Overview on the Preparation and Heat Transfer Enhancement of Nanofluids

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Abstract. Due to the great advantages of high thermal conductivity and strong heat exchange capacity, nanofluids have attracted great interest in many heat exchange fields, such as thermal power plant, solar energy, automobile cooling, nuclear power facilities and so on. In this paper, it reviews the research progress of nanofluids including preparation process, suspension stability, thermal conductivity, viscosity, and gives emphasis to analyse the influence factor of nanofluid convective heat transfer.

1. Introduction
In the past decades, with the economic development and population growth, the efficient use of energy is great significance to protect the global environment and human sustainable development. However, various technologies have been applied to enhance heat exchange, their performance is still limited by the low heat conductivity of heat transfer medium, which seriously restricts the performance and safety of heat exchanger. The concept of nanofluid was first proposed in 1995 by Choi[1] et al in Argonne National Laboratory. Compared with the traditional single - phase heat transfer working substance, the high thermal conductivity of nanofluids is conducive to enhancing heat transfer, but also improves the critical heat flux that the pipeline or components can bear. It has a strong application prospect in the field of solar energy devices, nuclear energy, aerospace and other fields, and has attracted the great interest of researchers.

2. Preparation of Nanofluids
The preparation of nanofluids can be divided into "one - step" and "two - step" methods. The one - step method refers to directly dispersing nanoparticles into the base fluids while preparing nanoparticles, and the preparation of nanoparticles and nanofluids is completed at the same time. The nanofluid prepared by one - step method has small particle size, good dispersion, high suspension stability, and the nanoparticle is not easy to agglomerate. However, due to incomplete reaction, the residual reactants (impurities) remain in the nanofluid, which is difficult to remove. Zhang et al[2], directly synthesized Cu - water nanofluids with uniform dispersion and high thermal conductivity by one step method.

The two - step method refers to the preparation of nanoparticles by chemical synthesis, and then the prepared nanoparticles are uniformly dispersed into the base fluids by some means, such as ultrasonic vibration, adding dispersant and so on. The ZnO - DW and ZnO - EG nanofluids based on deionized water (DW) and glycol (EG) were prepared by Majid Moosavi et al[3]; Li et al[4], used two - step method to add SiO2 (30 nm) nano powder to water and glycol respectively to obtain uniform and stable SiO2 - DW and SiO2 - EG nanofluids.
3. Agglomeration and Stability of Nanofluids

No matter one-step method or two-step method is used to prepare nanofluids, nanoparticles in nanofluids tend to agglomerate for the effect of van der Waals attraction, and the aggregation of nanoparticles is still a major hidden danger. According to the colloidal stability theory (DLVO theory), the stability of particles in solution is mainly determined by the sum of van der Waals force and the repulsive force of double electric layers between particles[5]. Wang Nan et al[6]. found that the particles present irregular Brownian motion in the base fluids, and the solid particles will adsorb the liquid molecules on the surface, forming a double electric layer structure, and the increase of solid-liquid gravity can effectively avoid or delay the occurrence of particle agglomeration. Xu et al[7]. found that the dispersion stability of nanofluids is related to the particle size, particle concentration and the characteristics of the base solution by analyzing the stress of nanoparticles uniformly dispersed in the base solution with the same particle size. Therefore, the interaction force or potential between nanoparticles and the surrounding base solution plays a decisive role in the dispersion stability of nanofluids. In general, the methods to improve the suspension stability of nanofluids can be generally divided into physical dispersion method and chemical dispersion method.

3.1. Physical Dispersion Method.

At present, ultrasonic dispersion is adopted as physical dispersion method which overcome the attraction between particles, break the original force balance and improve the stability of nanofluids under the action of strong shock wave or micro jet. However, if the ultrasonic oscillation time is too long, the temperature of the fluid will increase, and the violent random Brownian motion will increase the chance of collision between particles, and then agglomeration will occur inevitably. Therefore, there is a relatively optimal relationship between ultrasonic dispersion time and suspension stability of nanofluids. wang et al[8]. analyzed the suspension stability of Al$_2$O$_3$ nanofluid and SiO$_2$ nanofluid without adding dispersant, the suspension content of the obtained nanofluid was tested every 0.5 h. The results showed that Al$_2$O$_3$ nanoparticle had the best stability in ultrasonic dispersion for 3 h and SiO$_2$ nanoparticle obtained the best stability in ultrasonic dispersion for 5 h. Li et al[9]. studied the influence of ultrasonic dispersion for 5, 10, 20, 30, 45, 60, 90 and 120 min on the stability of AlN / EG nanofluids. The results showed that the particle size of AlN / EG nanofluids prepared by ultrasonic dispersion for 30 min was the smallest and its suspension stability was expected to be the best.

3.2. Chemical Dispersion Method.

The common chemical dispersion method in laboratory is to change the surface charge of nanoparticles by using dispersant or adjusting the pH value of nanofluid system, so as to achieve the purpose of dispersing particles. Dispersant (usually surfactant) is a kind of interfacial active agent with wetting characteristics, which is composed of polar hydrophilic group and nonpolar lipophilic group. It can effectively prevent particle agglomeration and sedimentation by forming an adsorption layer at the solid interface, reducing the solid-liquid interface tension, forming an effective space potential resistance or increasing the electrostatic repulsion between particles. Li et al[10]. studied the effect of surfactants on the solid-liquid phase transition characteristics of TiO$_2$-water nanofluids, and found that the anionic surfactant sodium dodecylbenzene sulfonate (SDBS) was beneficial to improve the dispersion stability, while the cationic surfactant cetyltrimethylammonium bromide (CTAB) could reduce the dispersion stability of TiO$_2$-water nanofluids. Mo et al[11]. studied the effect of different concentrations and doses of surfactants on the dispersion of TiO$_2$-water nanofluids, and found that the best dispersion of nanoparticles was when the dispersant was SDBS and its mass ratio to TiO$_2$ nanoparticles was 0.3. Ling et al[12]. found that the dispersion stability of Cu-water and ZrO$_2$-water nanofluids prepared by adding CTAB and octylphenyl polyoxyethylene ether and SDBS was better, and simulated by molecular dynamics method. The results showed that the stability of Cu-water and ZrO$_2$-water nanofluids increased first and then decreased with the increase of SDBS.

A large number of experimental results show that the type of surfactant is one of the important factors for the dispersion stability of imaging nanofluids. The analysis points to the adsorption mechanism of ionic surfactant and non-ionic surfactant is quite different at the solid-liquid interface of nanoparticles. The adsorption structure of ionic surfactant is mainly formed by dissociation of polar
groups in water and hydrophobic parts on the surface of nanoparticles, which increases the electrostatic repulsion force and reduces the agglomeration trend. However, nonionic surfactants can not ionize in water, and a small amount of nonionic surfactants adsorb on the surface of nanoparticles to form steric hindrance, which can inhibit the agglomeration of particles.

4. Thermal Conductivity

4.1. Theoretical Study on Thermal Conductivity.

| Model        | Expression                                                                 | Applicable conditions                                                                 |
|--------------|----------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Maxwell [13] | \[ k_{nf} = k_p + 2k_f \phi \rho (k_p - k_f) \]                           | Spherical model with low particle volume concentration.                                  |
| Bruggeman [17]| \[ \phi \left( \frac{k_p - k_{nf}}{k_p + 2k_{nf}} \right) + (1 - \phi) \left( \frac{k_{nf} - k_{eff}}{k_{nf} + 2k_{eff}} \right) = 0 \] | Spherical particles without limitation of particle volume concentration.                  |
| Choi [14]    | \[ k_{nf} = k_p + (2(k_p - k_f)(1 + \sigma)\phi_p) \]                      | Considering the influence of nano particle size and nano layer.                          |
| Avsec [18]   | \[ \frac{5 \times 10^4 \beta \phi_p \rho_C \sigma}{k_f} \left( \frac{\kappa_T}{\rho \sigma} \right)_f \] | Consider the thickness of liquid layer.                                                 |
| Vajha [19]   | \[ k_{nf} = k_p + (n-1)k_f - (n-1)\alpha_p(k_p - k_f) \]                   | Considering the influence of temperature, particle volume concentration, nanoparticle characteristics and other factors on the thermal conductivity of nanofluids. |
| Ho [20]      | \[ k_{nf} = \frac{2 + (\frac{k_p}{k_f}) + 2\phi_p}{2 + (\frac{k_p}{k_f}) - \phi_p} \] | For Al_2O_3 water nanofluids.                                                          |
| Li [15]      | \[ k_{nf} = k_0 + X_{nf} + \frac{\rho \phi_p k_p}{2k_f} \sqrt{\frac{k_n}{3 \pi \tau \eta}} \] | The influence of surface shape, particle size, density, viscosity of the base solution and test temperature on the thermal conductivity of nanofluids. The nanofluid consists of alumina, titanium dioxide, silicon dioxide and copper nanoparticles. The base solution is water, glycol (EG), glycol (PG) or ethanol (ETH) in allylene. |
| Corcion [21] | \[ k_{nf} = 1 + 4.4 \text{Re}^{0.64} \text{Pr}^{0.66} \left( \frac{T}{T_p} \right)^{10} \frac{k_p}{k_f} \phi^{0.66} \] | Considering the stochastic dynamics and stochastic heat transfer process of suspended particles |

Compared with the thermal conductivity of ordinary solid - liquid mixtures, the thermal conductivity of nanofluids is more complex. The particle size, volume fraction, temperature of the base liquid and random Brownian motion of nanoparticles all affect the thermal conductivity of nanofluids. In order to...
study the micro mechanism of improving the thermal conductivity of nanofluids, researchers have proposed a series of theoretical models displayed in the Table 1 to predict the effective thermal conductivity of nanofluids. Maxwell[13] used the effective medium theory (EMT) to obtain the thermal conductivity model of the composite mixture by considering the uniform electromagnetic response in space. Choi et al[14], considered that the solid nano layer plays a role of thermal bridge between the nano particles and the base liquid, so it is the key to improve the thermal conductivity. Based on this assumption, they modified the Maxwell equation for the effective thermal conductivity of solid / liquid suspensions to include the effect of this ordered nano layer. Li et al[15], proposed a model for calculating the effective thermal conductivity of nano suspension considering the effects of static thermal conductivity, dynamic Brownian motion and agglomeration. Xuan et al[16]. believe the random Brownian motion of nanoparticles in the base fluid causes and promotes the micro disturbance inside the fluid, thus enhancing the energy transfer rate between the nanoparticles and the base fluid. Therefore, they think that the apparent thermal conductivity of nanofluids is the sum of static thermal conductivity and dynamic thermal conductivity.

Although these models can predict the thermal conductivity of nanofluids well, the experimental results and theoretical predictions of nanofluids are not quite consistent. Therefore, researchers have successively supplemented the mechanism theory of enhancing thermal conductivity of nanofluids[22], including Brownian motion theory, the interface layer of nanoparticles, the nature of heat transfer between nanoparticles, the structure / aggregation of nanoparticles.

4.2. Experimental Study on Thermal Conductivity.
There are many factors affecting the thermal conductivity, including the volume fraction of nanoparticles, particle size, temperature of base solution and suspension stability. In recent years, some researchers have conducted in-depth research on the thermal conductivity of nanofluids. J.Li et al[4], measured the thermal conductivity of SiO$_2$ - DW and SiO$_2$ - EG nanofluids at different volume fractions, and found that the thermal conductivity of nanofluids improved with the increase of the volume fraction of nanoparticles, M.Moosavi et al[3], measured the relationship between thermal conductivity and volume fraction of ZnO nanofluids, and found that with the volume fraction of ZnO - EG and ZnO - DW increasing to 3.0%, the thermal conductivity increased by 10.5% and 7.2% respectively. According to the current experimental results, it can be agreed that the thermal conductivity of nanofluids depends on the volume fraction of nanoparticles. The main reason is that under the condition of good dispersion stability of nanofluids, the higher the volume fraction of nanoparticles, the larger the specific surface area of solids per unit volume, and the larger the heat transfer area of heat transfer, thus greatly improving the thermal conductivity.

However, researchers have not reached a consensus on how temperature affects the thermal conductivity of nanofluids. Duangtongsuk et al[23]. studied the thermal conductivity of TiO$_2$ - EG nanofluids in the range of 15°C to 30°C, the results showed that the thermal conductivity of nanofluids increased with the increase of temperature. In reference [3], it is also observed that the thermal conductivity of ZnO nanofluids increases nonlinearly with the increase of temperature under the condition of constant volume fraction of nanoparticles. In contrast, Chen et al[24], found that temperature had no significant effect on the thermal conductivity of the prepared nanofluids. Shima et al[25]. studied the relationship between the thermal conductivity and temperature of aqueous and non-aqueous nanofluids with an average particle size of 8 nm. They observed that the thermal conductivity is independent of temperature.

The suspension stability also affects the thermal conductivity of nanofluids. The agglomeration structure of nanoparticles in the base fluid, the addition of surfactants or dispersants will have different effects on the thermal conductivity of nanofluids. Duan et al[26]. conducted a comprehensive analysis of the dispersion and thermal conductivity of the Cu - tetradecane nanofluid, and found that the surface modified nanofluid has the best stability and the largest thermal conductivity enhancement effect. Jiang et al[27]. found that the thermal conductivity of γ-Al$_2$O$_3$ nanofluids increased and then decreased with the addition of surfactants, and the proper ratio of particle concentration and surfactant concentration is conducive to improving the thermal conductivity of nanofluids. Zhang [28] used equilibrium molecular dynamics to explore the influence of the aggregation form of nanoparticles on


the thermal conductivity of nanofluids. It was found that the thermal conductivity of nanofluids increased linearly with the decrease of the fractal dimension of aggregates under the condition of certain volume fraction and particle size of nanoparticles, and the aggregation of smaller nanoparticles was more conducive to the improvement of the thermal conductivity of nanofluids.

5. Viscosity

5.1. Theoretical Study on Viscosity.

Viscosity is one of the important parameters to measure the transport performance of fluid, which plays an important role in the process of flow and heat transfer. In engineering applications, the viscosity of nanofluids not only affects the pump power and fluidity, but also affects the convective heat transfer coefficient, Reynolds number and Prandtl number.

| Model          | Expression                                                                 | Applicable conditions                                                                 |
|----------------|-----------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| Einstein[29]   | \( \frac{\mu_{nf}}{\mu_{bf}} = [1 + 2.5\phi]\)                           | It is suitable for very low concentration of nanoparticles (< 0.02%).                   |
| Brinkman[35]   | \( \frac{\mu_{nf}}{\mu_{bf}} = \frac{1}{(1 - \phi)^{2.5}} \)              | Suitable for nanoparticles with volume concentration less than 4.0%.                    |
| Batchelor[30]  | \( \frac{\mu_{nf}}{\mu_{bf}} = [1 + 2.5\phi + 6.5\phi^2] \)              | The effects of Brownian motion on the isotropic suspension of rigid and spherical particles are considered. |
| Guo[31]        | \( \frac{\mu_{nf}}{\eta_{bf}} = (1 + 2.5\phi + 6.25\phi^2)(1 + 350\frac{\phi}{d}) \) | Introducing the influence factor D of particle size to modify the Batchelor empirical formula. |
| Namburu[33]    | \( \log(\mu_{nf}) = Ae^{-BT} \)                                           | The effect of temperature on the viscosity of nanofluids is considered.                 |
| Masoumi[32]    | \( \mu_{nf} = \mu_{bf} + \frac{C_P V_b d_f^3}{72 C \delta} \)            | Brownian motion based on nanofluids.                                                   |
| Corcion[21]    | \( \frac{\mu_{nf}}{\mu_f} = \frac{1}{1 - 34.87(d_p / d_f)^{0.3} \phi_p^{1.03}} \) | The nanofluid consists of \( \text{Al}_2\text{O}_3, \text{TiO}_2, \) \( \text{SiO}_2 \) and \( \text{Cu} \) nanoparticles. The base fluid is water, glycol (EG), Propylene glycol (PG) or ethanol (ETH). The diameter, volume fraction and temperature range of nanoparticles are 25 ~ 200 nm, 10^{-4} ~ 0.071 and 293 ~ 323 K, respectively |
| Ling Zhiyong[36] | \( \mu_{nf} = a e^{(-b(273 + T))} \)                                      | The effects of temperature and particle concentration on the viscosity of nanofluids are considered. |

In order to better predict the viscosity of nanofluids, researchers have put forward some prediction models. Einstein[29] proposed the viscosity formula of infinite dilution solid-liquid mixture system for the first time, which can be used to predict the viscosity of low concentration spherical particles. In 1977, Batchelor[30] considered the influence of Brownian motion of rigid and spherical particles, supplemented Einstein's model, and proposed a new correlation formula. The above two formulas
mainly reflect the relationship between the volume fraction of nanoparticles and the viscosity of nanofluids. For nanofluids, the interaction between particles, temperature, type and size of particles will affect the results. Guo et al[31]. think that the viscosity of nanofluids is mainly caused by the interaction between micro clusters, and the interaction between particles restricts each other to form a grid like structure, which leads to the increase of viscosity of the system. In addition, they found that the relative viscosity of the fluid has a good linear relationship with the concentration of the suspension, and the viscosity of the fluid decreases with the increase of the particle size. Therefore, the particle size influence factor D was introduced to modify the Batchelor empirical formula. Masoumi et al[32]. based on the Brownian motion of nanofluids, assume that the nanoparticles are uniformly distributed without any interaction between the particles, and introduce the shear force correction factor C to simplify the boundary conditions. The research of Namburu et al[33]. shows that temperature has a certain influence on the viscosity of nanofluids, but the influence of temperature on viscosity is not involved in the general prediction formula. Liu et al[34]. considered the influence of temperature and particle size on the viscosity of SiO$_2$ heat transfer oil nanofluids, according to the traditional viscosity temperature relationship, combined with experimental data, put forward an empirical formula suitable for the viscosity of SiO$_2$ heat transfer oil nanofluids changing with temperature and volume fraction. Table 2 shows different Viscosity model of nanofluids models for nanofluids.

5.2. Experimental Study on Viscosity.

The analysis mentioned above shows that the viscosity of nanofluids depends on many parameters, such as viscosity of the base solution, volume fraction of nanoparticles, particle size, type, temperature and dispersion stability. Therefore, it is necessary to determine the new viscosity model of Nanofluids and to understand the effect of viscosity change on natural convection heat transfer. At present, some literatures have reported the viscosity changes of nanofluids at different volume fractions and temperatures. Xuan et al[37]. found that adding Cu nanoparticles to the original pure liquid working medium increased the viscosity of the liquid, and when the volume fraction of Cu nanoparticles was 2.5%, the viscosity of the formed nanofluid increased to 1.973 mpa·s. Guo et al[31]. studied the viscosity of SiO$_2$ nanofluids, and found that with the increase of the concentration of nanoparticles, the viscosity of the nanofluids increased significantly, and the smaller the particle size, the greater the viscosity increase. Sundar et al[38]. studied the effect of the volume concentration and temperature of nanoparticles on the viscosity. The results showed that the viscosity of nanofluids increased with the increase of the volume concentration of nanoparticles, but decreased with the increase of temperature. Shah et al[39]. studied the effective viscosity of $\alpha$ - alumina nanofluids at 25°C ~ 40°C. The results showed that the viscosity of the nanofluids increased with the increase of the concentration of suspended particles. However, the viscosity of the nanofluids decreased exponentially with the increase of temperature. Ling et al[40]. measured the viscosity of TiO$_2$ - H$_2$O nanofluids with different mass fractions at 15°C ~ 40°C, and the conclusion was consistent with that of Sundar and Jankishah.

The results show that the addition of nanoparticles in the base solution can increase the viscosity, and the volume fraction and temperature of nanoparticles will affect the viscosity of nanofluids. The main reason is that the larger the volume percentage of nanoparticles, the smaller the particle size, the larger the specific surface area per unit volume, and the more energy is consumed by the internal friction to overcome when nanofluids flow.

6. Conclusion and Prospect

In this paper, the preparation, characterization, properties and application of nanofluids are described. At present, the research of nanofluids is still in its infancy, and many studies of nanofluids still need to be conducted further:

(1)The properties of nanofluids are mainly based on the preparation method, colloidal stability and heat and mass transfer. Due to the strong van der Waals interaction, nanoparticles always tend to aggregate. The stability of nanofluids is one of the key challenges hindering the wide application of nanofluids.
There are many literatures on thermal conductivity and viscosity models of nanofluids, but only the improved specific models of nanofluids are discussed here. The basic mechanism of heat conduction needs further study.

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8. References
[1] Choi S U S 1995 Enhancing thermal conductivity of fluids with nanoparticles ASME-Publications Fed 231:99-106
[2] Zhang Feilong, Zhu Huina, Wang Li, fan Zongliang, Wang Gang 2014 Synthesis of Cu-water thermal conductive nanofluids using sodium citrate as dispersant by one step method Functional materials 45 (23): 23138-23141
[3] Moosavi, M., E.K. Goharshadi and A. Youssefi 2010 Fabrication, characterization, and measurement of some physicochemical properties of ZnO nanofluids International Journal of Heat and Fluid Flow 31(4)
[4] Li Jinkai et al 2010 Researches on thermal conductivity of SiO2 nanofluids Chemical machinery 37 (04): 405-408 + 417
[5] I. Popa, G. Gillies, G. Papastavrou, M. Borkovec 2010 Attractive and Repulsive Electrostatic Forces between Positively Charged Latex Particles in the Presence of Anionic Linear Polyelectrolytes J Phys Chem B 114, pp. 3170-3177
[6] Wang Nan et al 2011 Elementary Research on the Dispersion and Stability of Nanofluids by Molecular Dynamics Simulations. Journal of Engineering Thermophysics 32 (07): 1107-1110.
[7] Xu Xiaojiao et al 2012 Review of Latest Developments on Stability of Nanofluids. Fluid mechanics 40 (10): 46-49 + 45
[8] Wang Hongyu et al 2016 Preparation and stability of nanofluids Journal of Henan University of science and Technology (NATIONAL SCIENCE EDITION) 37 (01): 5-8 + 25 + 4
[9] Li Yanjiao, et al 2015 Synthesis and investigation on stability of AIN/ EG nanofluids Functional materials 46 (08): 8018-8022
[10] Li Xing et al 2013 Influence of surfactant on characteristics of solid liquid phase change for water-based nanofluid Journal of chemical engineering 64 (09): 3324-3330
[11] MO Songping et al 2013 Effects of Surfactants on Dispersion of Titania Nanofluids Materials guide 27 (12): 43-46
[12] Ling Zhiyong et al 2015 Effect of surfactants on the stability of Cu - H2O and ZrO2 - H2O nanofluids Functional materials 46 (10): 10100-10103 + 10109
[13] Maxwell, J C 1881 A treatise on electricity and magnetism 2nd ed U K :Clarendon Press
[14] Yu, W., S.U.S. Choi and A.I.U.S. Argonne National Lab.ANL 2003 The Role of Interfacial Layers in the Enhanced Thermal Conductivity of Nanofluids: A Renovated Maxwell Model Journal of Nanoparticle Research 5(1): p. 167-171
[15] Dong Dong Li, Jin Kai Li and Wei Lin Zhao 2010 stability and thermal conductivity of SiO2-water nanofluids Journal of Jinan University (NATURAL SCIENCE EDITION)
[16] Xuan Y 2014 theory and application of nanofluid energy transfer Chinese science and technology 44 (03): 269-279
[17] D.A.G. Bruggemen 1935 Calculation of various physical constants of heterogeneous substances, I. dielectric constants and conductivities of mixing body from isotropic substances, Annalen der Physik Leipzig 24 636–679
[18] Avsec, J. and M. Oblak 2007 The calculation of thermal conductivity, viscosity and thermodynamic properties for nanofluids on the basis of statistical nanomechanics International Journal of Heat and Mass Transfe 50(21-22): p. 4331-4341.
[19] Vajjha, R.S. and D.K. Das 2009 Experimental determination of thermal conductivity of three nanofluids and development of new correlations International Journal of Heat and Mass Transfer 52(21-22): p. 4675-4682.
[20] C.J. Ho, L.C. Wei, Z.W. Li 2010 An experimental investigation of forced convective cooling performance of a microchannel heat sink with Al₂O₃/water nanofluid Appl Therm Eng 30, pp. 96-103
[21] Corcione, M. 2011 Empirical correlating equations for predicting the effective thermal conductivity and dynamic viscosity of nanofluids Energy Conversion and Management 52(1): p. 789-793
[22] Angayarkanni, S.A. and J. Philip 2015 Review on thermal properties of nanofluids: Recent developments Advances in Colloid and Interface Science 225: p. 146-176
[23] Duansthongsuks, W. and S. Wongwis 2009 Measurement of temperature-dependent thermal conductivity and viscosity of TiO₂-water nanofluids Experimental Thermal and Fluid Science 33(4): p. 706-714
[24] Chen, L., et al 2008 Nanofluids containing carbon nanotubes treated by mechanochemical reaction Thermochimica Acta 477(1): p. 21-24
[25] Shima, P.D., J. Philip and B. Raj 2010 Synthesis of Aqueous and Nonaqueous Iron Oxide Nanofluids and Study of Temperature Dependence on Thermal Conductivity and Viscosity The Journal of Physical Chemistry C 114(44): p. 18825-18833
[26] Duan Yuanyuan et al 2015 Exploration on influence factorsof thermal conductivity of tetrodecyl nanofluid Thermal science and technology 14 (06): 431-435
[27] Jiang Huanming, Xia Guodong and Liu ran 2014 Analysis of Factors Influencing the Thermal Conductivity and Stability of α-Al₂O₃ Nanofluids Journal of Engineering Thermophysics 35 (08): 1550-1553
[28] Zhang Zhiqi et al 2019 Effect of aggregation morphology of nanoparticles on thermal conductivity of nanofluid Acta physica Sinica 68 (05): 161-170
[29] A. Einstein 1906 A new determination of molecular dimensions Annalen der Physik 19 289–306
[30] G.K. Batchelor 1977 The effect of Brownian motion on the bulk stress in a suspension of spherical particles Journal of Fluid Mechanics 83 97–117
[31] Guo shunsong, Luo Zhongyang, Wang Tao, Zhao Jiafei 2006 Viscosity of Monodisperse Silica Nanofuils. Silicate dail (05): 52-55
[32] Masoumi N, Sohrabi N, Behzadmehr A 2009 A new model for calculating the effective viscosity of nanofluids J of Phys D: Appl Phys 42(5):055501
[33] Namburu, P.K., et al 2007 Viscosity of copper oxide nanoparticles dispersed in ethylene glycol and water mixture Experimental Thermal and Fluid Science 32(2): p. 397-402
[34] Liu Tengyue et al 2016 Investigation of Viscosity of SiO₂ Heat Transfer Oil Nanofuid Journal of Engineering Thermophysics 37 (01): 25-28
[35] H.C. Brinkman 1952 The viscosity of concentrated suspensions and solution Journal of Chemical Physics 20 571–581
[36] Ling Zhiyong et al 2011 Experimental study on the stability and viscosity of Cu-water nanofluids Functional materials 42 (S3): 481-483
[37] Xuanyimin, Li Qiang 2000 Study on enhanced heat transfer of nanofluids Journal of Engineering Thermophysics 21 (4): 466-470
[38] Sundar, L.S et al 2014 Thermal conductivity and viscosity of stabilized ethylene glycol and water mixture Al₂O₃ nanofluids for heat transfer applications International Communications in Heat and Mass Transfer 56
[39] Shah, J et al 2017 Temperature-dependent thermal conductivity and viscosity of synthesized α-alumina nanofluids Applied Nanoscience 7(8); p. 803-813
[40] Ling Zhiyong, et al 2013 Effect of temperature and nanoparticle concentration on the viscosity of nanofluids Functional materials 44 (01): 92-95