# EFFECT OF ALUMINA NANOFLUIDS WITH DIFFERENT VOLUME FRACTION WITH DIFFERENT FILL CHARGE RATIO ON THE HEAT TRANSFER PERFORMANCE OF SELF OSCILLATING MULTI HEAT PIPE

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**Abstract**

This experiment study was performed to investigate the effect of different volume fraction of alumina ($Al_2O_3$) with different fill charge ratio to the heat transfer performance of a self-oscillating multi heat pipe at different constant heat flux. Working fluid employed was alumina ($Al_2O_3$) with 0.1%, 0.5%, 1.0% and 5.0% volume fraction. The fill charge ratio $f_{cr}$ was varied from 30% to 100% at 10% interval. Heat pipe is consisted of an evaporation section, a condenser section and an adiabatic section. Evaporation and condenser sections have the same size and are connected by four circular parallel tubes. External dimension of evaporation and condenser section were a 45mm of length, a 45mm of width and a thickness of 8mm, also the internal dimension were 42mm, 42mm, and 5mm respectively. Adiabatic section (four circular parallel tubes) with a length of 45mm long, an inner diameter of 5mm and an outer diameter of 6mm was employed. The evaporation section is heated at constant heat flux for each different volume fraction and heat flux was 5W/cm$^2$ to 30W/cm$^2$ at 5W/cm$^2$ interval. 5 temperature measurements, 4 at the corner and center of the evaporation section and 3 temperature measurements at along the center line of condenser section were employed. 15°C of cooling water was supplied to the condenser section (to cool) in water tank at rate of 3.5l/min. A 7400Pavacuum pressure was maintained to create self-oscillating heat transfer. The thermal performance of higher volume fraction of nanofluids was enhanced in comparison with lower volume case.

**Keywords**

nanofluids, self-oscillating multi heat pipes, effective thermal conductivity

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## INTRODUCTION

Modern technology makes it possible to produce particle less than 100 nm in diameter and for suspending in conventional fluid such as water, engine oil, and ethylene glycol. This new class of fluid is referred as "nanofluids". Choi [1] is the first person to use and introduce nanofluids as working fluid for heat transfer. Compared to micron size particles, nano particles have much larger relative surface areas and have a great heat transfer enhancement potential. Its nano size particles reduce particle clogging and reducing pumping power to other liquids that have equivalent heat transfer capability. Based on this idea, many studies are conducted to explore the superiority of nanofluids's property, such as large surface area to volume ratio, stable suspension and no flow passage clogging which are suitable in heat transfer application that millimeter size particles fluid did not offer before. This is because larger surface areas not only improve heat transfer capability but also increase the stability of suspension. Oxide nanoparticle such as $Al_2O_3$ and CuO have excellent dispersion properties in water, oil and ethylene glycol and form suspension as demonstrated by Eastma et al. [2]. Torii and Yang [3] also demonstrated the superiority of nano fluid that significant enhancement of heat transfer performance due to suspension of nanodiamond particle in the circular tube flow is observed in comparison with water. Adding nanoparticles to fluid can effectively increase the thermal conductivity ratio of the fluid as studied by Teng et al. [4].

Heat pipes introduced by Akachi [5] is "The loop type of heat pipe" which is a self-oscillating type of heat pipe that contains three sections: an evaporation section, an adiabatic section and a condenser section. This type of heat pipes usually is made by a closed circuit copper tube with calculated internal diameter and is also filling with a fixed amount of working fluid.

Yoon et al. [6] also investigated the heat transfer characteristics of a self-oscillating heat pipe using pure water as a working fluid. Although excellent results of thermal conductivity were obtain, this study only applied with low heat fluxes. Closed-end oscillating heat pipe (CEOHP) has more reasonable thermal performance compared to those obtained by conventional heat sink cooler as showed by Rittidech et al. [7]. Guo and Nutter [8] had a deep study and showed the result of a type of heat pipe – thermosyphon: An experiment study of axial conduction through a thermosyphon pipe wall. The experiment data showed that the conduction through the pipe wall causes the wall temperature to decrease along the evaporator section. It also increases the overall heat transfer coefficient, evaporation heat transfer coefficient, and condenser heat transfer coefficient of the thermosyphon. However, the heat transfer associated with axial conduction decreased as the heat flux increased. Park et al. [9] had an investigation about heat transfer characteristic of a two-phase closed thermosyphon to the fill charge ratio. The author discovered dry-out phenomenon occurs when fill charge ratio is lower than 20%.

Based on the forgoing good result of researchers about application of nanofluids to heat exchanger, in this research, different volume fraction $Al_2O_3$ fluid was applied to the self-oscillating multi-heat pipe to study the heat transfer performance with different fill charge ratios and different constant heat fluxes. The particle size used in this experiment is less than 30nm in diameter.

## EXPERIMENT METHOD

Nanofluids applied in this experiment were Alumina ($Al_2O_3$) nanofluid. Pure water was mixed with $Al_2O_3$ particles around 30mm in diameter. The volumes fraction of nanofluid applied in this experiment were 0.1%, 0.5%, 1.0%, and 5.0%. The following equation is one used to determine volume fraction of Alumina $Al_2O_3$ nanofluid, i.e., 0.1% volume fraction.

$V_{nnp}/V_{nnf} = 0.1\%$

Where,

$V_{nnp}$ : the volume of nanoparticles in solution

$V_{nnf}$ : the volume of obtain nanofluid solution

After getting accurate weight of nanoparticles corresponding with volume of pure water, pure water and nanoparticles were mixed with the aid of ultrasonic vibration machine in 4 hours.

A schematic diagram of experimental apparatus is described in Fig. 1. In this figure, we can see all the equipment that is used during the experiment. It is important to point out that the self-oscillating heat pipe is made in Laboratory of Kumamoto University – Japan and the detailed drawing of the self-oscillating heat pipe can be found in Fig. 2. The heat pipe is heated on the heating section by the heater block which is made by copper containing 5 heaters inside. Also thermo-glue is used between two surfaces to improve heat transfer (5 heaters are not shown in this figure). Here, the working fluid in the insulated fort tubes is independentlly oscilated between the cooling and heating parts, as seen in Fig. 2.

In this experiment, the working was Alumina nanofluid 0.1% volume fraction. The fill charge ratio $f_{cr}$ which is ratio between fill charge volume of Alumina nanofluid 0.1% volume fraction and internal evaporator section volume, was changed from 30% to 100% at 10% interval. Here, 100% implies that the evaloration section is filled with the working fluid. The heat fluxes q applied to the evaporator section for each case of fill charge ratio were 5W/㎠, 10W/㎠, 15W/㎠, 20W/㎠, 25W/㎠ and 30W/㎠, respectively. After getting result and comparing heat transfer performance between the fore going fill charge ratios, we could obtain the optimal fill charge ratio of the heat pipe corresponding to the heat flux. The temperature of each section of the heat pipe was measured with thermocouples.

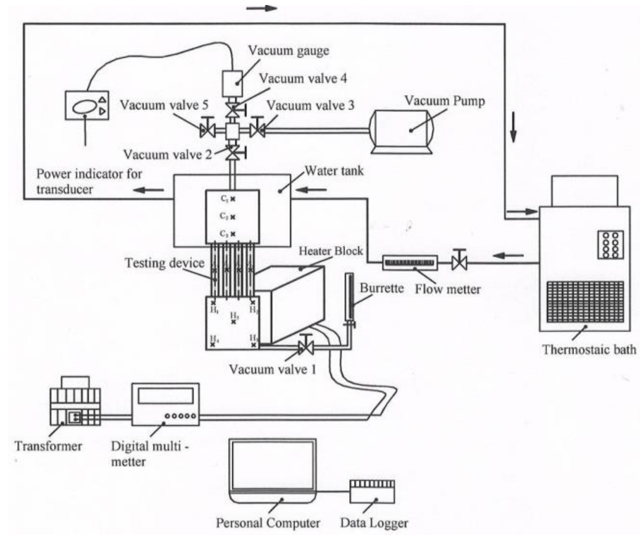


**Figure 1.** Schematic design of the experimental apparatus

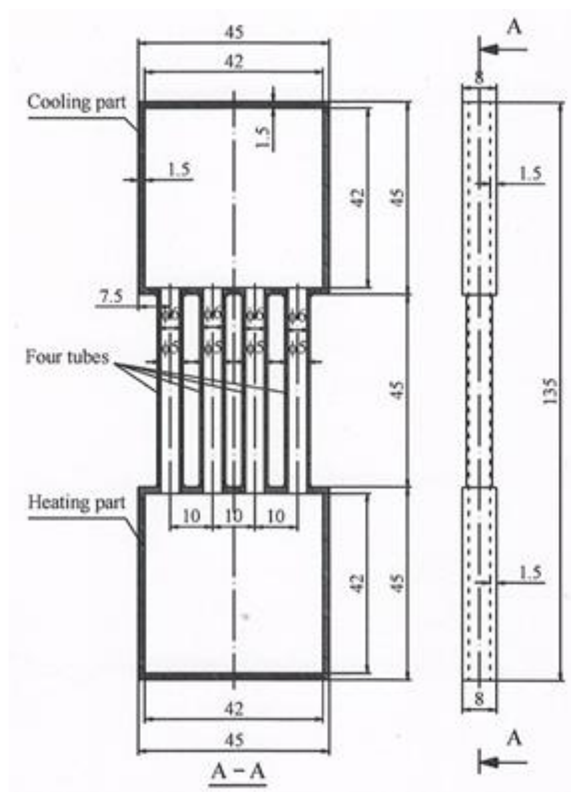


**Figure 2.** Structure of self oscillating multi heat pipe (unit inmm)

The inlet temperature of the cooling water was set at 15°C using the controllable thermostatic bath and was supplied to the water tank at rate of 3.5l/min. After filling a calculated amount of working fluid in the heat pipe, a 7400Pa vacuum pressure was maintained to create self-oscillating heat transfer. In order to get accurate vacuum pressure value, the vacuum pressure value was read on the power indicator transducer after 20 minutes and when changing from one fill charge ratio to another, the working fluid was filled when the evaporator section of the heat pipe was 25°C. Temperature was measured until experiment reachs a steady state and the steady time is at least 30 minutes. During experiment, the adiabatic section and evaporator section was insulated with fiber glass to prevent heat loss, and the condenser section was inserted to a water tank made by plastic containing cooling water circularly flowed from the thermostatic bath.

## DATA REDUCTION

Effective thermal conductivity is calculated as following equation:

$$Q = NAq' = NA k_{eff} \frac{T_H - T_c}{L}$$

$$k_{eff} = \frac{QL}{NA(T_H - T_c)} \quad (1)$$

Where Q is total heat load, q' is the heat flux from evaporator section to the condenser section, L is the length from the center of evaporator section to the condenser section, approximately the distance between $T_H$ measured point and $T_C$ measured point. N is the number of tubes of the adiabatic section (N=4). A is the heat flux area of the inner part of the tube in the adiabatic section ($m^2$). A=($\pi d^2$)/4. From equation (1), we obtain

$$k_{eff} = \frac{L}{NA}\frac{Q}{(T_H - T_c)} = \frac{L}{N\pi d^2/4}\frac{Q}{(T_H - T_c)} \quad (2)$$

Where L=0.1m, N=4, and d=0.005m

Applying with numerical value of L, N, and d we obtain,

$$k_{eff}=1273.88\ Q/((T_H - T_C)) \quad (3)$$

All data collected here are calculated using the above equation and effective thermal conductivity versus fill charge ratio are shown for different volume fractions.

## RESULTS AND DISCUSSION

From the result of the temperature of the evaporator and condenser section, we obtain effective thermal conductivity of the heat pipe. Figures 3 to 6 show the variation of effective thermal conductivity $k_{eff}$ versus fill charge ratio $f_{cr}$. As shown in Figs. 3 to 6 at all six constant heat fluxes, effective thermal conductivity of heat pipe tends to increase when fill charge ratio increases. In other words, the effective thermal conductivity becomes higher with an increaee in the fill charge ratio. From Figs. 3 to 6, the increase in effective thermal conductivity $k_{eff}$ is increasing gradually similar if compare to other heat fluxes. This can be explained that when heat flux is applied to the evaporator section of the heat pipe increases, high amount of heat transfer throught the wall of the heat pipe to the condenser section was cooled properly by cooling water. Therefore, heat transfer efficiency increases. In addition, the increasing of fill charge ratio $f_{cr}$ helps to tranfer large amount of heat from evaporator section to condenser section to enhance heat transfer efficiency. In other words, high temperature at higher fill charge ratio makes condensation performance increase and this corresponds to an increase in heat transfer performance. Thus, this type of heat pipe shows excellent transport characteristic even for a very simple structure.

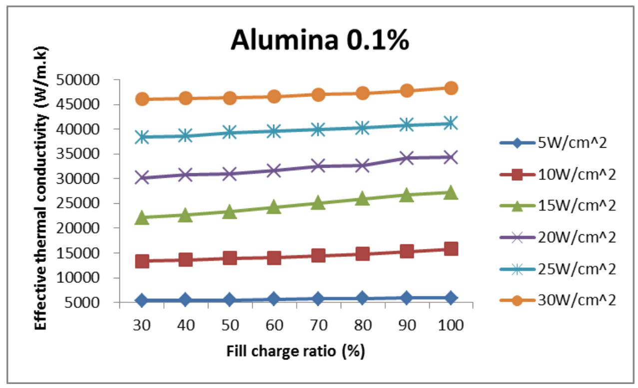


Figure 3. Effective thermal conductivity of the heat pipe versus fill charge ratio

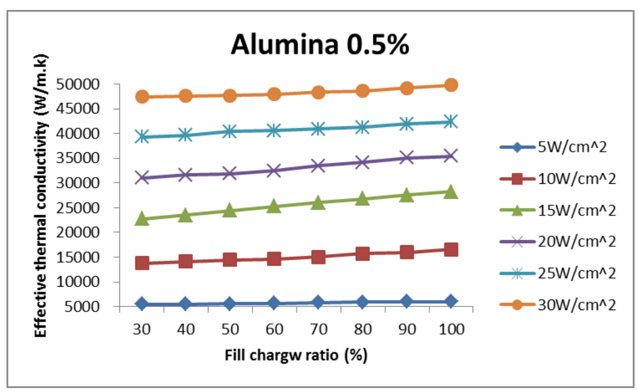


Figure 4. Effective thermal conductivity of the heat pipe versus fill charge ratio

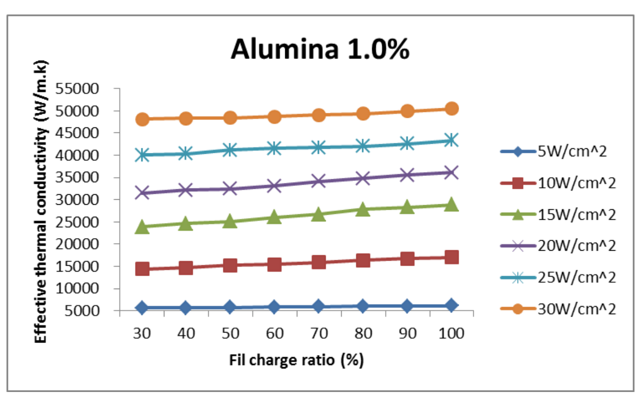


Figure 5. Effective thermal conductivity of the heat pipe versus fill charge ratio

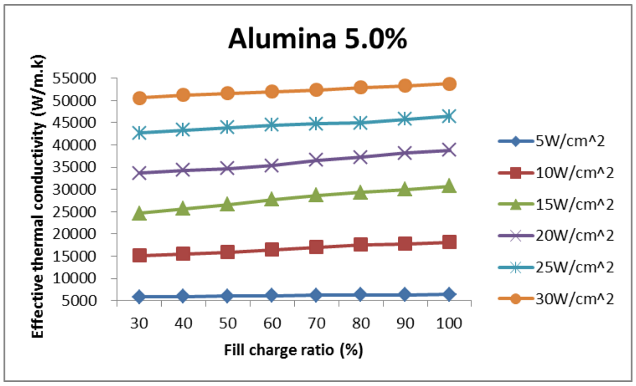

Figure 6: Effective thermal conductivity of the heat pipe versus fill charge ratio

Figures 7 to 10 show the variation of effective thermal conductivity $k_{eff}$ versus fill charge ratio $f_{cr}$. As shown in Figs. 7 to 10 at four different heat fluxes, effective thermal conductivity of heat pipe tends to increase when fill charge ratio increases. In other words, the higher fill charge ratio corresponds to the higher effective thermal conductivity. From Figs. 7 to 10, the effective thermal conductivity $k_{eff}$ is amplifying gradually with an increase in heat flux. This can be explained that when volume fraction increases the surface area increases. Thus, heat transfer coefficient increases. An increase in surface area yields the increasing of effective thermal conductivity. The volume fraction effects heat transfer performance.

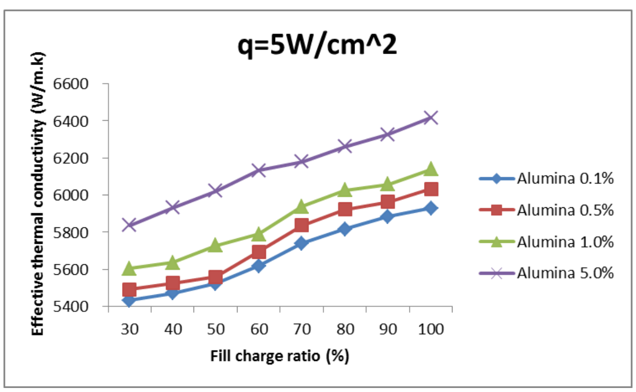

Figure 7. Effective thermal conductivity of the heat pipe versus fill charge ratio

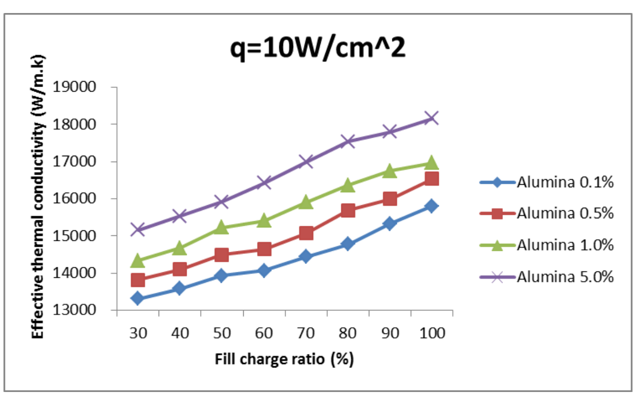

Figure 8. Effective thermal conductivity of the heat pipe versus fill charge ratio

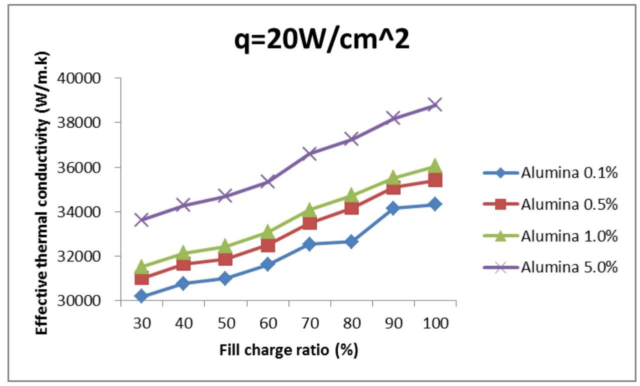

Figure 9. Effective thermal conductivity of the heat pipe versus fill charge ratio

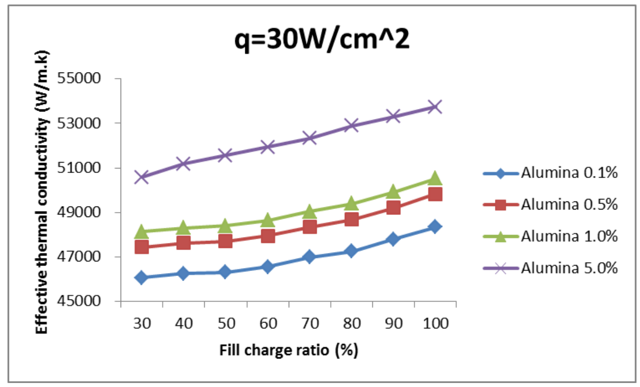

Figure 10. Effective thermal conductivity of the heat pipe versus fill charge ratio

From this result, we can see that with the use of alumina nanofluids with different volume fraction, the effective thermal conductivity of the heat pipe enhances effectively at heat flux $q=10W/cm^2$ for alumina nanofluid 0.5%, 1.0% and 5.0% volume fraction and this enhancement intensifies when heat flux increases. This can be explained that when heat flux applied to the evaporator section of the heat pipe is increased, high amount of heat transfer from the wall of the heat pipe to the condenser section was cooled properly by cooling water. Therefore, heat transfer efficiency increases. In addition, the increasing of fill charge ratio $f_{cr}$ helps to transfer large amount of heat from evaporator section to condenser section. In other words, higher fill charge ratio makes condensation performance increase and this corresponds with an increasing in heat transfer performance. Note that beyond heat flux $q=15W/cm^2$, in the condenser section particles tend to aggregate and this makes the suspension of concentration decrease resulting in attenuation of heat transfer enhancement. However, we can conclude that this type of heat pipe shows excellent transport characteristic even for a very simple structure.

## CONCLUSION

When heat flux was applied, the higher volume fractions (%) with higher fill charge ratio $f_{cr}$ the higher effective thermal conductivity $k_{eff}$.

1. This multi heat pipe has capability to increase heat transfer performance corresponding with the increase of heat fluxes in all four cases of using

alumina ($Al_2O_3$) with 0.1%, 0.5%, 1.0% and 5.0% volume fraction.

2. The effective heat transfer performance is intensified with an increase in volume fraction. This trend becomes larger the higher heat flux.
3. The heat transfer performance of this multi heat pipe can be enhanced around 15% when alumina ($Al_2O_3$) with 0.1% volume fraction is replaced by alumina ($Al_2O_3$) 5.0%.

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