Chapter 7

Heat transfer application of synthesized Gd doped Mn-Zn ferrofluids
CHAPTER-7

7.1 INTRODUCTION

Natural convection heat transfer is an important phenomenon in engineering and industry with widespread applications in diverse fields, such as, geophysics, solar energy, electronic cooling, nuclear energy and other industrial systems in various sectors. Limitation against enhancing the heat transfer in such engineering systems is inherently poor thermal conductivity of conventional fluids, including oil, water and ethylene glycol mixture. Therefore, for more than a century since Maxwell’s theories in 1873, scientists and engineers have made great efforts to break this fundamental limit by dispersing micrometer sized particles in liquids. However, the major problem with the use of such large particles is the rapid sedimentation of these particles in fluids. Maxwell’s concept is old but what is new and innovative is the concept of nanofluids is the idea of using nanometer-sized particles to create stable and highly conductive suspensions, primarily for suspension stability and for dynamic thermal interactions. Recognizing an excellent opportunity to apply nanotechnology to thermal engineering, Eastman et al. [1,2] were the first who conceived the novel concept of nanofluid by hypothesizing that it is possible to break down these century-old technical barriers by exploiting the unique properties of nanoparticles.

Nanofluids are dilute colloidal suspension of nanomagnetic particles of size smaller than 100 nm. This suspension of nanosize particles have recently been demonstrated to have thermal conductivities far superior to that of the fluid alone. This and their other distinctive features offer unprecedented potential for many applications in various fields including energy, bio- and pharmaceutical industry, and chemical, electronic, environmental, material, medical and thermal engineering [2-7]. With ever-increasing thermal loads due to smaller features of microelectronic devices and higher power outputs, thermal management of such devices to maintain their desired performance and durability is one of the most important technical issues in many high-technology industries such as microelectronics, manufacturing transportation.
John Philip et al. (2007) worked on nanomagnetic fluids in IGCAR, Kalapakkam [8]. They studied the effect of very small magnetic field on hexadecane based ferrofluids. They found out that by applying very small magnetic field, thermal conductivity of ferrofluid can be increased, which can be used to produce efficient heat sinks for many new generation devices and system. Popplewell at al. (1982) at University College of North Wales (U. S.A) measured thermal conductivity of ferrofluid containing different carrier fluids [9]. They observed that ferrofluid based on hydrocarbons has the maximum thermal conductivity with respect to their counterparts. Suomes et al. (2007) at North Dacota state university (U.S.A.) studied that the effects of additive like carbon nanotubes to the ferrofluid [10]. They found that the addition of CNT increased heat conductivity on the thermal conductivity of ferrofluids. Los Almos science describes the alignment of ferrofluid in the presence of a magnetic field [11]. Djurec at al. (2007) at University of Zegreb, Crotia measured the thermal conductivity of CoFe$_2$O$_4$ and Fe$_3$O$_4$ based nanomagnetic fluids [12]. They concluded that strength of conductivity enhancement of FF can be increased by increasing the number of nanomagnetic particles in it. Y. Ding et. al. at the University of Leeds, studied the heat transfer intensification using nanofluids [13]. They show that the boiling heat transfer of the ferrofluid can be enhanced at the nucleate regime. Liu. et. al (2006) studied the enhancement of thermal conductivity of nanofluids using chemical reduction method at ITRI, Taiwan. Copper atoms are produced in water by reduction of copper acetate, which then precipitate to form copper nanoparticles which can be used to increase the thermal conductivity of the ferrofluid. Trisaksri et. al at King Monkur’s University, Thailand, studied the nucleate pool boiling heat transfer nanofluids. They concluded that the nucleate pool boiling heat transfer declines with increasing particle concentration. Kosar et. al. studied the flow and convective heat transfer characteristics of water based ferrofluid. They observed that due to flattening of velocity profile convective heat coefficient enhancement exceeds the thermal conductivity coefficient.

The main objective of the experiment discussed in this chapter was to enhance the thermal conductivity of kerosene based ferrofluid using a small permanent magnet of different orientation. The arrangement of these magnetic fields is associated with the formation of proper channels through the ferrofluid which makes way for the transfer of heat.
In the absence of a magnetic field, the magnetic moments of the particles are randomly distributed and the fluid has no net magnetization [14]. The magnetization of the FF responds immediately to the change in the applied magnetic field and when the applied field is removed, the moments randomize quickly. The objectives of carrying out these experiments were to understand the direction of formation of these channels and the process transfer of heat through these channels.

The future coolants for electronic devices and engines will be magnetic nanofluids, as they more efficiently conduct heat than air [15, 16]. With the shrinkage in size of electronic chips, there will be more demand for very effective heat sinks. Such heat sinks can be made using high heat conducting nanomagnetic fluids. Thus requirement of high heat dissipation find application in new generation devices like NEMS and MEMS device systems. The tentative mechanism of heat transfer by the ferrofluids is shown in Fig. 7.1(a,b) and why they are better is discussed in the following section. Fig. 7.1 (a) explains the advantage of nanosized magnetic particles in ferrofluids due to large surface to volume ratio as compared to micron sized particles. This leads to more surface activity of nanoparticles in the rapid transfer of heat. Fig. 7.1 (b) demonstrates the alignment of magnetic nanoparticles of ferrofluids into specific arrays, to form channels or paths in the presence of magnetic field. These channels increase the fast heat dissipation through the fluid and hence the hot body placed inside the ferrofluids cools down faster in the presence of magnetic field. Gd$^{3+}$ ion doped Mn-Zn ferrite are technologically important due to high pyromagnetic coefficient ($\partial M/\partial T)_H$ and has a low-curie temperature [17,18]. The doping of Gd$^{3+}$ ions in Mn-Zn ferrite improves the thermomagnetic properties of material.

To confirm this, kerosene based Gd$^{3+}$ doped Mn-Zn ferrofluid developed and studied as effective heat sink. Five different experimental setups with different magnetic field environments were proposed and used to find the best results i.e. how effectively the heat can be transferred by the ferrofluid in the presence of magnetic field. The details of the different experimental steps are described in the following experiments as:
7.2 EXPERIMENTAL

Experiment 1

In the first experiment, ferrofluid was heated and cooled down for 10 min each. Heating was done in a temperature controlled water bath at temperature $50 \, ^\circ C$ and $60 \, ^\circ C$. The ferrofluid was cooled once in the absence of magnetic field and then in presence of magnetic field. The change in temperature was recorded. The set up was placed in an insulating medium to ensure that whole of the heat transfer takes place only from the top of the beaker and not through its walls.
After the cooling down of the ferrofluid, to the room temperature, the process was repeated and it was ensured that the FF reaches the same temperature as in the previous case. After 10 minute of heating, FF was removed from the water bath and this time, a bar magnet was placed under the beaker containing the FF. The change in temperature was noted for 10 min of cooling in the insulated medium. Fig. 7.2 (a) exhibits the experimental set schematic of this case.

Fig. 7.2: Experimental set up (a) Experiment 1, (b) Experiment 2, (c) experiment 3, experiment number 4 (d) Experiment 5

**Experiment 2**

Kerosene based Gd$^{3+}$ doped Mn-Zn ferrofluid was heated to different temperatures in the absence of magnetic field for 10 minute each. The change in temperature has been noted at an interval of every 1 minute and 3 min. respectively. The overall change in temperature after 10 minutes. The heated FF taken in test tube was allowed to cool down to the room temperature in the ring magnet surrounding. The decrease in temperature was recorded at the end of 1 min and 3 minute respectively for different temperatures. Fig. 7.2
(b) shows the experimental set up for this case. The test tube containing ferrofluid was completely surrounded by the ring magnets.

**Experiment 3**

In this experiment FF was heated to a certain temperature in the water bath and then placed in an insulated container. A test tube containing water at room temperature was placed inside the test tube containing FF and the temperature of water was noted down after every minute for 5 minutes.

The same experiment was repeated with the ring magnets surrounding the FF and kept in insulation containing a test tube of water at room temperature. This experiment was done to predict the heat transfer from the hot FF to comparatively colder water. The magnets were put to observe the change in temperature of water due to the formation of channels in the FF due to the presence of water. The experimental set for these case is shown in Fig. 7.2 (c). The test tube containing the hot ferrofluid was completely surrounded by the ring magnets.

**Experiment 4**

An experimental set up similar to experiment 3 was used. But in this experiment, water was heated in the bath and the test tube containing hot water was put inside the test tube containing FF at room temperature. Whole setup was placed inside insulation to facilitate heat transfer only through the channels formed when ring magnet were placed completely surrounding the test tube containing the FF. The heating time was 10 minutes and temperature readings were taken after every 2 minutes.

**Experiment 5**

In experiment 5, like experiment 4 water was heated for 10 minutes at different temperatures and placed inside the test tube containing FF to cool down. The setup was insulated and temperature readings were taken after every one and two minutes respectively.

Water was then allowed to come the room temperature and then was heated again for 10 minutes to the same temperatures as above. After ten minutes, the water test tube was removed from the bath and the ring magnets were placed surrounding the water
completely. This arrangement was then placed inside the FF and temperature readings were taken every minute. The change in temperature was noted for 10 and 15 minutes. The precautions were taken so that the ferrofluid does not stick to magnet. Fig. 7.2 (d) shows the experimental setup for this experiment.

**7.3 RESULTS AND DISCUSSION**

Fig. 7.3 and Fig. 7.4 present the curve between decrease in temperature vs. time for the ferrofluid sample cooled in the absence and presence of magnetic field (1000 G) as obtained from Experiment 1 when water bath temperature was 60 °C and 50 °C respectively.

![Graph 1](image1.png)

**Fig. 7.3:** Decrease in temperature of ferrofluid at 60 °C bath temperature (a) absence of magnetic field and (b) in the presence of magnetic field with time

![Graph 2](image2.png)

**Fig. 7.4:** Decrease in temperature of ferrofluid at 50 °C bath temperature (a) absence of magnetic field and (b) in the presence of magnetic field with time.
These graphs clearly indicate that in the presence of a magnetic field, the temperature of the ferrofluid drops down to a lower value in the same time. This can be explained by the formation of channels by the alignment of ferrofluid nanoparticles in the presence of magnetic field. These channels help in fast dissipation of heat. The results are more favorable at higher bath temperature.

**Experiment 2**
The results obtained from the experiment 2, when Gd$^{3+}$ ions doped Mn-Zn ferrofluid was heated to 50 ºC in 10 and 15 minutes heating time were plotted in the absence and presence of magnetic field(1000G) in Fig. 7.5 (a, b) respectively.

![Graphs showing temperature vs time for heating with and without magnetic field](image)

Fig. 7.5: Gd$^{3+}$ ions doped Mn-Zn ferrofluid at 50 ºC bath temperature in the absence and presence of magnetic field with (a) 10 minutes and (b) 15 minutes heating time

From the graphs, it has been observed that ferrofluid heats up more quickly in the presence of magnetic field than in its absence. This can be explained by the fact that the ferrofluid particles are attracted to the magnet surrounding them and thus, most of the nanoparticles come closer to the surface and absorb heat rapidly when they are not present on the surface. Furthermore, the channels formed in the presence of the magnet help in faster heat dissipation and hence, the results.

**Experiment 3**
When ferrofluid at 64 ºC, kept in test tube containing water placed inside ring magnets setup is used to transfer its heat to water in 5 minutes in the absence and presence of...
magnetic field, it does so more quickly in the presence of magnetic field due to more absorption of heat by surface particles and greater dissipation by the ferrofluid channels. Fig. 7.6 presents, heat dissipation trend of hot ferrofluid surrounded by water without and with magnetic field.

![Graph showing temperature vs. time for water surrounded by ferrofluid with and without magnetic field]

Fig. 7.6: Temperature vs. time (min.) of water surrounded by ferrofluid without and with magnetic field

It is also observed that after a point of maximum temperature ~ 42 °C, water cools down more quickly through the ferrofluid in the presence of magnetic field as compared to its absence. This studies further supports that presence of magnetic field leads to the formation of specific channels in the ferrofluid which takes heat away from the water.

**Experiment 4**

Water is cooled down more quickly when kept in the ferrofluid surrounding by ring magnets completely as shown in Fig. 7.7. When ferrofluid is surrounding by these magnets makes all the nanoparticles to be align and these channels let the heat to be transferred from water to the surroundings more swiftly.
Fig. 7.7: Temperature vs. time (min.) of ferrofluid surrounded by water in the absence and in the presence of magnetic field at 60 °C bath temperature.

**Experiment 5**

Fig. 7.7: Temperature vs. time (min.) of ferrofluid surrounded by water heated at 60 °C and 70 °C in 10 minutes heating time, in the absence and in the presence of magnetic field.

### 7.4 CONCLUSIONS

Kerosene based Gd$^{3+}$ ion doped Mn-Zn ferrofluids has been tested for its suitability in heat transfer application. It is observed that there is enhancement in the heat dissipation through the ferrofluids in the presence of magnetic field. The time taken by a hot object (water) to reach a specific temperature in the presence of magnetic field is just half of that
what it had taken in its absence. Thus, it is seen that the heat dissipation is increased in the presence of a very small magnetic field which can lead to the development of futuristic application of ferrofluids as heat sink in the electronic devices.
REFERENCES

[12] Thermal conductivity measurements of CoFe2O4 and Fe3O4 based nanomagnetic fluids CCACAA (3-4) 529.