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Investigation of Thermal Conductivity of Nanofluids with Liquid Gallium as a Base Fluid for Nuclear Applications

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1. Introduction

Nanofluids are a new class of nanotechnology-based transfer fluids engineered by dispersing and stably suspending nanoparticles in traditional heat transfer fluids such as water, ethylene glycol, and engine oil [1]. The small thermal conductivity of water or other organic fluids as base fluids would lower their effectiveness as a cooling fluid. Such concept of nanofluids can be extended to even liquid metals such as sodium, lead and lead-bismuth, as well as gallium being considered as potential coolants in Fast Breeder Reactor. Among them, the gallium is the naturally existing liquid having the lowest melting point (~30 °C) and has no explosive reaction with water. However, the liquid gallium has relatively lower thermal conductivity compared to other liquid metals. If nanoparticles were dispersed well in liquid gallium, nanofluids with liquid gallium as a base fluid having the highest conductivity are expected to be an idealistic and a promising way for making a highly conductive coolant for nuclear applications without the safety concern.

2. Experiment

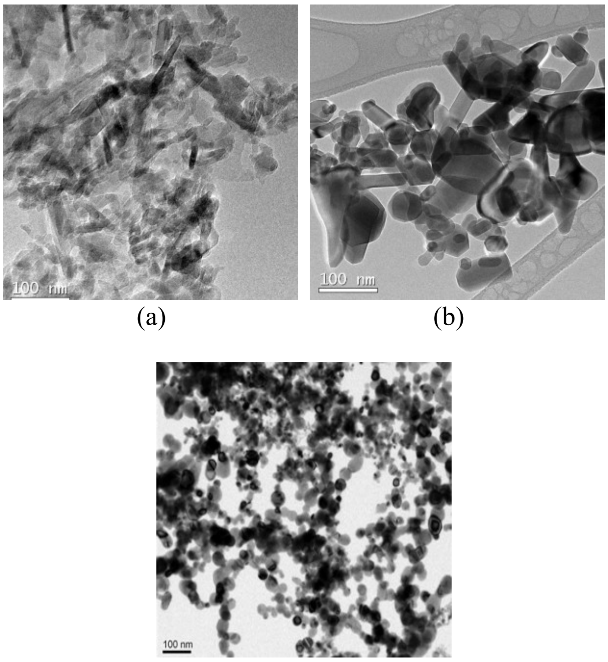
2.1 Preparation of the Experiment

Before doing the experiment, we anticipated thermal conductivity of nanoparticles/liquid gallium nanofluids. It is the important thing that the nanoparticles which the thermal conductivity is higher than that of liquid gallium must be selected. So, we selected Al_2O_3 (aluminum oxide), ZnO (zinc oxide) and Ni (nickel). The thermal conductivity of these is listed in Table I. And, because the properties of the nanofluids depend on the shape and size of nanoparticles, the images of Fig. 1 were taken by transmission electron microscopy (TEM). As shown in the images of Fig. 1, Al_2O_3 and ZnO nanoparticles are cylinders and Ni nanoparticles are spheres.

Table I: The thermal conductivity of nanoparticles

Nanoparticles	Thermal Conductivity
Liquid gallium	24 W/(mK)
Al_2O_3	40 W/(mK)
ZnO	100 W/(mK)
Ni	90.9 W/(mK)

Representative theoretical formulas have been developed to determine the thermal conductivity of a



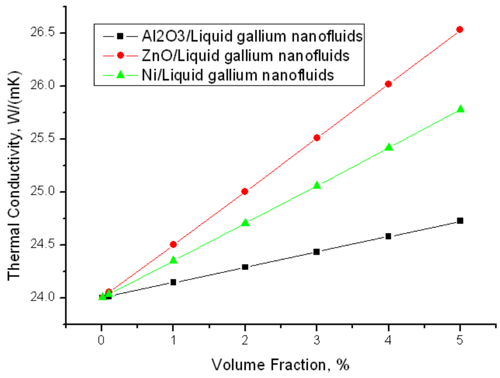
(a) (b) (c)

Fig. 1. TEM images of nanoparticles: (a) Al_2O_3, (b) ZnO and (c) Ni

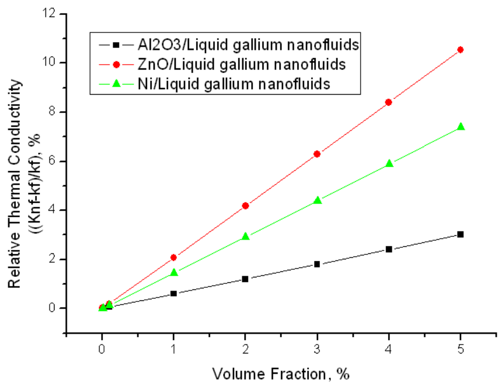
particle suspension. These formulas are still very useful in theoretically anticipating the enhancement of thermal conductivity of nanofluids. Representative theoretical formulas are Maxwell [2] and Hamilton-Crosser [3] formulas. Here, we are expected the thermal conductivity of nanoparticles/liquid gallium nanofluids to 5 volume fraction (%) using Hamilton-Crosser [3] formula. These results are shown in Fig. 2. The thermal conductivity of nanoparticles/liquid gallium nanofluids increases with increase of volume fraction. Hamilton-Crosser [3] formula is as follow.

$$k_{nf} = k_f \left[\frac{\alpha + (n-1) - (n-1)(1-\alpha)\varphi}{\alpha + (n-1) + (1-\alpha)\varphi} \right] \quad (1)$$

where, k_{nf} is the thermal conductivity of nanofluids, k_f is the thermal conductivity of base fluids, α is k_p/k_f(k_p is the thermal conductivity of nanoparticles), φ is particle volume fraction, and n is 3 for spheres or 6 for cylinders. In this study, Hamilton-Crosser [3] formula is only considered because Al_2O_3 and ZnO nanoparticles are cylinders and Ni nanoparticle is spheres.



(a)



(b)

Fig. 2. Expected results of thermal conductivity using Hamilton-Crosser formula: (a) Thermal conductivity-Volume fraction curve of nanoparticles/liquid gallium nanofluids. (b) Relative thermal conductivity-Volume fraction curve of nanoparticles/liquid gallium nanofluids

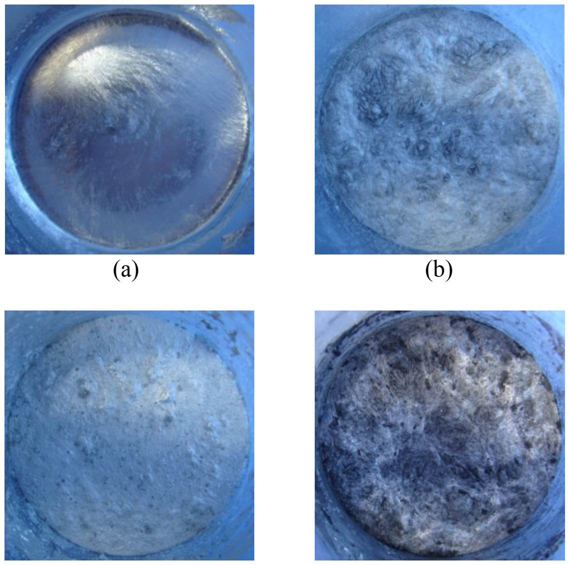
We expected that the mixing of liquid gallium and nanoparticles is a hard work, because unlike distilled water, the density of liquid gallium is high as shown in Table II.

Table II: The density of nanoparticles

Nanoparticles	Density
Liquid gallium	6,095 kg/m^3
Al_2O_3	4,000 kg/m^3
ZnO	5,606 kg/m^3
Ni	8,908 kg/m^3

2.2 Fabrication of nanoparticles(Al2O3, ZnO, Ni) / liquid gallium nanofluids

Nanoparticles/liquid gallium nanofluids are prepared by dispersing Al_2O_3, ZnO and Ni nanoparticles into liquid gallium as a base fluid. The size of Al_2O_3 nanoparticles is under 50nm, the size of ZnO is under 100nm and the size of Ni nanoparticles is about 100nm. All nanofluids were fabricated in 1 volume fraction (%). Unlike nanoparticles/DIW nanofluids, nanoparticles /liquid gallium nanofluids were not dispersed well. So, we were sonicated by probe sonication in addition to bath sonication, but, nanoparticles/liquid gallium nanofluids were not dispersed. Fig. 3 shows the macroscopic observation of the experimental results. Even Ni nanoparticles that are higher than the density of liquid gallium were not dispersed. Therefore, proper dispersion methods for gallium nanofluids are now under development.



(a) (b) (c) (d)

Fig. 3. Macroscopic observation: (a) pure liquid gallium, (b) Al_2O_3/liquid gallium nanofluid, (c) ZnO/liquid gallium nanofluid and (d) Ni/liquid gallium nanofluid

3. Conclusions

The following results are obtained.

(1) If nanoparticles were dispersed well in liquid gallum, nanoparticles/liquid gallium nanofluids having the highest conductivity are expected to be an idealistic and a promising way for making a highly conductive coolant for nuclear applications.

(2) Before doing the experiment, we anticipated thermal conductivity of nanoparticles/liquid gallium nanofluids. Thermal conductivity of Al_2O_3/liquid gallium nanofliud is 24.72 W/(mK), that of ZnO/liquid gallium nanofluid is 26.53 W/(mK) and that of Ni/liquid gallium nanofluid is 25.78 W/(mK) in 5 volume fraction (%)

(3) In spite of many attempts, nanoparticles/liquid gallium nanofluids were not dispersed well. Therefore, proper dispersion methods for gallium nanofluids are now under development.

REFERENCES

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[3] R. L. Hamilton, O. L. Crosser, I&EC Fund 1, 187, 1962.