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EXPERIMENTAL STUDY ON THERMAL CONDUCTIVITY OF LUBRICANT CONTAINING NANOPARTICLES

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Abstract. In this study, the Al_2O_3 nanofluids produced from the direct synthesis method were used as the experimental samples, and ultrasonic vibration was used for dispersing the nanoparticles into three types of different weight fractions (1.0, 1.5, 2.0 wt.%). The base solvent was the lubricant of R-134a refrigeration system. The objectives of this study were to discuss the dependence of thermal conductivity of Al_2O_3 nanofluids on the temperature (20~40 °C) under different weight fractions. This experiment used the thermostatic bath to stabilize the temperature of sample, and the transient hot-wire method to measure the thermal conductivity in the nanofluids of different weight fractions and sample temperature. The results showed that the thermal conductivities were enhanced by 2.0%, 4.6%, and 2.5% when the nanoparticles of Al_2O_3 of 1.0, 1.5, and 2.0 wt.% were added at 40 °C. Among them, the optimal enhancement of the thermal conductivity was at 1.5 wt.%. The enhancement of thermal conductivity did not grow with the increase of weight ratios, and it was obviously different from the general nanofluids with lubricant as the basic solvent. Besides, thermal conductivities increased from 1.5 to 4.6% when the sample temperatures were from 20 °C to 40 °C at 1.5 wt.%, and the trend of growth rates of the thermal conductivity was proportional to temperature. From the results, it can be realized that temperature has greater effects than weight fraction on the increase of thermal conductivities. Thus, it is better for nanpfluids of Al_2O_3 to be applied in the high temperature field than in the low temperature field.

1. INTRODUCTION

Nano technology can be regarded as one of the most important frontier fields in the 21st century. Its applications are extremely extensive, such as electronics, information technology, physics, chemistry, biology, medical science, material, *etc*. It has been developed in various new fields of scientific and technological industry. Scientists consider that nano-technology is the fourth wave of industrial revolution in the human society. As far as refrigeration and air conditioning industry is concerned, there will be breakthrough and great contribution in the aspects of energy economization, environment ecological protection, machine parts miniaturization, and so on, if nano-technology can be fully applied to improve its systematic function and efficiency. In the refrigeration and air conditioning system, refrigeration oil not only can lubricate parts to reduce frictions, but also help with heat dispelling and oil-sealing function of bearing. The heat dispelling can function well to cool activity parts of compressor by refrigeration oil, taking the inside frictional heat away to the outside of machine or the oil cooler. In 1991, Eckels and Pate [1] used two mixture fluids, one was refrigerant R-134a—refrigeration oil 169SUS (PAG oil), and the other

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was refrigerant R-12—refrigeration oil 150SUS (naphthenic oil), as the working fluids to measure the thermal conduction and depression. The results appeared that the thermal conductivity of these two mixture fluids increased by 5~15% for adding refrigeration oil on the ground of low oil concentration; however, in 5.5% high oil concentration, the thermo conductivity was 40~50% less than that in pure refrigerant circumstance. In 1995, Shao and Granryd [2] observed the influence induced by adding lubricant in working fluid of refrigerant R-134a. When they took experiment on refrigerant-lubricant to define the saturated temperature, the thermal conductivity decreased 10~20% after adding oil. But the drop amount was not apparent if saturated temperature was defined according to pure refrigerant. In the same year, Hambraeus [3] measured the thermal conduction of the three types of fluids with different viscosities in refrigerant R-134a system. In the measurement, the thermo conduction increased only on the condition of low flow rates and low viscosities, which were caused by the high viscosity fluids that raised moist degree on the walled pipes. In 1998, Eckels *et al*. [4], used refrigerant R-134a - refrigeration oil 150SUS as working fluid to test plain pipes and micro-fine pipes with external diameter 9.52 mm. The results on micro-fine pipes revealed that the thermal conductivity decreased with increasing oil quantity. At the oil weight fraction of 5 wt.%, the thermal conductivity decreased 8~18%. In 2001, Lin Jian-Shun [5] used pure refrigerant R-134a and the mixture of refrigerant and lubricant to compare the performance in small pipes. The outcome indicated that there was no notable influence on frozen thermal conductivity, inclusive of lubricant; and the evaporated thermal conductivity was higher than in pure refrigerant condition. The abovementioned documents relating to refrigerant R-134a and refrigeration oil are focused on the investigation of thermal conductivity properties merely among R-134a and refrigeration oils, which have no nanoparticle added inside. The relative periodicals and theses indicate that thermal conductivity can increase by adding nanoparticles in lubricants. However, most researches [6-10] put more emphasis on the friction and abrasion under oils of different viscosity.

To integrate and review the above relevant documents, we observe the refrigeration oil has great weight on lubrication and thermal conductivity. It is also acquired that adding nanoparticles in base solvent can decrease friction and raise thermal conductivity effectively. The temperature variation and weight fraction of nanoparticles also have effects on thermal conductivity improvement. This research used the Al_2O_3 nanofluids of different weight fractions to measure the thermal conductivity at the temperature range 10~40 °C in order to evaluate the relationship between thermal conductivity and nanofluids of different concentration or temperature.

2. RELATED THEORIES

The estimation and calculation equation for the amount of solid particles to be added in fluid to increase the thermal conductivity of fluid was earliest induced by Maxwell. However, Maxwell's equation only investigated how the volume fraction of the added particles affected the thermal conductivity coefficient of fluid. In 1962, Hamilton and Crosser [11] further developed a solid-liquid suspension theory, which took thermal conductivity of base liquid and the shape of particles as the parameters of equation, and considered how the relationship between the appearance and surface area of particles affected the rise of thermal conductivity of fluid. The equation for the thermal conductivity coefficient of solid-liquid suspension proposed by Hamilton and Crosser is expressed as follows:

$$\frac{k_{eff}}{k_L} = \frac{k_p + (n-1)k_L - (n-1)\phi(k_L - k_p)}{k_p + (n-1)k_L + \phi(k_L - k_p)}, \tag{1}$$

$$n = \frac{3}{\psi}, \tag{2}$$

where, k_{eff} denotes the thermal conductivity coefficient of solid-liquid suspension, k_L denotes the thermal conductivity coefficient of fluid, k_p denotes the thermal conductivity coefficient of powder, ψ denotes the volume fraction, n denotes the empirical shape factor of power, and ψ denotes the spherical ratio. From the above, it can be seen that adding nanoparticles to fluid can effectively enhance thermal conductivity coefficients of fluid. Many studies showed that H-C model was not suitable for nanofluid. In comparing the calculated result of the equation of thermal conductivity coefficient with the experimental value, a status of serious underestimation is found. Nevertheless, some research results are also found to be the same as the experimental values [12]. In recent years, many researchers involved in the studies of the size, movement status and interfacial shell of nanoparticles to be added, and induced the calculation equations of

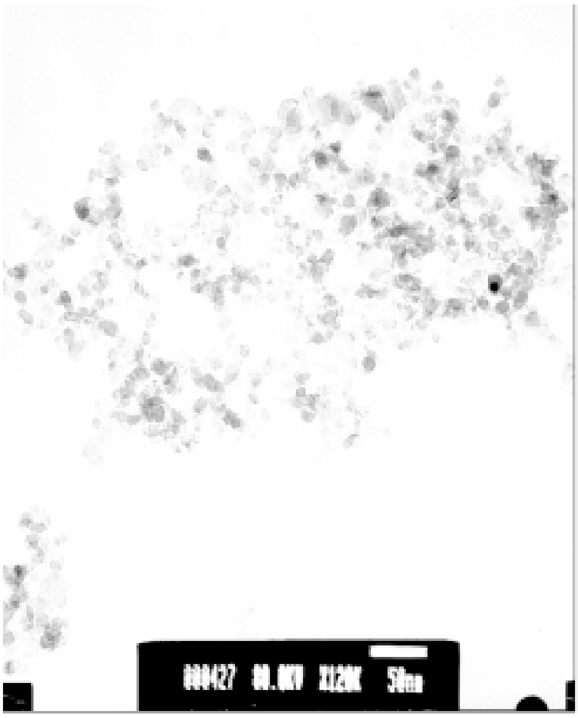

Fig. 1. TEM photograph of Al_2O_3 nanoparticle.

thermal conductivity coefficient [13-15]. But the fact is that each nanofluid had its uniqueness. Hence, the measurement methods used would be the direct and effective methods [16-19]. From HC-model, it can be seen that adding nanoparticles to fluid can effectively enhance thermal conductivity coefficients of fluid. Therefore, it can be predicted that adding nanoparticles in refrigeration oil should be able to improve the heat dispelling effect of refrigeration oil and the performance of refrigeration system.

3. EQUIPMENTS AND EXPERIMENTAL DESIGN

This study used nanofluid, which was directly synthesized from nanaparticles and refrigeration oils, and the nanoparticles (Fig. 1) of Al_2O_3 as the experimental samples. The base solvent was the lubricant of R-134a refrigeration system. Under the control of environmental temperature 25±1 °C, three types of concentration of different weight fractions (1.0, 1.5, 2.0 wt.%) were produced. Ultrasonic vibrator is used to mix the nanoparticles with the base solvent evenly. Fig. 2 shows the diagram of experiment, in which thermostatic bath (Firstek B403L) was used to stabilize the temperature of sample, and thermo analyzer (Decagon KD2) was used to measure the thermal conductivity. Finally, relative data were entered to the computer for analysis. The experimental methods and approach are as follows:

1. Put the measuring sample in an ultrasonic oscillator and shake it for one hour. After 24 hours, observe if any sediment appears.
2. Put the measuring sample on thermostatic bath and trace the temperature of sample until its temperature between targets is smaller than ±0.5 °C. Then, start measuring the thermal conductivity.
3. Insert the test stick to the sample solution to take measurement.
4. The measurement interval is 20 min. Take measurement for 3 times for each condition in order to diminish experimental error.

4. RESULTS AND DISCUSSION

Fig. 3 is a chart showing the characteristics of suspension. It indicates the ratios of absorbance of the samples with different concentration measured every 12 hours within the 48-hour stay to the initial absorbance of the corresponding samples. In Fig. 3, it is obvious that the absorbance ratio slightly varies with time for the samples of 1.0 wt.% and 1.5 wt.% under the condition of no surfactant added. Besides, it is found that no powder is gathered to deposit. Such a characteristic is good because it does not let the parts of compressors wear out under the condition of having a thin gap of the oil film, and the capillary of the system jam.

Fig. 4 is a chart showing the relationship between each weight fraction and thermal conductivity ratio (k_{eff}/k_L). For the weight fraction of nanofluid, there are three changes ranging from 1.0 to 2.0 wt.%. Under the condition that the temperature of experimental sample is 20 °C, the thermal conductivity increment rises 0.71%, 1.57%, and 0.85% respectively. Under the condition that the temperature of experimental sample is 30 °C, the thermal conductivity increment rises 1.77%, 3.68%, and 2.07% respectively. Under the condition that the temperature of experimental sample is 40 °C, the thermal conductivity increment rises 2.03%, 4.55%, and 2.47% respectively. It is realized from Fig. 4 that the value of HC-model is close to the experimental value only when it is 20 °C, and is far lower than the measured value under other temperature conditions. After putting the thermal conductivity

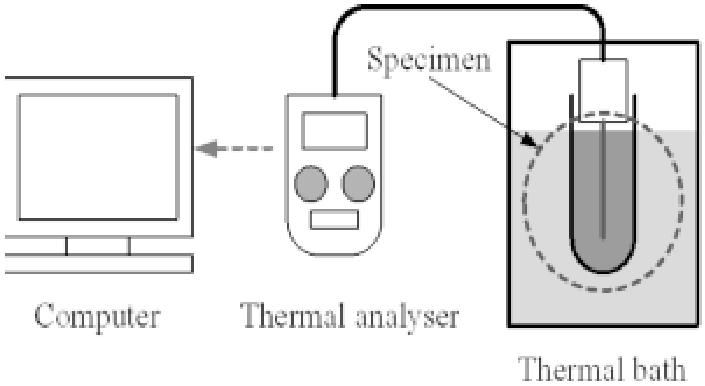

Fig. 2. Schematic diagram of experimental installation.

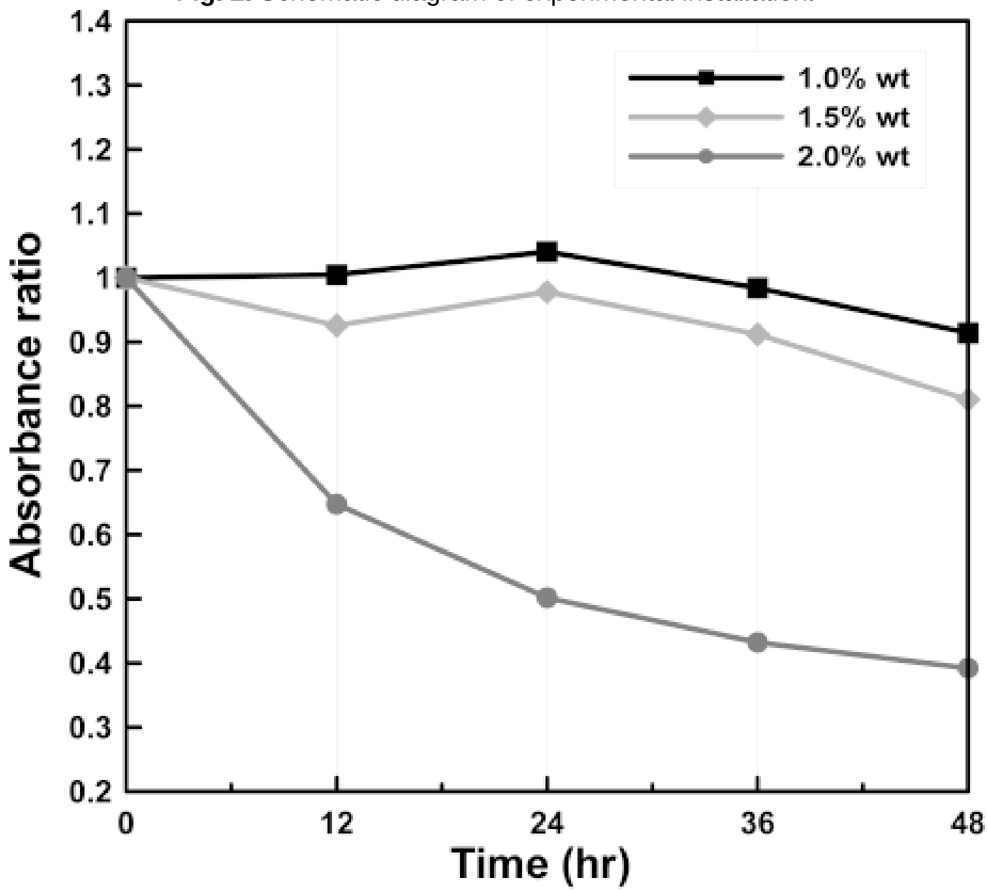

Fig. 3. Characteristic of suspension.

coefficients of material under different temperature conditions into the HC-model, it is found that temperature almost do not affect the calculation result at all. It is mainly because this way of calculation has neglected the factor for the probability increase of friction between nanoparticles and base liquid caused by the temperature rise. And this factor is the main reason for the growth of thermal conductivity in nanofluids.

Fig. 5 is a chart showing the relationship between the temperature of each sample and the thermal conductivity increment. For the temperature of experimental sample, it has four changes ranging from 20 to 40 °C. Under the condition that the

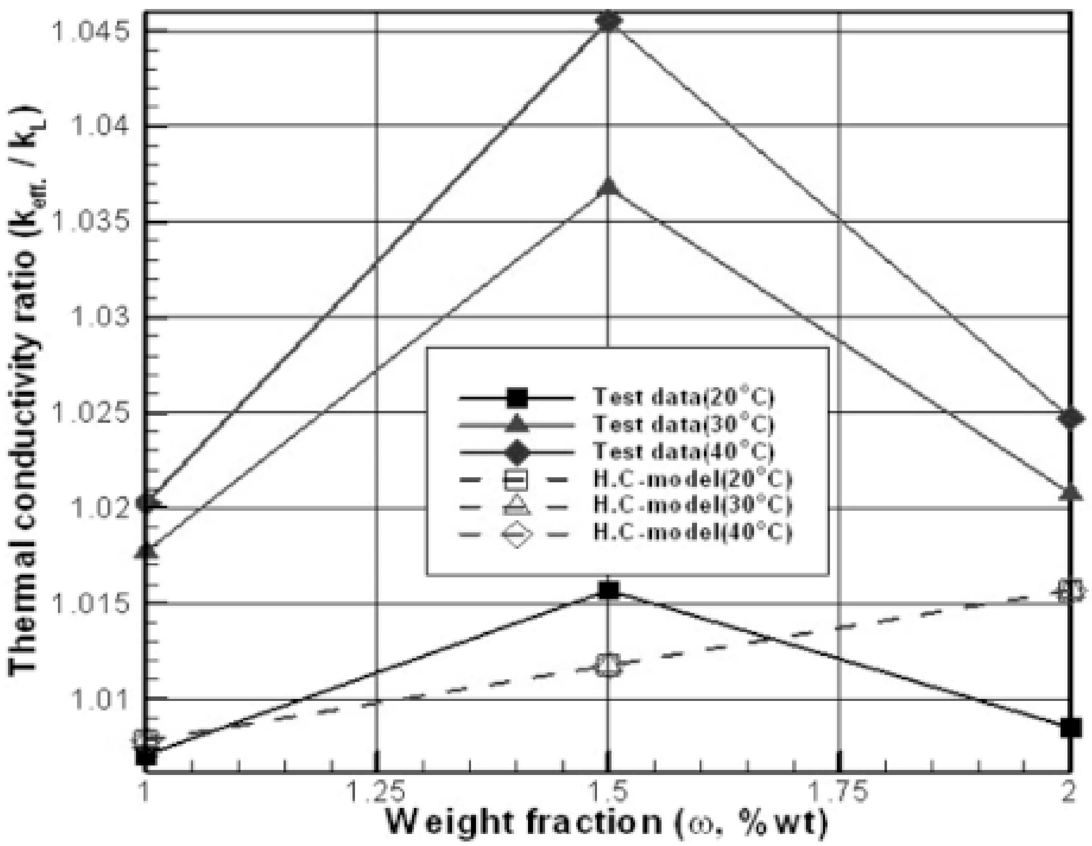

Fig. 4. Relationship between thermal conductivity ratio (k_{eff}/k_L) and weight fraction for different temperature.

volume fraction is 1.0% vol., the thermal conductivity increment rises from 0.71% to 2.07%. Under the condition that the volume fraction is 1.5% vol., the thermal conductivity increment rises from 1.57% to 4.55%. Under the condition that the volume fraction is 2.0% vol., the thermal conductivity increment rises from 0.85% to 2.47%.

Using these experimental data, it is known that raising temperature can enhance the thermal conductivity, and the experimental data demonstrates a quasi-two order polynomial relationship between the enhancement of thermal conductivity and both the volume fraction and temperature. Higher temperature causes the speed increment of molecules, and increases collisions between nanoparticles and the molecules of bulk liquid, resultin in an increased thermal conductivity. It can be understood from the HC-model that thermal conductivity growth increases with the rise of concentration of the added particles. In this experiment, the optimal value was achieved at 1.5 wt.%. From Fig. 3, it is known that the thermal conductivity growth rate at 2.0 wt.% is lower than that at 1.5 wt.%, mainly because the floating status at 2.0 wt.% is poor. Particle being in the fluid at floating concentration would fall rapidly. After 24 hours, its concentration falls to below 60% of its original concentration. Therefore, the growth rate of its thermal conductivity coefficient is similar to that of 1.0 wt.%. If the nanoparticles of higher concentration are adopted, we have to consider the stable floating status of the adding interfaces, surfactant and dispersant.

5. CONCLUSIONS

From the experimental results and the discussion above, conclusions are made as follows.

1. Nanoparticles should be added to the lubricant of R-134a refrigeration system without dispersant. The optimal suspension performance was achieved at weight fractios 1.0 wt.% and 1.5 wt.%.

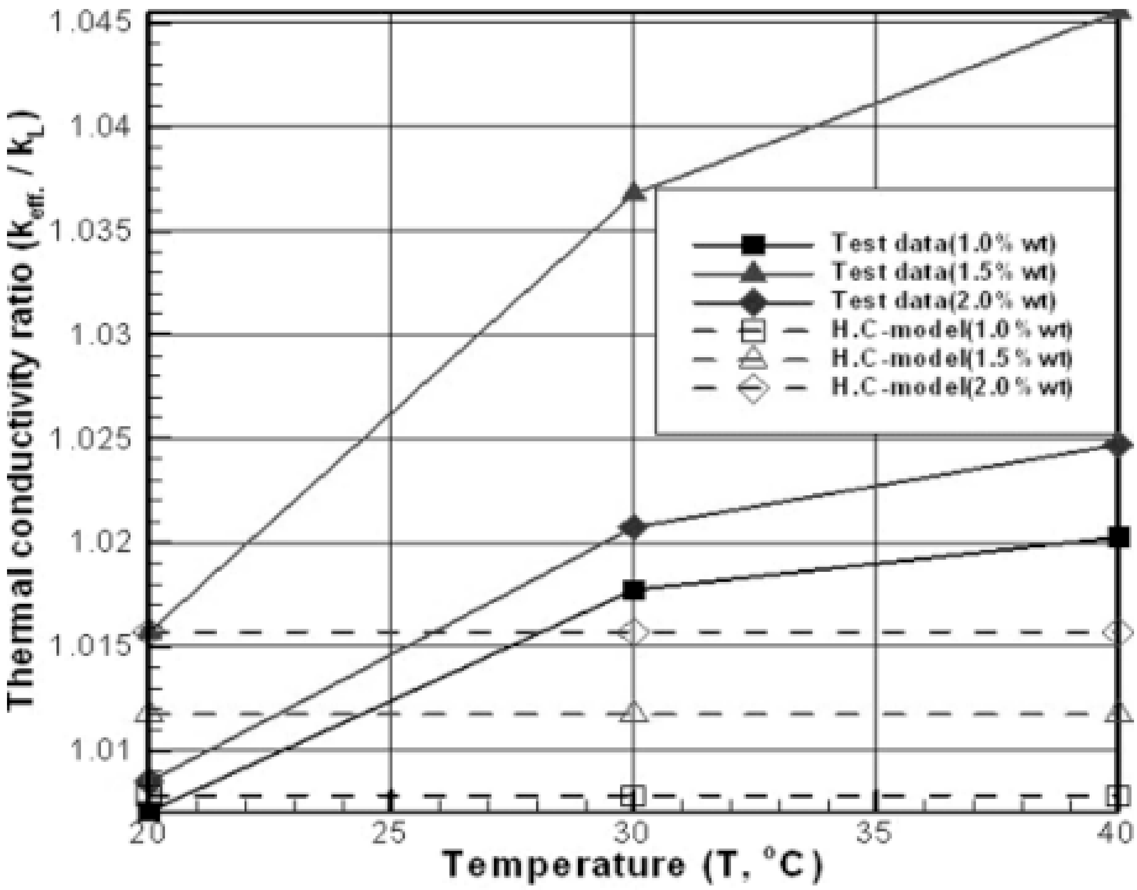

Fig. 5. Relationship between thermal conductivity ratio (k_{eff}/k_L) and temperature for different weight fractions.

2. Nanoparticles Al2O3 should be added to lubricant to acquire an effective increase of thermal conductivity. The results showed that the thermal conductivities were respectively enhanced by 2.0%, 4.6%, and 2.5% when nanoparticles of Al_2O_3 at 1.0, 1.5, and 2.0 wt.% were added at 40 °C.
3. In the three weight fraction specimens, the optimal enhancement of the thermal conductivity is 1.5 wt.%. The thermal conductivities increase from 1.5% to 4.6% when the sample temperature are from 20 to 40 °C at 1.5 wt.%, and the trend of growth rates of the thermal conductivity is proportional to temperature.
4. Al_2O_3 nanofluid has better growth rates of thermal conductivity at higher temperature, so nanofluid has better effects in the cases of higher temperature.

As for the nanofluids with Al_2O_3 and refrigerant that can enhance the thermal conductivities, one can further try to experiment at low temperature, and even experiment with circulation of the system, which includes measuring the performance of heat dissipation of the compressor, power consumption, COP, and heat transfer of the evaporator and condenser of the system.

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