Comparative Study of Magnetorheological Fluid's and Nanofluid's Thermal Behaviour

Saurabh More, Student, MITCOE Pune, moresaurabh98@gmail.com

Jui Kulkarni, Student, MITCOE Pune, kulkarni.jui9498@gmail.com

Nupur Kulkarni, Student, MITCOE Pune, nupur.k17@gmail.com

Vilas Kanthale, Assistant Professor, MITCOE Pune, vilas.kanthale@mitcoe.edu.in

Abstract Magnetorheological fluids and nanofluids provide huge scope in increasing efficiency of heat transfer systems. The interest in use of Magnetorheological fluids and nanofluids is due to possibility of controlling its heat transfer process and flow through external magnetic field. This review highlights various parameters like particle volume fraction, shape and size of particles, materials of particles and base fluid, and magnetic field which affects thermal conductivity of these fluids.

Keywords-Base fluid, Magnetorheological fluid, Magnetic field, Nanofluids, Particle volume fraction, Particle Size, Thermal conductivity

I. INTRODUCTION

Latest technological advancements in field of thermal systems and electronics have increased the demand for heat transfer systems with higher efficiencies. Various studies have been carried out to increase heat transfer rate using both active and passive methods. Active methods like mechanical agitating, rotating and vibration requires application of external energy. Whereas passive ones consists of methods based on fluid thermal properties and surface geometry. Application of nanofluids is one of such passive method. Nanofluids are fluids in which nanoparticles are added to a base fluid. This review concentrates on study done related to effect of magnetic field on thermal conductivity in nanofluids and MR fluid.

Magnetorheological fluid (MR fluid) is a smart fluid made of magnetic particles that have the ability to rapidly change their flow characteristics in the presence of an applied magnetic field. MR fluid particles are on micrometer scale and are too dense for Brownian motion to keep them suspended. Nanofluids on the other hand are two-phase media that consist of liquid and solid nanometer-scale particles. Studies have shown that even low concentration of nanoparticles can significantly change its thermal behavior.

Aim of this paper is to put forth a comparative study between MR fluids and nanofluids for factors affecting heat transfer rate in both fluids.

II. FACTORS AFFECTING THERMAL CONDUCTIVITY

A. Particle Volume Fraction

Numerous studies have been conducted on solid particles by varying the particle volume fraction to enhance the performance. Thermal conductivity in MR fluids increases in absence of magnetic field as particle volume fraction increases. In a study thermal conductivity ratios were recorded as approximately 1.4 and 2.0 for 10 vol% and 20 vol% respectively for iron based MR fluid. The measured thermal conductivities are normalized by the oil/ grease base fluid conductivity of 0.1242 W/mK [1].

Moreover thermal conductivity of MR fluids in presence of magnetic field increases when particle volume fraction and magnetic field strength are increased. At 2 mT of magnetic field strength, the thermal conductivity values for 20 vol% and 40 vol% of iron based MR fluids were recorded at approximately 0.42 W/m K and 0.46 W/m K, respectively. While at 15 mT of magnetic field strength, the thermal conductivity values increased again to approximately 0.49 W/m K and 0.54 W/m K, respectively [2]. However, the ratio of thermal conductivity in bulk MR fluids without magnetic field and with 290 kA/m of magnetic field is approximately 1.3. The experiment conducted to produce this finding was using bulk iron based MR fluids with particle volume fraction up to 33 % along the magnetic field direction. The result indicates that increasing particle volume fraction is insignificant on enhancing huge amount of thermal conductivity [3].

In case of nanofluids studies suggested that thermal conductivity increases with increase in particle volume fraction [4]. Increase of up to 1.5 vol% of Al2O3 nanoparticles resulted in thermal conductivity increase at about 5 % [5]. Thermal conductivity increased linearly with increase in particle volume fraction.

B. Size and Shape of Particles

Although shape and size of particles were proven to affect thermal conductivity in nanofluids, no reports found any description in magnetorheological fluid [6]. Nevertheless, mechanism of shape and size of particles in affecting the thermal conductivity remains relevant in the case of MR fluid. Commonly MR fluid particles are spherical shaped carbonyl iron particles and size is in the scale of micrometers [7]. Studies in MR fluid indicated that least enhancement in thermal conductivity is for spherical shaped particles due to its least surface area. Thus introduction of cylindrical shaped particles will help in increasing thermal conductivity of MR fluids.

Moreover, it was found that thermal conductivity of solid suspension increases as the particle size decreases. Taking nanofluid as an example, the thermal conductivity ratios could be enhanced up to 14.7 % for 20 nm nanoparticles at 50 °C as can be seen in figure 1. The experiment used water based Al2O3 nanofluids with different nominal diameters of 20, 50, and 100 nm under varied temperatures [8].

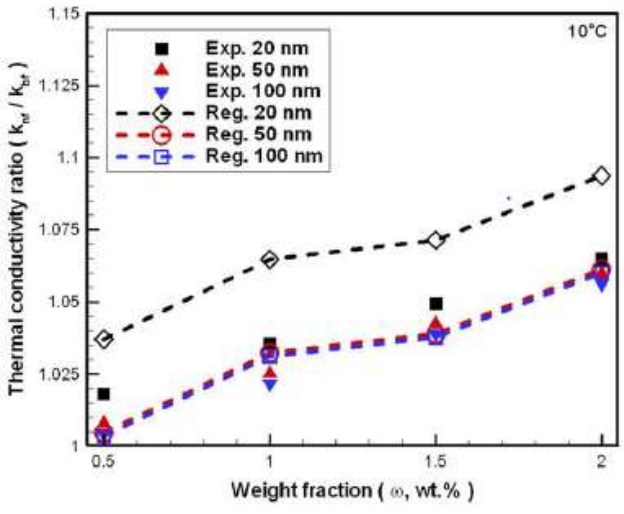

Fig 1: Dependence relationship between weight fraction and thermal conductivity ratio of Al2O3/water nanofluid with different particle sizes at 50°C [8].

C. Material of Particles

Studies have showed that thermal conductivity enhancement is higher for water based Cu nanofluids compared to water based Al2O3 nanofluids. The thermal conductivity ratios for Al2O3 nanofluids and Cu nanofluids are 1.10 and 1.12, respectively. These results showed that Cu nanofluids have higher thermal conductivity compared to Al2O3 [9].

Likewise, TiO2 nanofluid showed less enhancement of thermal conductivity compared to water based Al2O3 with respect to particle volume fraction. In a study 11% thermal conductivity enhancement was observed with Al2O3 nanoparticles, while there was 9% enhancement of thermal conductivity with TiO2 nanoparticles [10].

Additionally, it was found that oxide particles show less enhancement in thermal conductivity in comparison with metallic particles. For example, by using ethylene glycol as base fluid, 17% enhancement in thermal conductivity were recorded for Al2O3 particles whereas 27% enhancement was observed of Al nanoparticles [11].

Carbonyl Iron powder is mostly used as material of particles in MR fluids. Lack of research on material of particles in MR fluid possess a challenge in prediction of nature of change in thermal conductivity. Either way, metallic nanoparticles can also be used as an additive so as to enhance the thermal properties of MR fluid.

D. Material of Base Fluid

Most studies have shown that decrease in thermal conductivity of base fluids results in increase in thermal conductivity enhancement. For example in nanofluids , as seen in fig 2, dramatic improvement in thermal conductivity of graphene oxide nanosheets suspension is seen for a base fluid with lower thermal conductivity. This experiment on thermal conductivity of nanofluids comprises several base fluid materials like liquid paraffin (0.24 W/mK), propyl glycol (0.206 W/m K), ethylene glycol (0.255 W/m K) and distilled water (0.58 W/m K) [12]. Thus theoretically, as silicone oil has a very low thermal conductivity combined with the high thermal conductivity of carbonyl iron particles MR fluids would have a good thermal conductivity.

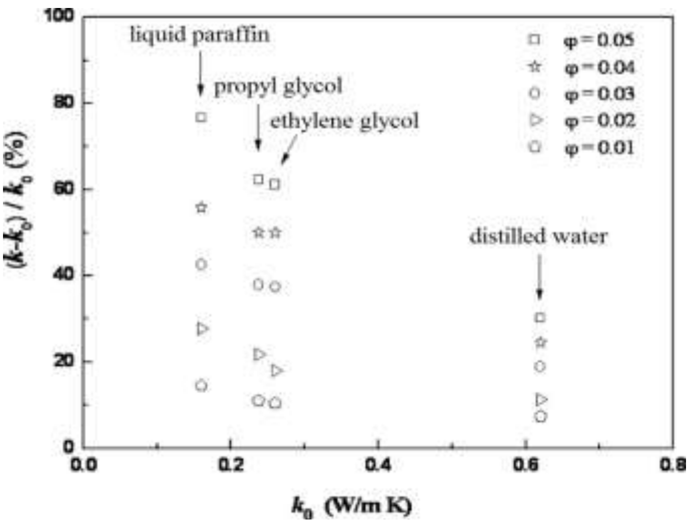

Fig 2: Thermal conductivity enhancement ratios as a function of the thermal conductivities of the base fluids with different volume fraction [12].

E. Strength and Direction of Magnetic Field

Thermal conductivity of MR fluid increases with increasing magnetic field. The substantial enhancement of the thermal conductivity is by almost 188% at magnetic field of 15 mT [1].

Thermal conductivity is also strongly influenced by direction of magnetic field, with the maximum being achieved when the field was parallel to the direction of thermal gradient. As in figure 3, for perpendicular alignment, the thermal conductivity has an inverse relationship to the magnetic field strength while for parallel alignment of the magnetic field, thermal conductivity increases with increasing magnetic field strength [13].

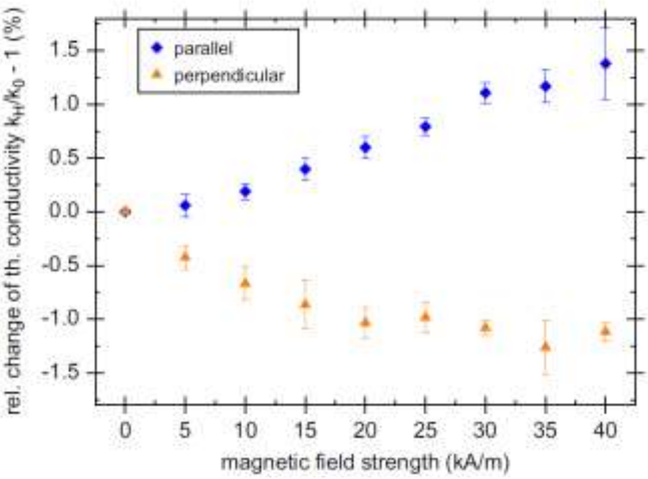

Fig 3: Relative change of thermal conductivity depending on magnetic field strength and orientation against heat flux direction [13].

In particular, the increase in thermal conductivity under external magnetic field is attributed to the effective conduction of heat through the chainlike structures formed under magnetic field when the dipolar interaction energy becomes greater than the thermal energy [14].

III. DISCUSSION

A review of studies related to thermal behaviour of MR fluids and nanofluids with special attention on thermal conductivity property was conducted. Variation in thermal conductivity has been studied according to variations parameters like particle volume fraction, shape and size of particles, material of particles, material of base fluid, and strength and direction of magnetic field. The potential applications of MR fluids with better thermal properties would be like thermomagnetic convection and heat pipe.

Future research should focus on understanding the thermal conductivity enhancement mechanisms, understanding of chain like structures formed in presence of magnetic field and their manipulation by controlling external magnetic field.

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