its thermal performance, so it has not been maturely applied in aerospace fluid cooling circuits [4]. In addition, in Zhu and Li's research on the heat transfer of nanofluids, they explained that nanofluids has wide scope for application in the field

of heat transfer, but they also mentioned that the research on the topic of heat transfer mechanism of nanofluids is insufficient, and the experimental results are different and other issues [5]. Last but not the least, the stability of nanofluid suspension is also an important part of nanofluid research [5]. Surfactants have a great influence on the stability of nanofluid suspensions. For example, in an experiment, sodium dodecylbenzene sulfonate (SDBS), hexadecyltrimethylammonium bromide (HTAB) and emulsifying agent OP, the carbon nanofluid has the best stability when the non-ionic surfactant—the emulsifying agent OP is used as the dispersant, and the concentration of the surfactant has an optimal value that can make the stability of the nanofluid reach the highest value, and deviate from this value will directly affect the stability performance of the nanofluid [6].

This paper aims to study the basic definition and principle of micro-nano fluids, the preparation engineering and the application of micro-nano fluids. In the first part, this research will talk about the basic principles of nanofluids, including the definition of nanofluids and the principle of its micro-nano fluid elements. Then, this study will talk about the preparation process of micro-nanofluids and the application of micro-nanofluids. Finally, one summarizes the research on micro-nanofluids.

2. Basic Description of Micro-Nano Fluid

To understand micro-nano fluids, one first needs to understand the meaning of this word, which refers to fluids composed of micro-nano particles or nanometers. In mathematics, a nanometer is a unit of measurement. Its unit symbol is nm, and 1 nanometer is equivalent to 10 minus 9 meters ($1nm=10^{-9}m$). If one looks at the particle size, a nanometer is equivalent to four times the size of an atom, and the human naked eye cannot see a single nanoparticle [7].

When it comes to the term fluid, the current research on fluid motion at conventional scales has been basically completed. Compared with the flow at the conventional scale, the flow at the micro-nano scale has very special properties, and one can reflect this through the definition and range of flow characteristic parameters, the establishment of basic equations and boundary conditions, etc. Here, one will learn about a parameter: the flow field parameters of micro-nano scale flow. An important part of this parameter is the Kundsen number. The ratio between the mean free path of the fluid molecules and the characteristic scale of the flow field is what it is defined as. Its formula is $Kn = \lambda/L$ [8]. In addition, there is another important parameter: Reynolds. The ratio of inertial force and viscous force is what defines it. Its equation is: $Re = \rho uL/\mu$. In this equation, u corresponds to the characteristic speed of the medium and μ to the dynamic viscosity of the medium [8].

Nanofluids are essentially suspensions of nanoparticles in base fluids like water, alcohol, etc. Nanofluids have become a hot topic in nanotechnology and thermal engineering in the past few decades. In addition, due to some special properties of nanofluids, the stability of nanofluids has become one of the focuses of current scientific research [9].

3. Principle of heat transfer characteristic of micro/nano fluid

The essence of nanofluid is a substance composed of nanoparticles and liquid objects, such as water and oil. The special properties of nanofluids make them have a lot of uses in heat transfer including fuel cells, coolants, etc. Nanofluid's thermal conductivity and convective heat transfer coefficient are very good compared to the base fluid. Dynamic viscosity and thermal conductivity, i.e., two important transport properties of nanofluids, depends on both concentration of nanoparticles and other parameters, such as size of nanoparticles. Extensive experimental studies have demonstrated that by dispersing nanoparticles into base fluids, both thermal conductivity and viscosity increase [11-13]. Hence, the Nusselt number of nanofluid may be defined as:

$$Nu = f(Re, Pr, \frac{K_p}{K_{bf}}, \frac{(\rho C_p)_p}{(\rho C_p)_{bf}}, \phi, size\ of\ particle, shape\ of\ particle, flow\ structure) \quad (1)$$

After a series of experimental calculations and research, during the investigation of Al_2O_3/water nanofluid in a triangular duct, Heris et al. discovered that the Nusselt number increases with a decrease in particle size and increase in volume fraction [10]. Yarmand et al. investigated Al2O3/ water nanofluid. They analyzed the numerical result with Dittus-Boelter, Gnielinski, Pak and Cho, and Maiga correlation. According to Fig. 1, the numerical result is the closest to the correlation between Pak and Cho [10].

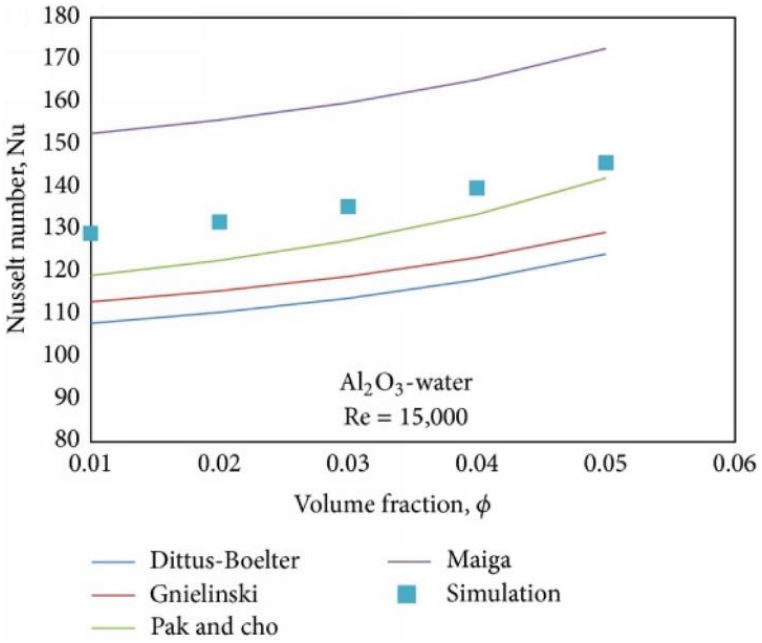


Figure 1. A sketch of Nusselt number against the volume fraction. A comparison of Nusselt numbers with various correlations.

The dynamic viscosity and thermal conductivity of nanofluids have been estimated using various correlations and various theoretical and experimental studies. However, because of the lack of consensus on nanofluidic mechanisms, general empirical correlations and theoretical models for the effects of particle concentration, size have not been proposed recently [11]. The thermal performance of nanofluids in industrial heat exchangers has been studied with the help of experimental flow loops developed as shown in Fig. 2. The heat transfer coefficient of nanofluids was shown to increase and decrease depending on the flow rate and concentration of nanofluids through the heat exchanger in the experimental results. For the SiO_2-water nanofluid at 5% by weight, a maximum increase of 5% in the overall heat transfer coefficient was observed, however, an 18% increase in pressure drop was observed for the same nanofluid [12].

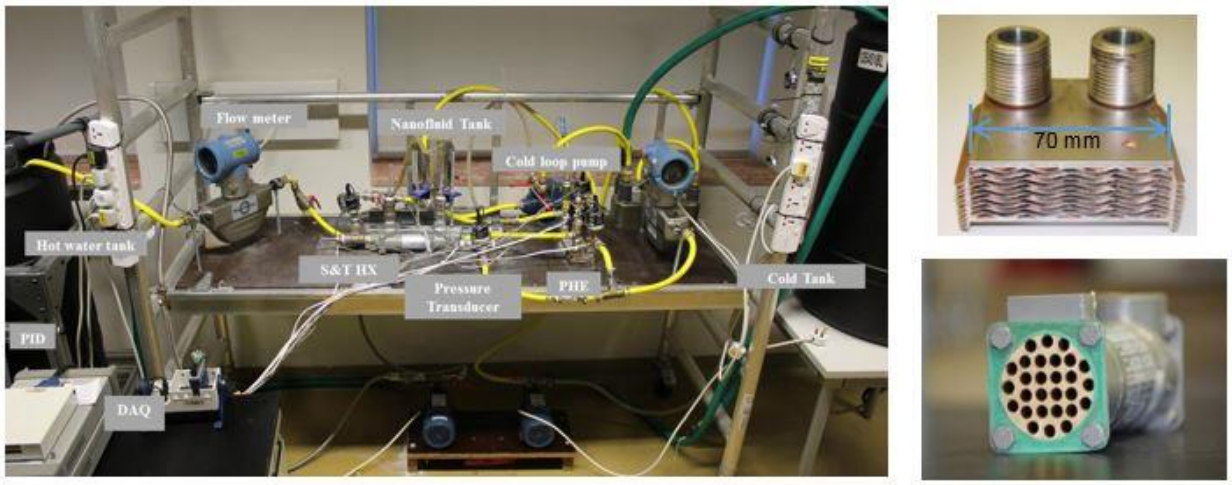


Figure 2. A photo of experimental flow loop developed.

4. Fabrication

In general, there are two approaches to preparing nanofluids: one is a one-step approach and the other is a two-step approach. So far, scientists in the past have used these two methods or modified similar procedures to prepare single nanofluids and hybrid nanofluids. The preparation method plays a crucial role in the production of nanofluids with low aggregation and uniform dispersion, so that the produced nanofluids can have stable thermal conductivity [14].

As for one step metho, certain steps are avoided such as drying, storing and trafficking of nanoparticles [10]. This method is a combination of dispersion and production. However, only low vapor pressure fluids are suitable for this method. Developing a single nanofluid is one of the earliest approaches, which involves evaporating metals by heating them with an electron beam. Then, the vaporized metal atoms condense on the surface of the flowing oil, thereby obtaining flowing oil with ultrafine particles [14]. For hybrid nanofluids, Hung used an acetylene flame synthesis system to produce hybrid carbon nanofluids (HCNF) as shown in Fig. 3. The C2H2 flame is used to generate smoke, and the carbon in the smoke is condensed into water mist in the synthesizer, so that the produced HCNF does not need secondary processing [14].

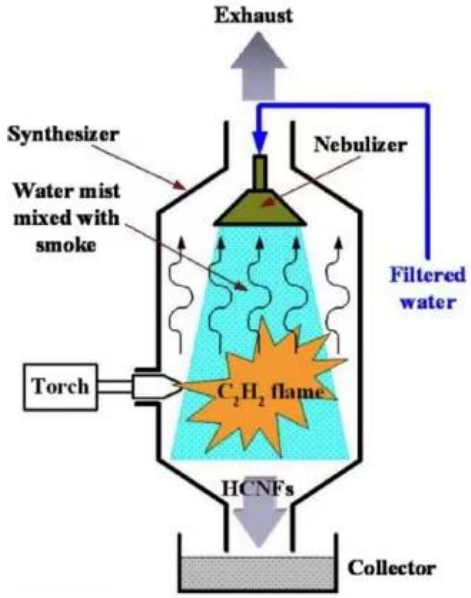


Figure 3. A schematic diagram of the combustion system. Schematic diagram of acetylene flame synthesis system.



Figure 4. An organizational chart of the two-step process.

The two-step method is the most cost-effective way to prepare nanofluids on a large scale [10]. Nanoparticles will be dispersed in a base fluid with or without surfactant in a volume or weight concentration in the two-step method [15]. In the two-step method, there are two primary processes. The production of nano powders is one of them, while the dispersion of nano powders into the base fluid is the other. First of all, nano powders are produced by chemical or mechanical processes, such as condensation of inert gases, etc. Then, the resulting nano powders was added to the base liquid through a mixing process and ultrasonic agitation. Due to the simple steps and low production cost, this method has been widely adopted by past researchers and is suitable for large-scale production, but the disadvantage is that it is more prone to agglomeration due to high surface activity. In conclusion, the agglomeration of nanoparticles can be reduced by adding surfactants in appropriate amount and temperature [14]. This method is preferred by most researchers to prepare nanofluid for research. Fig. 4 illustrates the two-step method [10].

5. Applications:

Several different kinds of heat exchangers are employed in sectors like heavy industry. Currently, scientists are researching the use of nanofluids in place of conventional heat transfer fluids to improve heat exchanger heat transfer performance [10]. A numerical analysis was carried out on the heat transfer, thermal efficiency, and temperature variations of H2O/Al2O3 non fluid in parallel and countercurrent dual tube heat exchangers as a component of the research on turbulent heat transfer and nanofluid flow in a doublepipe heat exchanger. One finding from this study is that increasing the Reynolds number of nanoparticles will have a greater impact on convection heat transfer and Nusselt number [16]. Over the years, there has been significant development in air conditioning and refrigeration systems, with a recent focus on improving the performance of the refrigerants used in these systems [17]. The experiment's findings indicate that Cuo nanoparticles can enhance the heat transfer coefficient in an evaporator section with a certain design. The refrigeration effect is thus enhanced [18].

Nanofluids have garnered interest as a new generation of heat transfer fluids in automotive cooling applications due to their remarkable thermal characteristics. Recently, numerous research results have highlighted the excellent heat transfer properties of nanofluids. Nanofluids could have meaningful effects as coolants in heat exchange devices. Although pure metal nanofluids have higher thermal conductivity than metal oxide nanofluids, oxide nanoparticles are widely used due to their ease of fabrication and stability compared to pure metal particles [19].

6. Limitation and Future Outlooks

Based on the study of nanofluids, there are several limitations: the first is the high cost of producing nanofluids, and the second is the poor stability of nanofluids without surfactants. Furthermore, nanofluid has a specific heat that is smaller than that of base fluid. Lastly, the pressure dropping and pumping power increase with fluid density and viscosity. Nanofluids are much denser and viscous than base fluids. Thus, nanofluids have higher pressure dropping and pumping power than base fluids [10]. At present, the research on nanofluids is not perfect enough, there is still a lot of research to be done.

At present, the progress of nano research is gradually being carried out. Examples include the study of heat conduction in nanofluids, which involves the preparation, transportation, and other aspects of nanofluids. Further research should be conducted to address some challenges in nanofluid. First of all, effective techniques are required for the nanofluid preparation in order to lower the cost. Then, the stability of nanofluid is a main problem as it is being used in heat transfer application. Moreover, more research is needed to determine the thermophysical properties of nanofluids since the study on the combination of nanoparticles has not yet been completed. At last, more research is needed before nanofluids can be applied to nuclear systems and other fields.

7. Conclusion

To sum up, the present study provides a detailed study on the principle, preparation and application of nanofluids. This study first talks about the principles of nanofluids, such as their thermophysical properties. Our next focus is on the thermal conductivity properties of nanofluids. Its excellent heat conductivity makes it one of the materials used in industry as a material for transferring heat energy. Although nanofluid is not steady under some condition, but it has immeasurable prospects in areas such as industry. As for the preparation of nanofluid, there are two commonly used methods. One of them is the one-step method, which is applied because of its simple operation, but it also has the disadvantage that it cost a lot. The other method is two-step method, which include production and dispersion in this process. The two-step process, which is the most practical, has been frequently utilized to create nanofluid. However, it also has disadvantages which is more prone to agglomeration due to high surface activity. Speaking of nanofluidic applications, nanofluids are already used in many ways. For instance, the heat exchanger, refrigeration, cooling system and etc. Although the application prospects of nanofluids are rich, the research on nanofluids still needs to be deepened. There are still many problems with nanofluids that need to be solved.

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