International Journal of Thermal Technologies
E-ISSN 2277 – 4114
Available at http://inpressco.com/category/ijtt/

Review Article

A Review on the Improvement in Convective Heat Transfer Properties using Magnetic Nanofluids

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Accepted 25 Feb 2016, Available online 25 March 2016, **Vol.6, No.1 (March 2016)**

Abstract

Magnetic nanofluids are the nanofluids, which possesses both magnetic and fluid properties. This review article presents the progress in the field on magnetic nanofluids, its synthesis, change in thermophysical properties and heat transfer characteristics. This review also presents the application of nanofluids in different areas. The aim of this review is to provide comprehensive summary of the work carried out in this field which will help the researchers to carry out further research.

Keyword: *Heat transfer, magnetic nanoparticles, two step method, thermophysical properties*

1. Introduction

Increasing world's population has led to the increasing demands of the various energy sources. So, everyone is looking for new equipment and devices with enhanced thermal performance. Technological developments such as microelectronic devices operating at high speeds, higher-power engines, and brighter optical devices are driving increased thermal loads, requiring advances in cooling. Hence cooling of the above-mentioned devices is one of the most important challenges we are facing now a days. The traditional method for increasing heat dissipation is to increase the area available for exchanging heat. Other method is to use a better heat conductive fluid (Sidik,*et al,*2014). Keeping it in view, Choi *et al* in 1995 developed a special type of fluids in the Argonne National Laboratory, U.S.A. These fluids were named as nanofluids. A nanofluid is a fluid produced by the dispersion of metallic or nonmetallic nanoparticles or Nanofiber with a typical size of less than 100 nm in a liquid. Water, organic liquids (e.g. ethylene, tri-ethylene-glycols, refrigerants, etc.), oils and lubricants, bio-fluids, polymeric solutions and other common liquids may be used as the base fluids. Whereas, the nanoparticles material are chemically stable metals, their oxides, oxide ceramics, carbides of metals, nitrides and various allotropic forms of carbon (e.g. gold, copper, alumina, silica, zirconia, titania, Al_2O_3, CuO, SiC, AIN, SiN , diamond, graphite, carbon nanotubes, fullerene) and functionalized nanoparticles (Sarkar,2011). Nanofluids have attracted huge interest lately because of their greatly enhanced thermal properties. For instance, experiments showed an increase for thermal conductivity by dispersion of a less than 1% volume fraction of Cu nanoparticles or carbon nanotubes in ethylene glycol or oil by 40% and 150%, respectively (Keblinski, *et al,*2005).

Generally nanofluids are prepared by suspending one type of nanoparticles(Cu, Zn ,Mg etc) in a base fluid(ethylene, tri- ethylene-glycols etc).But as per the needs of industry, the need of a hybrid nanofluids came in to existence due to massive heat dissipation and complicated machinery. Hybrid nanofluids are very new kind of nanofluids, which can be prepared by suspending (i) different types (two or more than two) of nanoparticles in base fluid, and (ii) hybrid (composite) nanoparticles in base fluid. A hybrid material is a substance, which combines physical and chemical properties of different materials simultaneously and provides these properties in a homogeneous phase (Sarkar,*et al,*2011). Synthetic hybrid nano materials exhibit remarkable physicochemical properties that do not exist in the individual components.

2. Magnetic Nanofluids

Mixing of various nano sized particles of different materials such as metals and metal oxides in a base or carrier fluid like water was investigated by various researchers over a long time due to their practical applications in cooling and heat transfer (Keblinski, *et al*,2008), (Keblinski, 2009), (Godson, *et al*,2010),(Özerinç,*et al*,2010)),(Wen, *et al*,2009). Magnetic nanofluids also called as ferrofluids, consist of colloidal mixtures of super paramagnetic nanoparticles suspended in a nonmagnetic carrier

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fluid, constitute a special class of nanofluids exhibiting both magnetic and fluid properties (Liu, *et al,*2009), (Odenbach,2004), (Ganguly and Puri,2007). In these suspensions, also known as smart or functional fluids all features such as fluid flow, particles movement and heat transfer process can be controlled by applying magnetic fields. However, in these types of fluids, there are chances of aggregation of the particles due to Vander wall interaction and magnetic interaction between the particles. In order to overcome this situation, the nanoparticles are coated by a surfactant layer. A surfactant is a compound that lowers the surface tension (or inter facial tension) between two liquids or between a liquid and a solid. Surfactants may act as detergents, emulsifying agents and dispersants e.g. oleic acid (Wang, *et al,*2010), (Zhang, *et al,*2006),(Li, *et al,*2010), tetramethyl ammonium hydroxide, (Abareshi, *et al,*2010), etc. The synthesis of MNFs is discussed in next section.

3. Synthesis of Magnetic Nano Fluids

In general, the preparation of a MNF is done by dispersing of nano-sized super- paramagnetic particles in to a non magnetic carrier fluid such as water, ethylene glycol, hydrocarbon oil, etc (Vékás, *et al*,2007). Actually, the synthesis of magnetic fluids consists of two steps:(a) The preparation of the nano sized magnetic particles, (b) The subsequent stabilization/dispersion of the nanoparticles in various non-polar or polar carrier .In the first step, the nano sized magnetic particles can be produced by various processes such as ball milling (Yin, *et al,*2005) , sono chemical (Lai, *et al,*2004) , sol–gel (Lu, *et al*,2002) micro emulsion(Kale, *et al,*2004) , co-precipitation (Teja and Koh,2009) , and thermal decomposition(Oh, *et al*,2011). In the second step the magnetic nanoparticles can be coated by some methods such as co-precipitation (Teja and Koh,2009) , core–shell (Rana, *et al,*2007),(Tamer, *et al,*2010) , micro-emulsion (Mathew and Juang,2007),(Rafferty, *et al,*2008) and then levitated in the carrier liquid. For example, the Magnetic Nanofluids which are based upon the magnetite Fe_3O_4 uses mineral oils or organic solvents are prepared by technique of co precipitation from aqueous salt solutions Fe (II) and Fe (III) in alkaline medium. Afterwards they are being suspended in the carrier liquid (Lopez, *et al,*2010),(Racuciu, *et al,*2005),(Hong, *et al,*2006). The resultant product magnetite so obtained is then stabilized by a surfactant. Generally oleic acid is used as surfactant, because it forms the waterproofing shell around the magnetite nanoparticles and hence acts as a seal. Mostly because of their chemical stability, metal oxides like as Fe_2O_3 and other ferrites having formula MFe_2O_4 (with M¼ Co, Ni, Zn etc.) are commonly used.

4. Thermal conductivity

The flow and heat transfer characteristics of a fluid are mainly affected by its properties such as thermal conductivity and viscosity. The Experimental investigations on thermal conductivity of MNF are mostly conducted at room temperature with the common methods for conventional (nonmagnetic) nanofluids (Paul, *et al*,2010). The transient hot wire (Abreshi, *et al,*2010), (Li, *et al,*2005), (Gutierrez, *et al,*2008), (Djurek, *et al,*2007) and thermal constants analyzer techniques (Nkurikiyimfura, *et al*,2011), (Phlip, *et al*,2007), (Phlip, , *et al*,2008) are the mostly used techniques for MNF thermal conductivity measurement. Mainly the thermal conductivity and rheological properties of a MNF is studied under the following two fields:

4.1 In the absence of a magnetic field

According to the experimental investigations done by (Paul, *et al,*2010) , on the thermal conductivity of MNF in the absence of magnetic fields it showed that the thermal conductivity enhancement is mainly affected by different parameters, i.e., volume fraction of magnetic nanoparticles, particle size/particle size distribution, chemical composition of magnetic nanoparticles, temperature, particle coating layer, etc. (Li, *et al,*2005) also investigated the effects of different parameters such as particle volume fraction, surfactants and magnetic field on the transport properties of a water based Fe magnetic nanofluid. Their results concluded that thermal conductivity of MNF increases with the increase of particle volume fraction both with and without applied magnetic fields. They further suggested that the viscosity of MNF increased with the particle volume fraction of the suspended magnetic nanoparticles and the surfactants. The effects of particle volume fraction on the thermal conductivity on the kerosene based Fe_3O_4 magnetic nanofluid prepared via a phase-transfer method was investigated by (Yu, *et al,*2010) . The values of thermal conductivity ratios obtained value was up to 34.0% at1vol%. To further investigate the influence of temperature on thermal conductivity enhancement, the measurements were performed in the temperature range from 10°C to 60°C. He further suggested that the absolute thermal conductivity of the MNF increased with increasing temperature, while the thermal conductivity ratio was almost constant and the thermal conductivities of the MNF tracked those of the carrier fluid. The thermal conductivity enhancement of an ethylene glycol Fe based magnetic nanofluid was investigated by Hong *et al*. (Hong, *et al,*2005) .

According to them, the thermal conductivity ratio increased nonlinearly with the increase of volume fraction. Furthermore, (Hong, *et al,*2006) , with different volume fractions of Fe nano particles in ethylene glycol again investigated the thermal conductivity of nanofluids. Their results confirmed the intensification of thermal conductivity with the particle volume fraction. Their results also showed that among the copper and iron nanoparticles dispersed in ethylene glycol, iron nano particles showed a higher thermal conductivity enhancement than that of copper-based nanofluid.

(Sunder, *et al,*2013) also investigated the effective thermal conductivity and viscosity of Fe_3O_4/water MNF experimentally. They conducted the experiments in the concentration range of 0 to 2% and the temperature range of 20°C to 60°C. They concluded that the thermal conductivity enhances with increase in particle concentration and temperature.

4.2 In presence of Magnetic Field

To the best of author's knowledge, only a few researchers have undergone research on studying the thermal conductivity of magnetic nanofluids so far. In the presence of magnetic field, the orientation and the intensity of the applied magnetic field affects the thermal conductivity of Magnetic Nano Fluid (Odenbach, *et al,*2008).In this method, the magnetic field in the process is produced either by electro magnets or permanent magnets. Several researchers investigated the thermal conductivity in presence of a magnetic field. Generally, when the solid particles are being suspended in the magnetic fluid they form some chainlike aggregated structures under the externally applied magnetic field. The characteristics of flow and energy transport inside the magnetic fluids is determined by such particles (Li,*et al,*2005).Also the energy transport process of nanoparticles inside the magnetic nanofluid is affected by the orientation of external magnetic field. Hence, it supports to use the magnetic nanofluid in various thermal applications. Various researchers gave their views in respect to thermal conductivity of magnetic nanofluids: (Li, , *et al,*2005) stressed on the influence of magnetic field strength and direction on the transport properties of MNF. They reported that use of an external magnetic field had remarkable effects on thermal conductivity of the MNF.

(Philip , *et al,*2007) (Philip , *et al,*2008) also studied thermal conductivity of magnetite-based nanofluid. Their results showed a dramatic enhancement of the thermal conductivity up to K/Kf¼4.0 (300%) in magnetite-based nanofluid, under the influence of an applied magnetic field along the direction of heat flow. They reported thermal conductivity enhancement was within the predicted value for parallel mode conduction.

(Wright,*et al,*2007) integrated magnetically sensitive metal or metal oxides in a fluid with carbon-nanotubes in order to increase the thermal conductivity of the fluid. They concluded that the Magnetic Nano Fluid with Ni coated single wall nanotubes was significantly enhanced in the presence of magnetic field. The thermal conductivity enhancement was observed due to the influence of magnetic field on the microstructure of the fluid.

(Wensel, *et al,*2008) also used metal oxides nanoparticles (Fe_3O_4 and MgO) and carbon nanotubes in the presence of magnetic field to observe the thermal conductivity of nanofluids. Their observations showed that by using low particle weight fraction of 0.02wt%, thermal conductivity could be increased by up to 10%.They further concluded that nano fluid can also be used as coolant applications since their viscosity was similar to that of water.

(Nkurikiyimfura, *et al,*2011) investigated the thermal conductivity ratio of magnetic nanofluid as a function of magnetic field with respect to the effects of particle size and particle volume fraction. They reported that the particle size has a dominant effect on the thermal conductivity ratio in applied magnetic fields. According to them, higher thermal conductivity ratio, particularly at a higher particle volume fraction of 5% can be attained by smaller particle size. Thermal conductivity is dependent on fineness of particles. The thermal conductivity ratio was found to be 2.81 for the nanofluids with the smaller particles and 2.51 for the nanofluids with the larger particles at a particle volume fraction of 5 % in presence of an external magnetic field.

5. Flow and heat transfer characteristics

5.1Natural Convection

In the phenomenon of natural convection by magnetic nanofluids, a body force is induced by the magnetic field. This body force is applied on the fluid and hence the fluidic motion is being controlled. The thermo-gravitation phenomenon means natural movement in the fluid due to buoyancy force, in which fluid motion is caused by the existence of density difference as a result of temperature gradient. Along with such phenomenon, magnetic fields can be applied in order to exert a force on MNFs and hence, control the fluid motion. In last few years, researchers have been continuously working on the area of natural convection of MNFs. They used uniform magnetic field. Their results concluded the possibility of enhancement and controlling the heat transfer phenomenon by applying uniform magnetic fields (Bahiraei, *et al,*2015). The heat transfer characteristics of magnetic fluid of Mg–Zn ferrite nanoparticles suspend in a kerosene solution within a cubic container with a heat generating square cylinder stick inside and under a uniform magnetic studied by (Yamaguchi, *et al,*2010).They investigated the heat transfer enhancement on applying the magnetic field.

(Jin, *et al,*2013) studied the laminar convection of the temperature sensitive magnetic fluids in a porous cavity by using uniform magnetic field. They developed a lattice Boltzmann method for this. Their experimental set up comprises of wall type structure. The upper and lower walls of the cavity were respectively maintained at higher and lower temperatures while the side walls were adiabatic. They results showed that magnetic force was the key factor which enhanced the average Nusselt number. They further remarked that magnetic fluid and porous medium can be beneficiary to design an energy storage device.

Lattice Boltzmann method was also used by the (Roussellet, *et al,*2011) to study the Natural convection of a temperature-sensitive MNF in a porous media. They used a cubic enclosure under the effect of uniform magnetic fields with different magnitudes. They researched that when magnetic field was increased, heat transfer enhancement was obtained.

Natural convection of the water based Mn–Zn ferrite MNF in a square cavity under non-uniform magnetic field was investigated by (Bahiraei, *et al,*2014) .They used the two-phase Euler–Lagrange method for finding the natural convection. Their results showed that convection of the nano fluid inside the cavity and heat transfer rate can be improved by applying the magnetic field.

5.2 Mixed and forced convection

Magnetic nanofluids and magnetic fields can also be used for fluid flow control and to improve the heat transfer in case of mixed and forced convection also. The convective heat transfer is due to both changes in the thermo-physical properties of the MNFs and motion and migration of magnetic nanoparticles in that section. Researchers are working, studying the hydrothermal characteristics of MNFs. In 2009, (Li, *et al,*2009) experimentally investigated the convective heat transfer of Fe_3O_4–water nanofluid flow over a fine wire under the influence of both uniform and non-uniform magnetic fields. They predicted that Magnetic Nano fluid shows higher heat transfer enhancement as compared with water when there is no magnetic field. Moreover, presence of external magnetic field adversely affects the convective heat transfer performance of the magnetic fluid and heat transfer process. When the orientation of the magnetic field gradient is along with the main flow of magnetic fluid, the rate of heat transfer is remarkably enhanced. However, heat transfer rate is lowered when magnetic field gradient is opposite to the main stream. (Ghofrani, *et al,*2013) experimentally investigated the study of laminar forced convection heat transfer of a ferrofluids flowing through a circular tube .Their study includes the presence of an alternating magnetic field. They studied the effects of magnetic field, volume concentration and Reynolds number on the convective heat transfer. They investigated that on increasing the alternating magnetic field frequency and the volume fraction better heat transfer enhancement is obtained. Also they pointed out that at low Reynolds number; the effect of the magnetic field is higher. Their studies reveal a maximum of 27.6% enhancement in the convection heat transfer.

(Lajvardi, *et al,*2010) experimentally studied the convective heat transfer of water – Fe_3O_4 ferrofluid flowing through a tube in laminar regime in the presence of magnetic field perpendicular to the flow direction. They performed their experiments on different ferrofluids concentration and at different magnetic positions in magnetic fields. They concluded that by improving the thermo physical properties of the ferrofluids, heat transfer can be attributed in the presence of magnetic field.

The experimental evaluation of the convective heat transfer coefficient and friction factor of magnetic Fe_3O_4 MNF flowing in a circular tube in the range of $3000 \leq Re \leq 22000$ and volume concentration $0 < u < 0.6\%$. was done by (Sunder,2012a) .Accordingly, the rate of heat transfer in case of using nanofluid was higher as compared to that of water and increased with volume concentration. They developed correlation on their experimental data for determining the friction factor of water and nusselt number. They suggested enhancement in heat transfer coefficient by 30.96% at 0.6% volume concentration when compared with water. They also performed their experiments in absence of an external magnetic field and by inserting twisted tape. Their results indicated that both heat transfer and friction coefficient increase on utilization of twisted tapes (Sunder,2012b).

6. Applications of Magnetic Nanofluids

- **Biomedical applications:** Magnetic nanofluids play a vital role in new techniques for cancer treatment. These nanofluids are being used in delivering the radiation or drugs to various parts of the body. At AC magnetic fields, these nanofluids absorb more power as compared to microparticles. Because of their adhesiveness to tumor cells, magnetic nanoparticles are more predominantly used in treatment of cancer . Magnetic nanofluids surfacted with lauric acid are used for magnetic drug testing and bio molecules immobilization (Timko, *et al,*2004).
- **Detection of Ammonia:** In several parts of the earth, ammonia is predominantly found in water. It is very dangerous for living beings health and environment if exceeds beyond a certain value (Mader and Wolfbeis,2010). Hence, its amount must be regularly checked to avoid contamination of water. Various methods used for detection of ammonia include potentiometer electrodes and infra red gas analyzers detectors based on semiconductor oxide films such as SnO_2 and MoO_3. Magnetic nanoparticle nano emulsion produces change in visual color in presence of ammonia. So, by using these fluids ammonia concentration can be checked (Park and Parj,1999),(Shen and Liou,2008) .
- **Rotating seals:** One of the predominant applications of magnetic nanofluids is the leakage free rotating seal (Raj,1996) . In Vacuum deposition systems, high power electric switches and liquefied gas pumps magnetic nanofluids finds great use as they provides leakage - free rotating seals. Use of magnetic seals is in computer hard disk drives, high vacuum systems, chemical plants and oil refineries (Kim, *et al,*1999),(Liu, *et al,*2005), (Liu, *et al,*2002) . Large diametric, high speed magnetic fluid seals are used in the manufacturing

of optical component of high precision. These MFS provides good stability in vacuum, highly non uniform magnetic field as well as in intense magnetic fields.

- **Display Devices:** Magnetic nanofluids are also being used in display devices such as CD, DVD players. These players have a laser head in their display units which comprises of drop of ferrofluids in them. These droplets of ferrofluids acts as a damper (Raj,*et al,*1995)**Error! Reference source not found.**.
- **Heat transfer**: Magnetic nanofluids are particularly used in heat transfer in various industrial and commercial applications. Magnetic nanofluids treated with stabilized water are used in heat transfer in space as well as terrestrial applications (Stoian, *et al*,2003). In recent times, it was found that magnetic nanofluids with appropriate composition show signs of huge thermal conductivity enhancement. This is possible due to percolating paths of nanoparticles. This application led to what is called smart cooling devices.
- **Cleaning of crude oil:** According to S Khushrushahi, magnetic nanofluids can also be used for environmental and energy applications such as cleaning and recovering oil from oil wells. It can be achieved by using an oleo-philic (oil-loving) surfactant layer of magnetic nanoparticles which absorbs all the oil and repels all other particles.
- Several other applications include the delivery of genes, in magnetic resonance imaging as a contrast agent, in genetic research in the area of medical diagnosis and also in the therapy of cancer in human and veterinary medicines (Ozakaya, *et al,*2009),(Neuberger, *et al,*2005),(Maity, *et al,*2007). Besides theses applications, some technical applications of magnetic nanofluids are in optical actuators of high sensitivity, in electrical motor bearings, as dampers in automobiles and other vehicles, in recording devices, in recording industries and fluidic pumps and magneto-resistive devices (Gubin,2009,(Park and Park,1999),(Paer and Seo,2004),(Nethe, *et al,*2002),(Choi, *et al,*1999),(Ahn, *et al,*2003).

Conclusion

This review article presents the work done by various researchers using magnetic nanoparticles with base fluid. The magnetic nanoparticles enhances the magnetic and fluid properties of the nanofluids. Further the magnetic nanoparticles enhances the heat transfer. It finds many applications. The field of using magnetic nanoparticles is new and further research on synthesis of magnetic particles possessing enhanced properties can be explored.

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