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# Graphene nanoplatelets nanofluids thermal and hydrodynamic performance on integral fin heat sink

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ABSTRACT

In this work, graphene nanoplatelets nanofluids (GNPs) thermal and hydrodynamic performance is observed experimentally in comparison with distilled water on integral fin heat sink. Water based GNPs nanofluids is used with 10% weight concentration. Experimentation is performed in laminar range at heat flux of 47.96 $KW/m^2$, 59.95 $KW/m^2$ and 71.94 $KW/m^2$. Higher pumping power is noticed for GNPs nanofluids as compared to distilled water. From inlet to outlet of heat sink, rise of local base temperature is observed for both distilled water and GNPs nanofluids. With the increase of heat flux, GNPs nanofluids thermal performance decreases. Using GNPs nanofluids, the lowest base temperature and maximum convective heat transfer enhancement is noted as 36.81 °C and 23.91% corresponding to Reynolds number of 972 for heat flux of 47.96 $KW/m^2$, respectively. Pumping power requirement depends upon flow rate and heat flux, and it is found to be maximum 0.04 W for GNPs nanofluids at heat flux of 47.96 $KW/m^{2.}$

## 1. Introduction

With the advancement of electronics industry, heat dissipation from electronics chips is being increased, and it is reached up to 100 $W/cm^2$ [1]. Consequently, there was a need of an ideal cooling method to remove this excessive heat for its proper performance and life as air cooling method had become insufficient for high heat removal aptitude. Due to air limitations, researcher's attention was moved to smart liquid cooling techniques. In this context, nanofluids which contain small dispersed nanoparticles had proven promising candidate for heat removal applications.

Three decades ago, Tuckerman and Pease [2] used microchannels for thermal management of microprocessor, in which higher surface area was available for heat transfer. They investigated performance of silicon made microchannels using water as coolant. Although, they found, heat transfer performance was increased with higher surface area. However, they also noticed a great increase in pressure drop using microchannels. Their investigation gave new direction to researchers. Particularly, after the discovery of nanofluids by Choi and Eastman [3], the applications of microchannels further increased. After this innovation, Kandlikar et al. performed series of investigation on microchannels using liquid as coolant. They found 4–10-fold increment in heat transfer using liquid as a coolant than that of air [4–6].

Sohel et al. [7] experimentation showed that increase of volumetric concentration of $Al_2O_3/H_2O$ nanofluid in range 0.1–0.25%, increased thermal effectiveness. However, they also found that thermal effectiveness was not necessarily increased with the increase of flow rate. They found 18% convective heat transfer coefficient enhancement using 0.25% concentrated $Al_2O_3/H_2O$ nanofluid as compared to distilled water.

Liquid impingement cooling is also very useful technique in terms of heat transfer enhancement. Naphon and Wongwises [8] used this technique to lower the base temperature, and found significant temperature reduction than conventional cooling systems. They observed that the velocity was one of the dominant factors in heat transfer rate. Heat transfer enhancement was increased with a decrease in inlet diameter of the nozzle.

Singh et al. [9] demonstrated the effects of three volumetric concentrations of 0.25%, 0.5% and 1.0% of $Al_2O_3$ nanoparticles in base fluid, mixture of water and ethylene glycol. They used two different nanofluids having particle sizes of 45 nm and 150 nm along with microchannels having hydraulic diameters of 130 μm, 211 μm and 300 μm. They found that nanofluids in microchannels did not behave like single phase. They also found that transition phenomenon from laminar to turbulence occurred quickly for 211 μm and 300 μm due to higher surface roughness.

Anoop et al. [10] used three weight concentrations 0.2%, 0.5%, 1% of $SiO_2/H_2O$ nanofluids to find heat transfer rate flowing through poly di-methyl siloxane microchannels in Reynolds number range of 4–22. They found that nanofluids was more effective

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**Nomenclature**

| | |
|---|---|
| $A$ | area, m$^2$ |
| $A_c$ | cross sectional area of channel, m$^2$ |
| $C_p$ | specific heat, J/kg°C |
| $d$ | diameter, m |
| $d_h$ | hydraulic diameter, m |
| $h$ | convective heat transfer coefficient, W/m$^2$ °C |
| $h_f$ | fin height of heat sink, m |
| $h_t$ | total height of heat sink, m |
| $H_w$ | distance b/w thermocouple and wall, m |
| $k$ | thermal conductivity, W/m °C |
| $L$ | total length of heat sink, m |
| $LMTD$ | log mean temperature difference, °C |
| $\dot{m}$ | mass flow rate, kg/s |
| $n$ | empirical shape factor |
| $Nu$ | Nusselt number |
| $P_c$ | perimeter of channel, m |
| $Pr$ | Prandtl number |
| $Q$ | heat flow rate, W |
| $Q_f$ | flow rate, m$^3$/s |
| $Re$ | Reynolds number |
| $R_{th}$ | thermal resistance of heat sink, °C/W |
| $T$ | temperature, °C |
| $v_{max}$ | maximum velocity, m/s |
| $W$ | total width of heat sink, m |
| $w$ | weight fraction |
| $w_c$ | channel width of heat sink, m |
| $w_{cc}$ | center to center distance of two consecutive microchannel, m |
| $w_f$ | fin width of heat sink, m |

*Greek symbols*

| | |
|---|---|
| $\mu$ | viscosity, kg/ms |
| $\varnothing$ | volume fraction |
| $\rho$ | density, kg/m$^3$ |

*Subscripts*

| | |
|---|---|
| *avg* | average |
| $b_f$ | base fluid |
| *e* | effective |
| *f* | fin |
| *hs* | heat sink |
| *in* | inlet |
| *m* | mean |
| *nf* | nanofluid |
| *np* | nanoparticle |
| *out* | outlet |
| *r* | room temperature |
| *tc* | thermocouple |
| *wl* | wall |

in term of heat transfer at lower Reynolds number as compared to higher Reynolds number.

Nazari et al. [11] performed experimental investigation on CPU cooling using water based carbon nanotubes (CNT) and alumina nanofluids. They also tested ethylene glycol having 30% and 50% vol. concentration with base fluid water and compared results of all tested fluids with water. They found 13% enhancement in convective heat transfer coefficient by 0.25 (%w/w) CNT nanofluid and 6% enhancement by 0.5 (%w/w) alumina nanofluid. Results of their investigation also showed that 30% ethylene glycol was more efficient as compared to 50% ethylene glycol.

Ho et al. [12] assessed $Al_2O_3/H_2O$ nanofluid forced convection heat transfer. They observed 1% vol. nanofluid was more efficient than that of 2% vol. nanofluid due to more variation occurrence in dynamic viscosity with temperature. Using 1% vol. concentrated $Al_2O_3/H_2O$ nanofluids, 70% enhancement was found in convective heat transfer coefficient.

Thermal performance is highly dependent on heat sink material and its surface roughness. Tullius and Bayazitoglu [13] observed effects of 0.01% vol. concentrated alumina/water nanofluid on pure, along with 6 × 12 fin array and fully grown MWCNTs silicon minichannels. They found, 58%, 84% and 136% more heat flux could be applied using pure, fully MWNCTs grown and 6 × 12 fin array minichannels respectively, while keeping constant base temperature. Further, Vanapalli and Brake [14] research revealed that heat transfer capabilities of nanofluids were highly dependent on heat sink geometry and flow conditions. They also derived a correlation relating heat transfer potential with viscosity, specific heat and thermal conductivity.

According to continuum-level phenomenological devising, thermal and dynamic performance is dependent on particle size and volumetric concentration. Ray et al. [15] had compiled a correlation for thermal/dynamic performances, accounting particle size and volumetric concentration of nano- particles. Experimentally, they used ethylene glycol and water mixture based nanofluids; alumina, silicon dioxide and copper oxide with 1% vol. concentration on minichannels. All fluids showed better performance as compared to base fluid. Ferrouillat et al. [16] studied shape factor effects of two different nanofluids, $SiO_2/H_2O$ and $ZnO/H_2O$ with two different morphologies. They found small enhancement in Nusselt number for nanofluids with respect to base fluid.

Chein and Chuang [17] experimentally measured the thermal superiority of $CuO\text{-}H_2O$ nanofluids against base fluid. They used silicon microchannels heat sinks with four concentration of $CuO\text{-}H_2O$ nanofluids and found that nanofluids at low flow rates were more effective and well correlated with analytical model. They also noticed reduction in particle agglomeration at high mean temperature. Further, Chein and Huang [18] used $Cu/H_2O$ nanofluids with different concentrations on two different microchannels. They found that, no extra pressure drop occurred by nanofluids due to low volumetric concentration and small size of dispersed particles.

Rafati et al. [19] investigated cooling performance of water/ethylene glycol based dispersed titania, alumina and silica nanofluids under real computer processor condition. They observed decrease in processor temperature with the increase of flow rate. They measured alumina as best of three nanofluids, which decreased temperature up to 5.5 °C as compared to base fluid using 1% vol. Naphon and Khonseur [20] experimentally explored the effects of forced convection heat transfer of air in the Reynolds number range of 200–1000. They found that pressure drop was increased with surface roughness. However, they also noticed surface roughness important role in heat transfer enhancement. Ali and Arshad [21] investigated effects of staggered and inline pin fin heat sink heat transfer performance. They observed that staggered geometry is much better than inline geometry because of better interaction of fluid with pin fin and correspondingly they found 61.13% enhancement in average Nusselt number.

Some researchers also explored nanofluids heat transfer enhancement effects in two phase flow. Lee and Mudawar [22] investigated two phase flow heat transfer effects using microchannels with water and 1% and 2% vol. concentrated $Al_2O_3$/water nanofluids and compared results with single phase

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