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Investigation 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 ℃) and has no explosive reaction with water. However, the liquid gallium has relatively lower thermal conductivity compared to other liquid metals. Researches for dispersion in sodium [2-4] are active, an research for dispersion in gallium [5] is inactive. 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 Prediction of Thermal Conductivity

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, ZnO, Ni, SiC and MWCNT. The thermal conductivity and density of nanoparticles are listed in Table I. The thermal conductivity of MWCNT nanoparticle is the biggest and density of Ni nanoparticle is the biggest.

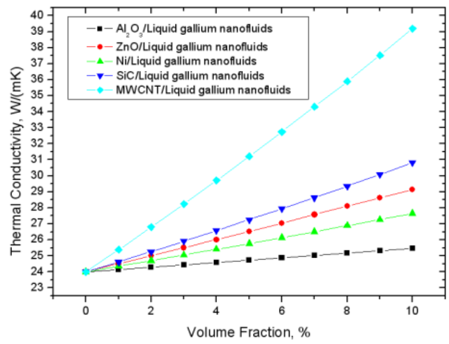
Representative models on prediction of thermal conductivity are Maxwell [6] and Hamilton-Crosser [7] models. These models are still very useful in theoretically anticipating the enhancement of thermal conductivity of nanofluids. Here, we are expected the thermal conductivity of nanoparticles/liquid gallium nanofluids to 10 volume fraction (%) using Hamilton-Crosser model. These results are shown in Fig. 1.

Hamilton-Crosser model is as follows:

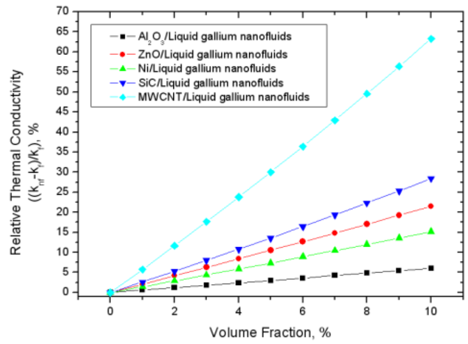
$$k_{nf} = k_f \left[\frac{\alpha + (n-1) - (n-1)(1-\alpha)\varphi}{\alpha + (n-1) + (1-\alpha)\varphi} \right] \quad (1)$$

Table I: The thermal conductivity and density of nanoparticles

Nanoparticles	Thermal Conductivity (W/mK)	Density (kg/m^3)
Gallium	24	6,095
Al_2O_3	40	4,000
ZnO	100	5,606
Ni	90.9	8,908
SiC	490	3,160
MWCNT	3,000	1,500



(a)



(b)

Fig. 1. Expected results of thermal conductivity using Hamilton-Crosser model: (a) Thermal conductivity according to volume fraction of nanoparticles/liquid gallium nanofluids, (b) Relative thermal conductivity according to volume fraction of nanoparticles/liquid gallium nanofluids

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.

2.2 Preparation of liquid gallium nanofluids

Nanoparticles/liquid gallium nanofluids are prepared by dispersing Al_2O_3, ZnO, Ni, SiC and MWCNT nanoparticles into liquid gallium as a base fluid using mechanical overhead stirrer. Fig. 2 shows the macroscopic observation of representative experimental results.

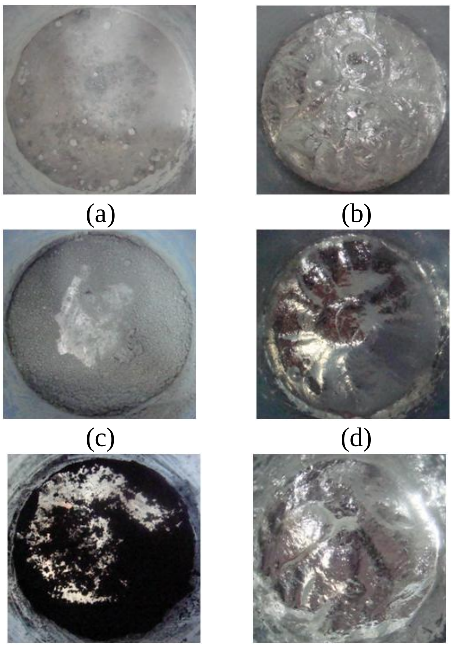
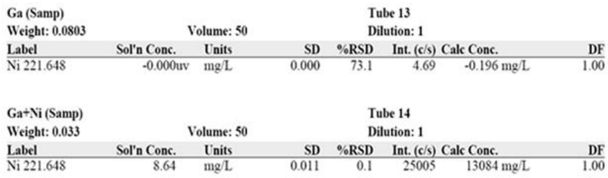


Fig. 2. Dispersion experimental results: (a) Ga+Al_2O_3-Before, (b) Ga+Al_2O_3-After, (c) Ga+SiC-Before, (d) Ga+SiC-After, (e) Ga+MWCNT-Before, (f) Ga+MWCNT-After

3. Results and Discussion

The results of dispersion experiment of nanoparticles with liquid gallium show that dispersion is well done to the naked eye. To confirm dispersion results in more detail, we analyzed samples using ICP (Inductively Coupled Plasma) and TOF-SIMS (Time-of-Flight Secondary Ion Mass Spectrometry). Fig. 3 shows ICP results on Ni/liquid gallium nanofluid and Fig. 4 shows TOF-SIMS results on liquid gallium, Al_2O_3/liquid gallium and SiC/liquid gallium. As shown in Fig. 3 and Fig. 4, Ni, Al_2O_3 and SiC nanoparticles are dispersed well in liquid gallium. Table II shows the thermal conductivity of liquid gallium, SiC/liquid gallium and MWCNT/liquid gallium according to the temperature. These data are acquired using LFA 446 and DSC 204F1 (laser flash method). The measurement value of thermal conductivity is not correct because of uncertainty of specific heat.



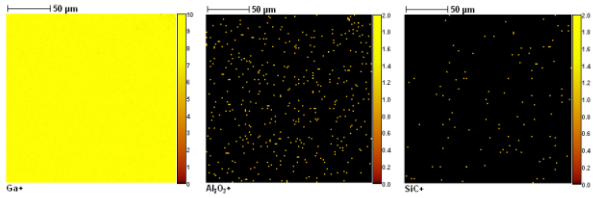
Ga (Samp) Tube 13
Weight: 0.0803 Volume: 50 Dilution: 1

Label	Sol'n Conc.	Units	SD	%RSD	Int. (c/s)	Calc Conc.	DF
Ni 221.648	-0.000uv	mg/L	0.000	73.1	4.69	-0.196 mg/L	1.00

Ga+Ni (Samp) Tube 14
Weight: 0.033 Volume: 50 Dilution: 1

Label	Sol'n Conc.	Units	SD	%RSD	Int. (c/s)	Calc Conc.	DF
Ni 221.648	8.64	mg/L	0.011	0.1	25005	13084 mg/L	1.00

Fig. 3. ICP results on Ni/liquid gallium nanofluid



(a) (b) (c)

Fig. 4. TOF-SIMS results: (a) liquid gallium, (b) Al_2O_3/liquid gallium, (c) SiC/liquid gallium

Table II. The thermal conductivity of nanofluids with liquid gallium according to the temperature (W/mK)

nanofluids	50 ℃	60 ℃	70 ℃
Gallium	24.086	23.706	24.180
SiC	7.500	7.166	7.308
MWCNT	10.578	10.651	10.802

4. Conclusion

The following results are obtained.
(1) Nanoparticles are dispersed in liquid gallium using mechanical overhead stirrer after many tries.
(2) We confirmed that Ni, Al_2O_3 and SiC nanoparticles are dispersed well in liquid gallium through ICP and TOF-SIMS
(3) The thermal conductivity of nanofluids is measured. The measurement value of thermal conductivity is not correct because of uncertainty of specific heat.

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