# A REVIEW ON SYNTHESIS, MECHANISM AND UTILIZATION OF NANOFLUIDS

**Aditya Abhang[1], Shashank Sonawane[2], Suraj Avhad[3]**
**Amol Kakade[4], B. M. Dusane[5]**

[1] *T.E. Mechanical, NDMVP's KBT College of Engineering Nashik Pune University, (India)*
[2]*T.E. Mechanical, Sandip Institute of Engineering and Management Nashik Pune University, (India)*
[3]*T E. Mechanical, PES Modern College of Engineering Pune University, (India)*
[4]*Mechanical Engg. Dept. NDMVP's KBT COE Nashik, (India)*
[5]*Assistant Professor, Mechanical Engg. Dept. Sandip Foundation's SIEM Nashik, (India)*

## ABSTRACT

*Nanofluids are a colloidal suspension of Nanoparticles in a base fluid. Nanoparticles are micro-scaled particles having a particle size ranging from 1-100nm. Nanofluids show many unique features and improved properties which include thermo-physical properties such as thermal conductivity, thermal diffusivity, viscosity, heat transfer coefficient, magnetic and versatility to vary these properties. These improved properties pave the way in the field of research and innovative applications. The field of research is still in its initial phase and hence it faces some challenges which are also focused in this paper for implementing these fluids as working fluids in a number of applications. The stability of nanofluids and its production is one of the most important concern to be looked upon. Nanofluids provide an alternative solution to be used as a working fluid in many applications. However, there is still a lot of work and research to be done before Nanofluids can be used and produced on a mass scale in industries. It can be used in broad range of applications like industrial cooling, energy storage, solar absorption, transportation, space and defence, friction reduction, magnetic sealing and biomedical applications. Nanofluids offer eco-friendly solution to current technological problems.*

***Keywords: Nanofluid, Nanoparticles, Base fluid, Thermal conductivity, Thermal diffusivity, Viscosity, Heat transfer coefficient***.

## I. INTRODUCTION

In many industrial applications, the conventional heat transfer fluids are refrigerants, water, engine oil, ethylene-glycol etc. Heat transfer is amongst the vital industrial processes. In any industry, heat must be efficiently managed by adding, removing or moving in the relevant sectors. There are several methods to improve the heat transfer efficiency. Some methods are utilization of extended surfaces, application of vibration to the heat transfer surfaces, and usage of micro channels. Heat transfer efficiency can also be improved by increasing the thermal conductivity of the working fluid. Despite considerable research and developmental efforts on enhanced heat transfer surfaces, major improvements in cooling capabilities have been constrained because of the poor thermal conductivities of traditional heat transfer fluids used in today's thermal management systems. In the development of energy-efficient heat transfer fluids, the thermal conductivity enhancement in heat transfer plays a vital role. The enhancement of heating or cooling in an industrial process may create a saving in energy, reduce process time, raise thermal rating and lengthen the working life of equipment. Development of highly efficient heat transfer fluids for solving the drawback of conventional fluids has become one of the most important priorities in the cooling industries. High thermal conductivity of solids can be used to increase the thermal conductivity of a fluid by adding small solid particles to that fluid. One such latest advancement in heat transfer fluids, is the use of nano-sized (1 - 100 nm) solid particles, a technique for heat transfer enhancement. Improving the thermal conductivity is the key idea in enhancing the heat transfer characteristics of conventional fluids and in turn the heat transfer coefficient. The paper focuses on the preparation of nanofluids, stability barriers and possible applications in various fields and future scope.

### 1.1 Nanotechnology and Nanofluids

Nanotechnology is the act of manipulating materials at very tiny scales – at the level of atoms and molecules sized from 1 to 100 nanometres. When working with materials under 100 nanometres, the normal rules of physics and chemistry no longer apply and many materials start to display unique and, sometimes, surprising and distinctive properties [1]. Nanotechnology is one of the fastest growing field of research and nanofluids can be termed as an application of it. Nanofluids are a colloidal suspension of Nanoparticles in a base fluid. Nanoparticles are micro-scaled particles having a particle size ranging from 1-100 nm. A colloid is a substance in which one substance of microscopically dispersed insoluble particles is suspended throughout another substance. To be a colloid, the mixture must be one that does not settle or would take a very long time to settle appreciably. Nanofluids are stable colloidal suspensions of nano-materials (Nanoparticles, nano rods, nanotubes, nanowires, nanofibers, nanosheets, other nanocomposites, or even nano-droplets and nano-bubbles) in common, base fluids, such as water, oil, ethylene-glycol mixtures, polymer solutions, refrigerants, heat transfer fluids bio-fluids, and others. Nanoparticles are very small, nanometer-sized particles with their smallest dimension usually less than 100 nm (nanometers). The smallest Nanoparticles, only a few nanometers in diameter, may contain a few thousand atoms. These Nanoparticles can possess properties that are substantially different from their parent materials. Similarly, nanofluids may have properties that are substantially different from their base fluids, like much higher thermal conductivity, and other flow and heat transfer characteristics. Nanofluids have adjustable properties, including thermal conductivity and surface wettability, by varying particle concentrations to suit different applications.

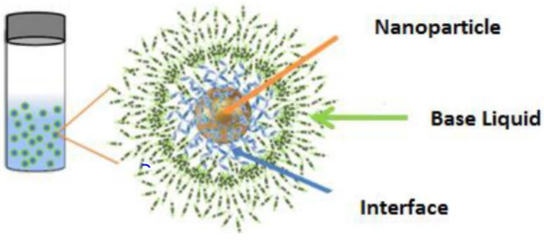


**Figure1.1** Schematic of NPs dispersion systems (NFs) as a three phase suspension system

### 1.2 Nanomaterials and Base fluids

Nanofluids are made by dispersing nanomaterials in to base or conventional fluids to enhance their properties. Nanomaterials can be metallic/intermetallic compounds (such as Ag, Cu, Ni, Au, Fe, etc.), ceramic compounds such as oxides, sulphides and carbides. Among the ceramics, $Fe_3O_4$, CuO, $Al_2O_3$ $MoS_2$, $TiO_2$, $SiO_2$, $Fe_2O_3$. Nanostructured materials can be also carbon based compounds, such as carbon nanotube, graphane, graphane oxide, graphite, etc. Base liquids are selected from water, ethylene glycol (EG), mixture of water and EG (W/EG), diethylene glycol (DEG), polyethylene glycol, engine oil, vegetable oil, paraffin, coconut oil, gear oil, kerosene, pump oil, etc. This new dispersion can be considered a suspension with three phase system as figure 1.1 shows: solid phase (Nanoparticles), solid/liquid interface and the liquid phase. From more than a decade ago since the introduction of nanofluids concept was originated, the potentials of nanofluids applications in different area have attracted increasing attention.

## II. PREPARATION METHODS OF NANOFLUIDS

The preparation of nanofluids is not only simple mixing and dispersing solid particles in a base liquid. It is the most important stage in the use of nanoparticles or any nanostructured materials to enhance the thermal characteristics of conventional heat transfer fluids. This is because the agglomeration of solid particles could happen in base liquid media if the nanofluids are not prepared properly which may in turn result in poor thermo-physical property of nanofluids.There are two main categories for production of Nanoparticles, namely, physical synthesis and chemical synthesis.

**Physical Synthesis:** Mechanical grinding, inert-gas-condensation technique.

**Chemical Synthesis:** Chemical precipitation, chemical vapour deposition, micro-emulsions, spray pyrolysis, thermal spraying.

### 2.1 Two Step Method

The two step method is the most widely used method for preparation of nanofluids. In this method, first the nanoparticles, nanofibers, nanotubes or other nanomaterials are produced as dry powders by physical or chemical methods. Then, this produced nanosized dry powder is dispersed into a base fluid in the second step with the help of intensive magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenizing, and ball milling. This is the most economical method for production of nanofluids in a large scale because industrial production is already underway. However, because of high surface activity of particles and large surface area, agglomeration/aggregation of nanoparticles is unavoidable.The important technique to enhance the stability of nanoparticles in fluids is the use of surfactants. However, the functionality of the surfactants under high temperature is also a big concern, especially for high-temperature applications. It is quite difficult to prepare stable nanofluids using two step method, therefore one step method was developed.

### 2.2 One Step Method

One step method was developed by Eastman et al. to reduce the agglomeration of Nanoparticles [2]. The one step preparation method consists of making and dispersing the Nanoparticles in the base fluid itself. Preparation of nanofluids via one-step method provides some advantages such as minimizing the agglomeration of nanoparticles and increasing the stability of nanofluids. This is because, in this method the processes of drying, storage, transportation, and dispersion of nanoparticles is avoided which leads to minimization of aggregation/agglomeration of nanoparticles. The one-step processes can prepare uniformly dispersed Nanoparticles, and the particles can be stably suspended in the base fluid. The vacuum-SANSS (submerged arc nanoparticle synthesis system) is another efficient method to prepare nanofluids using different dielectric liquids. However, the One-step physical method cannot synthesize nanofluids in large scale, and the production cost is also high.

## III. STABILITY OF NANOFLUIDS

Stability of nanofluids is one of the key features for any nanofluid system in each application, especially in heat transfer application. The aggregation of Nanoparticles results not only in the settlement and blocking of micro channels but it also decreases the thermal conductivity of nanofluids. So, the investigation on stability is a key issue that influences the properties of nanofluids for application. Although a lot of studies have been done about the stability of dispersion containing solid particles, fabrication of homogeneous nanofluids with high stability is still a technical challenge. In this section we discuss these points.

### 3.1 Factors affecting stability of Nanofluids

The factors which influence the stability of nanofluid are surface modifiers (surfactants), pH adjustment, nanofluid preparation method, mixing/homogenization etc. It should be mentioned that each nanofluid system needs its specific dispersion method to stabilize the nanoparticle in base liquid. Sometimes these chemical and physical methods can be combined while in other cases applying one method may be enough to obtain stable suspension.

#### 3.1.1 Solution pH (Nanoparticles Surface Charge)

Surface charge on Nanoparticles surface is also an important factor for the stability when it is dispersed into a base liquid. Surface charge causes a nanoparticle to emit an electric filed resulting in attraction or repulsion of Nanoparticles. This charge depends on the pH value of the suspension. It is well known that to obtain a stable nanofluids, the pH value of the suspension must be far from the Isoelectric Point (IEP) of the particles, where the overall charge on the Nanoparticles becomes zero [3-4]. When the pH value of suspension gets close to the IEP, Nanoparticles, due to weak repulsive forces between them tend to agglomerate and finally precipitation takes place. If the pH value is adjusted far from the IEP the absolute electrical charge on particles is increased resulting in increasing the repulsive interaction among Nanoparticles. Therefore, by adjusting the pH value of suspension, stability of nanofluids can be well controlled. Optimum value of pH will result in optimal stability for nanofluids system.

#### 3.1.2 Surface Modifiers

Surface modifiers are molecules, which applied for modification of surface of suspended particle in the liquid media. Addition of proper surface modifier such as surfactant or other kind of surface modifiers such as polymers are other ways of avoiding sedimentation of Nanoparticles. Surfactants, which comprise hydrophilic head and hydrophobic tails, are typically used to enhance the stability of suspensions. Selection of the surfactant depends on the type of nanoparticles and the base liquid, the nanoparticles surface is modified which result in promising electrostatic repulsion between nanoparticles. By this method hydrophilic surfaces of nanostructured materials (Nanoparticles, nanotube, etc.) are modified to become hydrophobic and vice versa.

## IV. ADVANTAGES

Nanofluids can have a great impact when used in industrial heat exchangers which are used in almost every industry and increase in its efficiency can save a large sum of money. Some of the specific potential benefits of nanofluids are described below.

### 4.1 Improved Heat Transfer and Stability

Because heat transfer takes place at the surface of the particle, it is desirable to use a particle with a large surface area. Nanoparticles provide extremely high surface areas for heat transfer and therefore have great potential for use in heat transfer. The much larger relative surface areas of nanophase powders, when compared with those of conventional micrometer-sized powders, should remarkably improve the heat transfer capabilities and stability of the suspensions.

### 4.2 Reduced Pumping Power

In heat exchangers that use conventional fluids, the heat transfer coefficient can be increased only by significantly increasing the velocity of the fluid in the heat transfer equipment. However, the required pumping power increases significantly with increasing velocity. For a nanofluid flowing in the same heat transfer equipment at a fixed velocity, enhancement of heat transfer due to increased thermal conductivity can be estimated. For example, to improve the heat transfer of a conventional fluid by a factor of 2, pumping power must be increased by a factor of about 10. However, if a nanoparticle-based fluid with a thermal conductivity =3 times that of a conventional fluid were used in the same heat transfer equipment, the rate of heat transfer would be doubled [5]. Therefore, the potential savings in pumping power is significant with nanofluids.

### 4.3 Minimal Clogging: ANL

Micrometer-sized particles cannot be used in practical heat transfer equipment because of severe clogging problems. However, nanophase metals are believed to be ideally suited for applications in which fluids flow through small passages, because the metallic Nanoparticles are small enough that they are expected to behave like molecules of liquid. This will open up the possibility of using Nanoparticles even in microchannel for many envisioned high-heat-load applications.

### 4.2 Miniaturized Systems:

Nanofluid technology will support the current industrial trend toward component and system miniaturization by enabling the design of smaller and lighter heat exchanger systems. Miniaturized systems will reduce heat transfer fluid inventory.

### 4.3 Cost and Energy Savings

Successful employment of nanofluids will result in significant energy and cost savings because heat exchange systems can be made smaller and lighter and will consume less energy units.

## V. UTILIZATION OF NANOFLUIDS

Nanofluids find a great potential for its utilization in various fields due to versatility of properties and improved heat transfer efficiency of systems. Many research projects are carried out based on the development and utilization of nanofluids by automotive companies like GM and Ford. The following section gives a brief idea of various sectors of utilization of nanofluids.

### 5.1 Electronic Heat Dissipation

The electronic industry is growing on a large scale with increasing complexity and architecture of the electronic chips. The chips are getting denser with the increase in complexity and on the other hand are reducing in size or becoming compact. This has made the electronics industry to face a great challenge of optimizing electronic equipment in such a way that there is a optimum design of chips to meet the requirements of compactness of the size as well as to have a large surface area for large heat dissipation. Using the conventional fluids has a limitation over the heat transfer coefficient and hence limits the heat dissipation capacity over a given surface area. The use of nanofluids can help to overcome this limitation and to avoid making a compromise somewhere between the compactness and proper heat dissipation through a large surface area. So the reliable thermal management system is vital for the smooth operation of the advanced electronic devices. In general, there are two approaches to improve the heat removal for electronic equipment. One is to find an optimum geometry of cooling devices; another is to increase the heat transfer capacity. Nanofluids with higher thermal conductivities are predicted to have higher convective heat transfer coefficients compared to those of base fluids. Recent researches illustrated that nanofluids could increase the heat transfer coefficient by increasing the thermal conductivity of a coolant. Higher cooling performance was obtained when compared to the device using pure water as working medium. In case of electronic equipments utilizing a nanofluid as a working medium for cooling, it was found that the thermal resistance between walls of the pipe and that of nanofluid flowing through the pipe was much reduced and the heat transfer from the walls to the nanofluid increased significantly which ultimately leads to higher heat transfer to the working medium and this dissipating higher amount of heat. Due to this much better cooling performance is obtained from the cooling arrangement and the efficiency of the cooling arrangement also increased significantly. The overall effect of increase in the efficiency of the cooling system, ultimately increases the working and performance of the electronic equipment.

### 5.2 Solar Absorption

Solar energy is one of the most abundantly available renewable energy sources present. Although the density of solar energy is lower as compared to other conventional resources, still if it is harvested on a large scale with greater absorption efficiency, it can help to minimize the environmental impacts by replacing it over the conventional energy sources. The main limitation of utilization of solar energy on a large scale is its lower density and lower absorption efficiency of the current absorption systems. The energy absorption can be increased with the employment on nanofluids. The conventional direct absorption solar collector is a well-established technology, and it has been proposed for a variety of applications such as water heating; however, the efficiency of these collectors is limited by the absorption properties of the working fluid, which is very poor for typical fluids used in solar collectors. Recently, this technology has been combined with the emerging technologies of nanofluids to create a new class of nanofluid-based solar collectors. Otanicar et al. (2010) demonstrated efficiency improvements of up to 5% in solar thermal collectors by utilizing nanofluids as the absorption mechanism [6]. The experimental and numerical results demonstrate an initial rapid increase in efficiency with volume fraction, followed by a levelling off in efficiency as volume fraction continues to increase. Theoretical investigation on the feasibility of using a non-concentrating direct absorption solar collector proved that the use of Nanoparticles increased the absorption of incident radiation by more than nine times over that of pure water [7]. Also, the efficiency of an absorption solar collector using nanofluid as the working fluid was found to be up to 10% higher (on an absolute basis) than that of a flat-plate collector.

### 5.3 Space and Defence

Space and defence are considered to be flagship applications which requires highest reliability and functionality of the equipments under severe operating conditions. In such applications, the effect of failure of the equipment can cause a substantial financial loss or can prove danger to human lives. Therefore, it becomes essential for the equipments to have good performance under all working conditions. In such applications, there a restriction of energy, space and weight like in space stations and aircraft. Also, the energy density is very high. Due to this, there stands a need to develop efficient cooling systems which are compact in size. You et al. [8] and Vassalo et al. [9] have reported order of magnitude increases in the critical heat flux in pool boiling with nanofluids compared to the base fluid alone. In future, nanofluids will lead to the development of next generation of cooling devices that would employ nanofluids for ultrahigh-heat-flux electronic systems, presenting the possibility of raising chip power in electronic components or simplifying cooling requirements for space applications. A number of military devices and systems require high-heat flux cooling to the level of tens of MW/m2. At this level, the cooling of military devices and system is vital for the reliable operation. Nanofluids with high critical heat fluxes have the potential to provide the required cooling in such applications as well as in other military systems, including military vehicles, submarines, and high-power laser diodes.

### 5.4 Transportation

In automobile arena, nanofluids have potential application as engine coolant, transmission fluid, automatic transmission fluid, engine oil and greases, brake fluid, gear lubrication. The first application in cooling automatic power transmission system done by Senthilraja et al (2010) show that CuO nanofluids have the lowest temperature distribution and accordingly the best heat transfer performance.

#### 5.4.1 Nanofluid as a Coolant

The cooling rates of automotive and heavy-duty engines can be increased along with increase in efficiency and lowering the weight and increasing of the simplicity of thermal management systems can be done with the employment of nanofluids like CuO as a working fluid. The improved cooling rates for automotive and truck engines can be used to remove more heat from higher horsepower engines with the same size of cooling system. Hence, for the same cooling effect to be produced, a short size of cooling system is required than the normal or the same size of cooling system as of conventional, using nanofluids provides greater cooling effect. Alternatively, it is beneficial to design more compact cooling system with smaller and lighter radiators. It is, in turn, beneficial the high performance and high fuel economy of car and truck.

The researchers of Argonne National Laboratory have assessed the applications of nanofluids for transportation [10]. The use of high-thermal conductive nanofluids in radiators can lead to a reduction in the frontal area of the radiator up to 10%. The fuel saving is up to 5% due to the reduction in aerodynamic drag. It opens the door for new aerodynamic automotive designs that reduce emissions by lowering drag. The application of nanofluids also contributed to a reduction of friction and wear, reducing parasitic losses, operation of components such as pumps and compressors, and subsequently leading to more than 6% fuel savings. In fact, nanofluids not only enhance the efficiency and economic performance of car engine, but also will greatly influence the structure design of automotives. For example, the engine radiator cooled by a nanofluid will be smaller and lighter. It can be placed elsewhere in the vehicle, allowing for the redesign of a far more aerodynamic chassis. By reducing the size and changing the location of the radiator, a reduction in weight and wind resistance could enable greater fuel efficiency and subsequently lower exhaust.

#### 5.4.2 Nanofluid Vehicular Brake Fluids

A vehicle's kinetic energy is dispersed through the heat produced during the process of braking and this is transmitted throughout the brake fluid in the hydraulic braking system [11], and now, there is a higher demand for the properties of brake oils. Copper-oxide and aluminium-oxide based brake nanofluids were manufactured using the arc-submerged nanoparticle synthesis system and the plasma charging arc system, respectively [12, 13]. The two kinds of nanofluids both have enhanced properties such as a higher boiling point, higher viscosity, and a higher conductivity than that of traditional brake fluid. By yielding a higher boiling point, conductivity, and viscosity, the nanofluid brake oil will reduce the occurrence of vapour-lock and offer increased safety while driving.

### 5.5 Biomedical Applications

Nanofluids can have some of the most interesting and innovative application in the biomedical field. Using Nano drug delivery system increases the residence time of drug by a controlled release of drug over a long period of time. In case of cancer therapy, radiation can be administered to the cancer patients using iron based Nanoparticles. Nanofluids with magnetic properties can be used as biomarkers and can help in the targeted delivery of anticancer drugs without causing damage to the healthy cells in the vicinity. Magnetic Nanoparticles stick to tumour cells easily and not to the healthy cells, this helps in the selective targeting of tumour cells.

## VI. CONCLUSION AND FUTURE SCOPE

Nanofluids have a great potential to replace the conventional working fluids in different thermal management and heat transfer applications. Due to distinctive features of nanofluids, they prove promising alternative in many future applications. This paper presents an overview of the recent developments in the study of nanofluids, the preparation methods, benefits and its utilization in various sectors. Apart from the exciting properties and applications of nanofluids, they face many challenges regarding the agglomeration and stability of nanofluids on a large scale. Also, increase in viscosity by the use of nanofluids is an important drawback which increases the pumping power. Once, a complete theoretical and experimental study is completed on nanofluids, the stability and large scale production problems can be overcomed. Nanofluids are potential candidate not only to heat transfer applications but also in biomedical applications and in future, they may be applied to most of the heat transfer systems allowing increase in the efficiency, reduction in energy consumption and thus it will help to maintain a cleaner and healthier environment.

## REFERENCES

[1] Sulabha K. Kulkarni, NANOTECHNOLOGY – Principles and Practices (Second Edition) (Daryaganj New Delhi: Capital Publishing Company 2011)

[2] J. A. Eastman, S. U. S. Choi, S. Li, W. Yu, and L. J. Thompson, "Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles," Applied Physics Letters, vol. 78, no. 6, pp. 718–720, 2001.

[3] D Zhu, X Li, N Wang, X Wang, J. Gao, H. Li, Curr Appl Phys, 9 (2009), 131

[4] X J Wang, D S Zhu, S Yang, Chem Phys Lett, 470 (2009), 107

[5] Choi, U. S., 1995, "Enhancing Themal Conductivity of Fluids with Nanoparticles, "Developments and Applications of Non-Newtonian Flows, eds. D. A. Siginer and H. P. Wang, The American Society of Mechanical Engineers, New York, FED-VO1. 23 VM.D-VO1.66, pp. 99-105.

[6] T. P. Otanicar, P. E. Phelan, R. S. Prasher, G. Rosengarten, and R. A. Taylor, "Nanofluid-based direct absorption solar collector," Journal of Renewable and Sustainable Energy, vol. 2, no. 3, Article ID 033102, 13 pages, 2010.

[7] H. Tyagi, P. Phelan, and R. Prasher, "Predicted efficiency of a low-temperature Nanofluid-based direct absorption solar collector," Journal of Solar Energy Engineering, vol. 131, no. 4, pp. 0410041–0410047, 2009.

[8] S. M. You, J. H. Kim, and K. H. Kim, "Effect of nanoparticles on critical heat flux of water in pool boiling heat transfer,"Applied Physics Letters, vol. 83, no. 16, pp. 3374–3376, 2003.

[9] P. Vassallo, R. Kumar, and S. D'Amico, "Pool boiling heat transfer experiments in silica-water nano-fluids," International Journal of Heat and Mass Transfer, vol. 47, no. 2, pp. 407–411, 2004.

[10] D. Singh, J. Toutbort, G. Chen et al., "Heavy vehicle systems optimization merit review and peer evaluation," Annual Report, Argonne National Laboratory, 2006.

[11] I. Popa, G. Gillies, G. Papastavrou, andM. Borkovec, "Attractive and repulsive electrostatic forces between positively charged latex particles in the presence of anionic linear polyelectrolytes," Journal of Physical Chemistry B, vol. 114, no. 9, pp. 3170–3177, 2010.

[12] M. J. Kao, C. H. Lo, T. T. Tsung, Y. Y.Wu, C. S. Jwo, and H.M. Lin, "Copper-oxide brake nanofluid manufactured using arcsubmerged nanoparticle synthesis system," Journal of Alloys and Compounds, vol. 434-435, pp. 672–674, 2007.

[13] M. J. Kao, H. Chang, Y. Y. Wu, T. T. Tsung, and H. M. Lin, "Producing Aluminum-oxide brake nanofluids derived using plasma charging system," Journal of the Chinese Society of Mechanical Engineers, vol. 28, p. 123, 2007.