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A SURVEY ON THERMO PHYSICAL PROPERTIES OF NANOFLUIDS

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ABSTRACT

Nanofluids are a new generation of heat transfer fluids is an emerging area of research. Because of their superior thermophysical properties, researchers have been attracted to their application in various thermal devices. Researchers have indicated that the positive impact of the application of nanofluids on thermal performance is due to their improved thermal properties such as thermal conductivity, specific heat, viscosity, etc. The application of nanofluids in a variety of thermal devices has been shown to have a positive impact on thermal performance. This paper summarizes recent advances in the study of nanofluids, such as preparation methods, synthesis of the thermo-physical properties of nanofluids, and factors that influence its thermophysical properties were discussed. All these parameters have distinct or combined effects on the thermophysical properties of nanofluids.

KEYWORDS: Nanofluid, Thermal conductivity, Thermal performance, Specific heat, Viscosity.

INTRODUCTION

Conventional fluids such as water, oil and ethylene/propylene glycol are used in many engineering sectors such as power generation, electronic applications, air conditioning, chemical production, heating and cooling processes, microelectronics, etc. These liquids have mediocre thermal properties relative to solids. Therefore, new technologies to improve the thermo-physical properties of conventional fluids have been the subject of significant research[1]. Recent developments in nanotechnology have led to the development of a new class of liquids called nanofluids, which was first employed by Choi[2] to describe liquid suspensions containing nano-sized particles (nanoparticles). Improved heat conduction is a major advantage of nanofluids, as the large surface area of nanoparticles allows for better heat transfer. Some types of materials have been used by researchers to synthesize nanoparticles including oxide ceramics, metal carbides, nitrides, metals (Al, Cu, Au…), non-metals, single and multiple wall carbon nanotubes (MWCNT), and nanoparticles functionalized to form nanofluids. An optimal process of synthesis is necessary to produce stable suspensions of nanoparticles in base fluids. Researchers have usually used a one-step and two-step approach to make nanofluids. The one-step method involves simultaneous manufacturing and direct dispersion of the particles in the base fluid. Nikkam et al[3] manufactured copper nanoparticles in diethylene glycol as a base liquid in a single step, resulting in highly stable nanofluids. The two-step process is the other most widely used technique for preparing nanofluids. This method consists of forming nanoparticles in the form of fine dry particles; chemical/physical process. Then, in the second step of manufacturing, using various techniques such as ultrasonic agitation, high friction mixing, these nanoscale powders are dispersed in a base fluid. The two-step method has been used by many researchers to prepare CNTs [4]. This study provides a complete review of thermophysical properties, i.e. thermal conductivity, viscosity, specific heat based on different base fluids (water, ethylene glycol, motor oil...) and nanoparticles. The concentration of nanoparticles, the shape, type and size of nanomaterials are some of the main factors that greatly affect thermophysical properties.

NANOFLUIDS

Nanofluids consist of solid-liquid mixtures or suspended particles produced by the dispersion of small carbon,metal, oxide and ceramic in base fluids. The size of nanoparticles (typically less than 100 nm) in liquid mixtures gives them the ability to react with liquids at the molecular level and to transmit heat better than current nanoparticle-dependent heat transfer fluids. The heat transfer of nanofluids is enhanced by the combination of convection and conduction, as well as additional energy transfer through particle dynamics and particle interactions. Nanofluids have been found to have improved thermo-physical properties, such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficients compared to those of base

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fluids such as oil or water. The particle size, which is used to adjust the thermal properties of nanofluids and stability, is a major parameter of the nanofluids of suspended nanoparticles. Due to their higher thermal conductivity, nanofluids are used as heat transfer fluids in many applications.

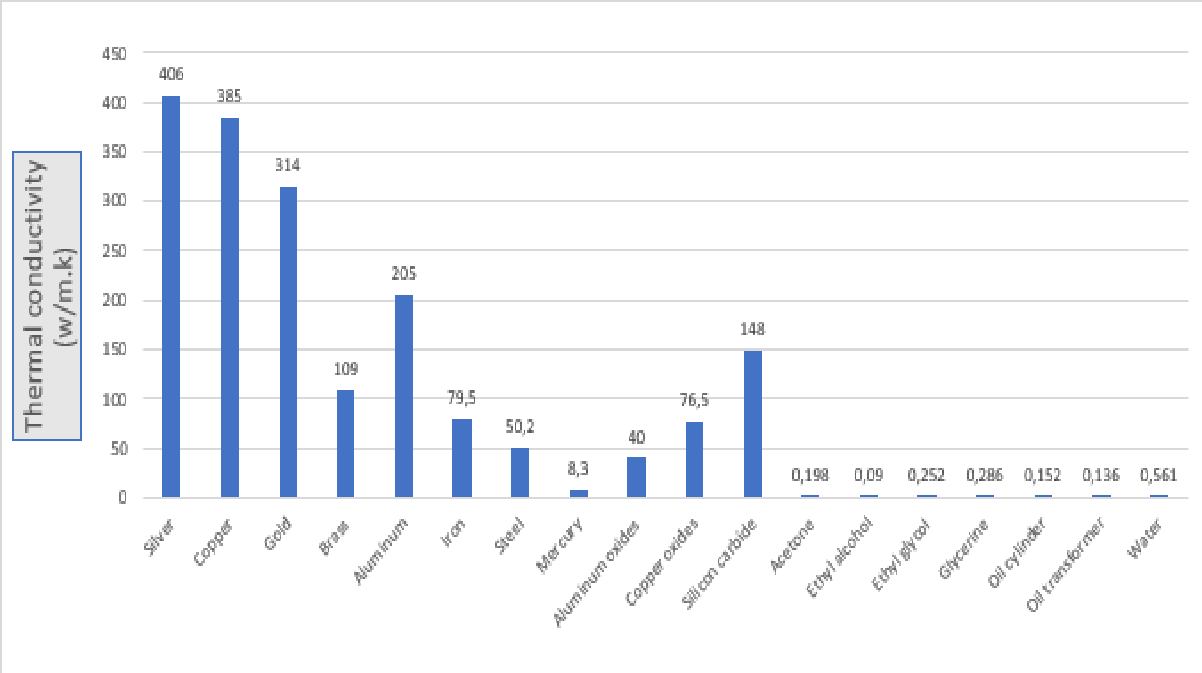

Fig.1. Thermal conductivity of various solids and liquids[5],[6].

Preparation of Nanofluids

Nanofluids are characterized by improved thermophysical properties such as thermal conductivity, specific heat, convective heat transfer coefficient and viscosity, which differ from those of base liquids such as water or oil. They have shown an extraordinary potential for application in many areas. Nanofluids are combined suspensions of carbon, metal, oxide and ceramic nanoparticles with base fluids such as water, ethylene, motor oil, glycol, acetone, etc. The nanoparticles are synthesized by two techniques known as the one-step method and the two-step method[7]. Preparation of the nanofluid is an important step in nanofluid research in order to obtain a stable nanofluid that would not agglomerate at high temperatures or after a given period of time. In all nano powder technologies, the agglomeration of nanoparticles is the major problem for both methods to produce good nanoparticle suspensions. A significant improvement in the heat transfer characteristics of nanofluids depends on the synthesis and suspension of non-agglomerated or uniformly dispersed nanoparticles. The one-step method consists of preparing and mixing nanoparticles together with the base fluid at the same time, where the agglomeration of the nanoparticles is reduced by avoiding the drying, storage and transport process that led to the stable suspension of the nanoparticles in the base fluid. It is mainly suitable for liquids with low vapor pressure. The two-step method is considered to be the most cost-effective for large-scale production. In this method, the nanoparticles are first prepared, or commercially available Nanoparticles are also used and dispersed in the base fluid with ultrasonic stirrers, high shear mixing homogenizers, ball mills, etc. as the second processing step is mainly suitable for oxide nanoparticles and has proven to be instable with metallic nanoparticles.

Single Step Preparation Process

This technique includes the synthesis and dispersion of nanoparticles in a single movement, as shown in Figure 2. This means that nanophase powders could be condensed directly from a vapor phase into a flowing fluid under low pressure [8]. Due to the complexity of separating nanoparticles from liquids into dry powders, this technique has not been promoted. Although nanofluids produced by a one-step method have shown excellent properties.

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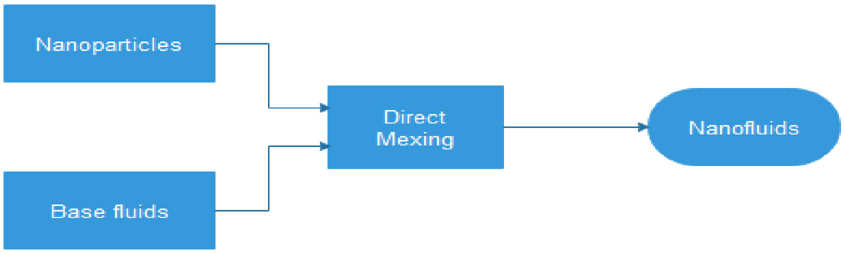

Fig.2. Schematic diagram of one step process for preparing nanofluids.

Two Step Preparation Process

The two-step technique is the most widely used for the preparation of nanofluids. The nanoparticles, nanofibers, nanotubes and other nanomaterials used in the two-step method are first produced as a dry powder by chemical or physical methods. Then, the nanomaterials (nanometric powder), will be dispersed in a base fluid by means of ultrasonic agitation, magnetic force agitation, etc. Due to their large surface area and surface activity, nanoparticles have a strong tendency to clump together. Due to their large surface area and surface activity, nanoparticles have a strong tendency to aggregate. The use of surfactants is an important technique to improve the stability of nanoparticles. However, its use at high temperatures is also a major concern.[9] as shown in Figure 3.

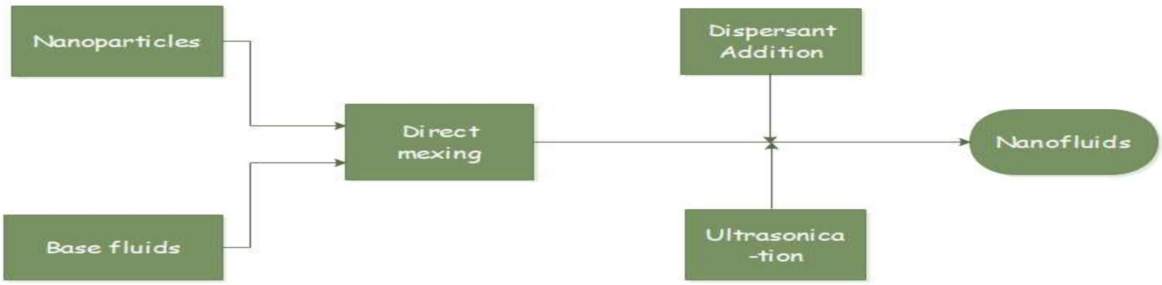

Fig.3. Schematic diagram of two step preparation method of nanofluids.

THERMAL PHYSICAL PROPERTIES

The integration of nanoparticles into the base fluid changes the thermophysical properties such as thermal conductivity, viscosity and specific heat that affect convective heat transfer. Different nanomaterials change their parameters to varying degrees. Nanoparticle concentration, shape and size of nanomaterials are some of the main factors that greatly affect thermophysical properties. This section presents an overview of the thermophysical properties of different base fluids and nanoparticles.

Thermal Conductivity

Thermal conductivity is the main parameter determining the improvement of heat transfer. Numerous experiments as well as theoretical research have been carried out in this field, the results of which have shown that the addition of nanoparticles improves thermal conductivity [10]. The parameters involved in the determination of thermal conductivity include the level of dispersion of the nanofluids in the working fluid, the volume concentration, the size and shape of the nanoparticles. As the temperature rises, the thermal conductivity increases[11]. The addition of solid nanoparticles to a base fluid alters the Brownian motion mechanism that controls the thermal behavior of nanofluids. Thermal conductivity therefore increases when the nanoparticles are suspended in the base fluid.Table 1 below summarizes the research carried out by various researchers on thermal conductivity.

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Impact Factor 3.802

Table 1. Summary of thermal conductivity augmentation of nanofluids.

Year	Researcher	Nanoparticles	Base fluid	Volume fraction (%)	Particle size(nm)	Enhancement (%)
2009	[12]	Al_2O_3	Water	4	282	17.7
2012	[13]	CuO	Water	7.5	25	32.3
2013	[14]	SiO_2	Water	1.2	10	11
2013	[14]	SiO_2	Water	1.2	60	13
2013	[15]	Al_2O_3	EG–Water	8	36.5	17.89
2013	[16]	ZnO	Water	0.5-5	90-210	3-19.8
2013	[15]	CuO	EG–Water	8	27	24.56
2014	[17]	SiO_2	EG–Water	0.005-0.15	10	23.03
2015	[18]	Al_2O_3	Water	4	40	14.4
2015	[19]	Al_2O_3	EG–Water	2	13	8.4
2016	[20]	ZnO	EG	2.4	50	13
2016	[21]	CuO	Water	2	55–66	24
2016	[22]	SiO_2	Tetra-ethyl ortho silicate	0.15-1.17	10.6,20,38 .6,62	70

Viscosity

The viscosity of nanofluids is another important factor in the application of heat transfer. It has been determined as a function of temperature and concentration. [23]. Most studies have indicated that viscosity will increase with particle size. Based on these results, it reinforces the claim that the viscosity of nanofluids depends on particle size, the type of base fluids and the volume concentration of the nanofluid. Table 2 below summarizes the research conducted by various viscosity researchers.

Table 2. Summary of augmentation in viscosity of nanofluids.

Year	Researcher	Nanopar-ticles	Base fluid	Volume fraction (%)	Particle size(nm)	Characterization Technique/Equipment	Remark
2007	[24]	Al_2O_3	Water	1- 9.4	36 and 47	Piston-type viscometer	dynamic viscosity increases considerably with particle volume fraction but clearly decreases with a temperature increase
2007	[25]	SiO_2	Ethanol	1.4-7	35, 94, and 190	Capillary viscometers	The increase in the viscosity of the nanofluid is governed by a size factor which is a function of the particle diameter.
2009	[26]	Al_2O_3	Water and EG	1, 2, 4, 6	45 and 150	Ubbelohde viscometer	The viscosity value increase with particle concentration
2010	[27]	CuO	EG	0.18	10	Rotational rheometer with a cone and plate geometry	The viscosity increases in line with the average particle size
2013	[16]	ZnO	Water	0.5-5.0	90-210	Ubbelohde viscometer	Viscosity increases with increasing volume concentration up to 69%.
2014	[21]	Ag	Water	0.1–0.3	10 and 80	Cone plate viscometer	A little increase in the effective viscosity
2015	[28]	Al_2O_3 and TiO_2	Water	3–14.3	200, 250, and 300	Viscometers, a capillary and a falling ball	The viscosity of nanofluids is reduced by increasing the temperature
2017	[29]	SiO_2	EG	0.1-3	25	Brookfield Viscometer	The dynamic viscosity increases with the concentration of nanoparticles and decreases with temperature. The dynamic viscosity increases up to 116%.

Specific Heat

The energy conservation capacity of the operating fluid is determined by the specific heat that is a characteristic of the nanofluid. It is the amount of heat required to raise the temperature of a nanofluid by one gram of degree centigrade[30]. Several parameters such as the type, size and volume concentration of nanoparticles and base fluids at various temperatures are responsible for the variation in specific heat. Table 3 below summarizes the research conducted by various specific heat researchers.

Table 3. Variation of specific heat of nanofluids with various parameters.

Year	Researcher	Nanoparticles	Base fluid	Volume fraction (%)	Particle size(nm)	Remark
2007	[31]	SiO_2	Ethylene Glycol/Water	10	20	The specific heat of the nanofluid SiO_2 decreases when the volume concentration of the nanoparticles increases by about 12% less than that of the base fluid.
2008	[32]	Al_2O_3	Water	21.7	45	The specific heat Cp of the nanofluid gradually decreases as the volume fraction of the nanoparticles increases from 0.0% to 21.7%.
2010	[33]	CuO	Ethylene glycol	0.1-0.6	25-50	The specific heat capacity of the nanofluid CuO reduces progressively with increasing volume concentration of nanoparticles.
2012	[34]	ZnO	Ethylene Glycol/Water	1-7	77	The increase in the volume concentration of the nanofluid decreases the specific heat capacity despite the use of different types of base fluids
2014	[35]	Al_2O_3	Water	0 to 1%	50	The specific heat of the nanofluid decreased as the volume concentrations of the nanoparticles increased.
2017	[36]	SiO_2	Water/K_2CO_3/ Li_2CO_3/Na_2CO_3	1	5,20,30,60	Specific heat capacity of ternary carbonates is improved from 78.0 to 116.8 % in the range 500 to 540 °C by adding SiO_2 in the range 5 to 30 nm.
2017	[37]	TiO_2	Eutectic Hydrate Salt (EHS)	0.1, 0.3, and 0.5	21	The loading of 0.3 % of TiO_2 nanoparticles can increase the specific heat up to 83.5%

CONCLUSION

A comprehensive review of nanofluids research for the application of heat transfer was carried. Their preparation is a important steps in experiments on nanofluids, the two-step method is widely used, but the one-step method is particularly advised for the synthesis of metal-based nanofluids. Most of the work presented in this review indicated that the improvement in the heat transfer coefficient due to the inclusion of an optimal concentration of nanoparticles in the base fluid. In addition to the heat transfer application, nanofluids can be used in many applications. This paper shows that nanofluids can be used as a working fluid to increase the efficiency of heat transfer compared to conventional fluids such as water. In addition to thermal conductivity, viscosity should be considered the most essential thermal property of nanofluids as it affects the pumping energy required in potential heat transfer applications. Finlay Specific heat is one of the important properties and plays an important role in the heat transfer rate of nanofluids. It is the amount of heat required to raise the temperature of one gram of nanofluids by one degree centigrade. It's reduced when the volume concentrations of the nanoparticles increased.

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