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Experimental Investigation of Natural Convective Heat Transfer of a Bio-Inspired (*Mangifera Indica*) Leaves Nanofluid in a Square Enclosure

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ABSTRACT

The enhancement of heat transfer by thermal systems using nanofluids has been reported. The challenges reported associated with metallic oxide-based nanofluids include toxicity as it affects human health and the high cost of nanoparticle production. Researchers have demonstrated the use of bio-inspired materials for the production of nanofluids to overcome those challenges. This study investigates the effect of particle concentration, the temperature difference between the hot and cold side, and the Nusselt number on the natural convection heat transfer process of mango (Mangifera indica) leaves-based nanofluid. The transient hot wire method was used to measure the thermal conductivity of the nanofluid. This study also evaluated the nanofluid heat transfer characteristics. The effects of volume fraction and the size of particles on the convective heat transfer coefficients were also investigated. The experimental results showed that the Nusselt number decreases as the volume fraction increases and using nanofluid in a cavity causes a decrease in effective heat transfer coefficients.

Keywords: Nanofluids, Nusselt Number, Heat Transfer, Thermal Conductivity

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1.0 INTRODUCTION

The low heat transfer performance of conventional fluids obstructs the performance enhancement and the compactness of engineering equipment.An effective way of improving the thermal conductivity of these heat transfer fluids is to suspend small solid particles in the fluids [1]. The dilute suspension of nanometer-sized particles or fibers dispersed in a liquid is known as nanofluid. The dilution of such particles in the basefluid changes the physical properties of the mixture such as viscosity, density, and thermal conductivity.

The use of conventional nanoparticles for the production of nanofluid is faced with the problem of toxicity and cost of nanoparticles. Several researchers have investigated experimentally the effective thermal conductivity of fluids containing particles. The transient hot wire method [2], the steady-state parallel-plate technique [3], and the temperature oscillation technique [4] have been employed to measure the thermal conductivity of nanofluids. Among these, the transient hot wire method has been used most extensively. Because in general nanofluids are electrically conductive, it is difficult to apply the ordinary transient hot-wire technique directly. A modified hot-wire cell and electrical system was proposed and constructedby coating the hot wire with an epoxy adhesive which has excellent electrical insulation and heat conduction [5].

Concentration of ions of the conducting fluids around the hot wire may affect the accuracy of such experimental results [4]. The oscillation method was proposed by Roetzel et al[6] and further developed by Czarnetski and Roetzel[7]. This method is purely thermal and the electrical components of the apparatus are removed from the test sample. Hence ion movement should not affect the measurement. Alumina (Al_2O_3) and copper oxide are the most common and inexpensive nanoparticles used by many researchers in their experimental investigations. All the experimental results have demonstrated the enhancement of the thermal conductivity by the addition of nanoparticles.

Eastman [8] measured the thermal conductivity of nanofluids containing Al_2O_3, CuO, and Cu nanoparticles with two different basefluids: water and HE-200 oil. A 60% improvement of the thermal conductivity was achieved as compared to the corresponding basefluids for only 5 vol% of nanoparticles. They also showed that using Cu nanoparticles (using the one-step method) results in greater improvements than that of CuO (using the two-step method).Lee et al. [9] suspended CuO and Al_2O_3 (18.6 and 23.6 nm, 24.4 and 38.4 nm, respectively) in two different basefluids: water and ethylene glycol (EG) and obtained four combinations of nanofluids: CuO in water, CuO in EG, Al_2O_3 in water and Al_2O_3 in EG. Their experimental results showed that nanofluids have substantially higher thermal Conductivities than the same liquids without nanoparticles. The CuO/EG mixture showed enhancement of more than 20% at 4 vol% of nanoparticles. In the low volume fraction range (<0.05% in the test), the thermal conductivity ratios increase almost linearly with volume fraction. Results suggest that not only particle shape but size is considered to be dominant in enhancing the thermal conductivity of nanofluids. Wang et al. Wang et al [10] measured the effective thermal conductivity of nanofluids by a steady-state parallel-plate technique. The basefluids (water, ethylene glycol (EG), vacuum pump oil, and engine oil) contained suspended Al_2O_3 and CuO nanoparticles of 28 and 23 nm average diameters, respectively. Experimental results demonstrated that the thermal conductivities of all nanofluids were higher than those of their basefluids. Also, a comparison with various data indicated that the thermal conductivity of nanofluids increases with decreasing particle size. Results demonstrated a 12% improvement of the effective thermal conductivity at 3 vol% of nanoparticles compared to a 20%

improvement reported by Masuda et al. [12] and 8% reported by Lee et al. [9] at the same particle volume fraction.

The thermal conductivity of water was enhanced using Cu particles of comparatively large size (100 nm) to the same extent as has been found using CuO particles of much smaller dimension (36 nm) [12]. An appropriate selection of dispersants may improve the stability of the suspension. They used oleic acid for transformer oil- Cu nanofluids and laurate salt for water-Cu suspension in their study and found that Cu particles in transformer oil had superior characteristics to the suspension of Cu particles in water. They also investigated convective heat transfer and flow features in a tube. They measured both the convective heat transfer coefficient and friction factor[13]; the tube wall temperatures, inlet and outlet temperatures of the sample nanofluid, mass flow rates, and electric power inputs as well as static pressure. They concluded that the suspended nanoparticles remarkably enhance the heat transfer process and the nanofluid has a larger heat transfer coefficient than that of the original basefluid under the same Reynolds number and the heat transfer features of a nanofluid increase with the volume fraction of nanoparticles. They also claimed that the friction factor for the nanofluids at low volume fraction did not produce an extra penalty in the pumping power.
For forced convective heat transfer, Lee and Choi [14] studied the heat transfer behavior in parallel channels using an unspecified nanofluid. They observed a reduction in thermal resistance by a factor of 2.

Heris *et al.*[15] investigated the laminar flow of CuO/water and Al_2O_3/water nanofluids through a 1 m annular copper tube with a 6 mm inner diameter and 0.5 mm thickness and 32 mm diameter outer stainless steel tube, where saturated steam was circulated to create a constant wall temperature boundary condition rather than the constant heat flux condition employed by other researchers. A comparison of experimental results showed that the heat transfer coefficient enhanced with increasing volume fraction of nanoparticles, as well as Peclet number, while Al_2O_3/water showed more enhancement. They also claimed in their studies that the heat transfer enhancement of nanofluids is not only caused by the thermal conductivity increase, but also attributed to other factors such as dispersion and chaotic movement of nanoparticles, Brownian motion, and particle migration, and so on.

Ding *et al.* [16] investigated the heat transfer performance of CNT nanofluids in a tube with a 4.5 mm inner diameter. They found that the enhanced heat transfer coefficient is much higher than the increase in the thermal conductivity of the nanofluid for the various volume fractions. They associated the possible reasons with the improved thermal conductivity, shear-induced enhancement in flow, reduced boundary layer, particle re-arrangement, and high aspect ratio of CNTs. These observations suggest that the aspect ratio should be associated with the high enhancement of heat transfer performance of CNTs-based nanofluids.

Natural convective heat transfer in a cavity
Natural convection is convection where the fluid motion is driven by buoyancy forces. A few works have been published by researchers on natural convection.

Arefmanesh and Tavakoli[17] procured a numerical solution through an application of the meshless local Petrov-Galerkin (MLPG) method to the 3D natural convection fluid flow and heat transfer in a cubic cavity filled with nanofluids. The left and the right vertical sidewalls of the considered cavity were maintained at constant temperatures T_h and T_c, respectively,

with $T_h > T_c$. The remaining walls of the cavity were insulated. They used three different nanofluids, Al_2O_3-water, Cu-water, and TiO_2-water for the experiment with various volume fractions of the nanoparticles. They also investigated the effect of the Rayleigh number and the volume fraction of the nanoparticles on the characteristics of the natural convection inside the cavity. They reported that the average Nusselt number increased with an increased volume fraction of the nanoparticles.

Ben-Cheikh *et al.*[18]numerically studied water-based nanofluids under natural convection in a square enclosure with non-uniform temperature distribution maintained at the bottom wall and filled with nanofluids using different types of nanoparticles. They kept the remaining walls of the enclosure at a lower temperature. Calculations were performed for Rayleigh numbers in the range $5 \times 10^3 \leq Ra \leq 10^6$ and different solid volume fractions of nanoparticles for 0, 0.1, and 0.2 %. They reported that an enhancement in heat transfer rate was observed with the increase of nanoparticle volume fraction for the whole range of Rayleigh numbers. They also reported that the heat transfer enhancement strongly depends on the type of nanofluids. For $Ra = 10^6$, the pure water flow became unsteady.

Parvin *et al.*[19] investigated the heat transfer performance and entropy generation of natural convection inside an odd-shaped cavity filled with Cu-water nanofluid. They focused specifically on the effect of natural convection parameters on the mean Nusselt number, total entropy generation, and Bejan number. Penalty finite element method with Galerkins weighted residual technique [20] was used to solve the governing equations. The results revealed that the average Nusselt number increases and the total entropy generation decreases as the Rayleigh number increases. They concluded that the proper choice of Rayleigh number could be able to maximize heat transfer rate while simultaneously minimizing entropy generation.

Nasrin *et al.*[21] investigated the influences of variable thermal conductivity and viscosity depending on temperature across a horizontal thin nanofluid layer. The water-based nanofluid with copper nanoparticles was used as the working fluid inside the layer. The governing partial differential equations with proper boundary conditions were solved by Finite Element Method using Galerkin's weighted residual scheme [20] with discretization by triangular mesh elements. The effects of temperature-dependent thermal conductivity and viscosity related to performance such as temperature and velocity distributions, heat transfer, mean temperature, and velocity of the nanofluid were also investigated by the researchers. Their results showed that the better performance of heat transfer inside the nanofluid layer is found by using the highest and lowest values of variable thermal conductivity and viscosity respectively.

Hasan and Mahmood [22] numerically studied Transient natural convection heat transfer and fluid flow of Al_2O_3-water nanofluid in an enclosure. They applied Isothermal boundary conditions to the horizontal walls of the enclosure, while the two vertical ones were kept adiabatic. The governing equations were discretized using the finite volume method and SIMPLER algorithm. The results are presented over a range of Rayleigh numbers from 7×10^3 to 5×10^4, volume fraction, $\varphi = 0.02$, and aspect ratio ranging from 0.6 to 1. They reported that different behaviors (enhancement or deterioration) were observed in the heat transfer and fluid flow as the time, Rayleigh number, and aspect ratio increased. They also stated that heat transfer enhancement is more pronounced at high Rayleigh numbers and the heat transfer decreased by increasing the aspect ratio.

Grobler *et al.* [23] investigated the effect of the natural convection of a porous medium on fluid motion driven by buoyancy forces in a cavity. The nanofluid used for the experiment consists of Al_2O_3 nanoparticles in the basefluid of 60 % ethylene glycol (EG) and 40 % water. A Rayleigh number range of $6 \times 10^3 < Ra^* < 1.6 \times 10^4$, for a volume fraction of 0.2 % nanoparticles was considered. They used a porous medium of glass spheres of 16mm. They reported that heat transfer is affected by both the porous medium and the nanofluid. They concluded that the heat transfer in the case of porous media with nanofluid is more than in the case of pure basefluid.

I. RELATED WORKS

Research into the use of biomass for the production of bio-material nanofluids has been investigated in the recent past to finda solution to problems associated with the use of conventional nanofluids. Awua *et al*. [24] investigated the thermo-physical properties of nanofluids prepared from palm kernel fibers with the aim of improving the thermal conductivity of the basefluid. They used ethylene glycol with deionized water in a ratio of 40:60 as basefluid and established that palm kernel is environmentally friendly with enhanced thermal conductivity properties. They recommended that it can be used as an alternative source for nanofluid production to enhance heat transfer. Sharifpur et al [25] also investigated the thermal conductivity and viscosity of Mango bark/water nanofluid and reported an enhancement of the thermal conductivity of the base fluid on the dispersion of mango bark nanoparticles.

Barki et al [26] also investigated the use of mango bark for the preparation of nanofluid. In their paper titled ‘Preparation, Stability, and Viscosity of Nanofluid Produced from Mango Bark (*Mangifera Indica*) Fibres’ stated that Preparation of the nanofluid was carried out using a two-step method with de-ionized water as the basefluid. Volume fractions of 0.1% to 4% were used to determine the stability of the nanofluid with de-ionized water and by adding various surfactants using the sedimentation method. The viscosity of the fluid was also investigated for volume fractions up to 4% at varying temperatures from 10^oc to 60^oc. They reported the good stability of the nanofluid without the use of surfactant and stated that the viscosity of the nanofluid showed variation with the varying volume fraction, particle size, and working temperature. Similarly, the preparation and characterization of both mango bark and mango leaves-based nanofluids were carried out by Chen et al [27]

Usman *et al.*[28] also investigated the use of banana fiber nanoparticles for the production of nanofluids for heat transfer enhancement. Deionized water was used as the basefluid. They reported 35 % enhancement. Labe et al [29] reported on the experimental studies of the viscosity and thermal conductivity of mango (*Mangifera Indica*) leaves-based nanofluid. Their report showed thermal conductivity enhancement of 5.56% at a volume fraction of 0.5% and concluded that *Mangifera indica-based* nanofluid has the potential to be a good alternative for metallic oxide-based nanofluid for heat enhancement. Other researchers also further investigated the effectiveness of using Mangifera indica-based nanofluid for heat transfer enhancement. A numerical investigation of the Mango-Leaves water nanofluid under a laminar flow region was carried out by Onyiuriuka and Ikponmwoba [30]. Similarly, Solomon et al [31] investigated the convective heat transfer with water-based Mango bark nanoparticles. Results showed a deteriorating heat transfer with the use of mango nanoparticles in the cavity.

MATERIALS AND METHODS

EXPERIMENTAL SETUP AND PROCEDURE

Natural convection setup consisted of two thermal baths (cold and hot) placed side by side with pvc pipes connected with valves and pressure gauges and a square cavity box with dimensions 120.04 x 96.3 x 102.3mm (W x H x L) connected to two water baths at varying temperature (cold and hot) the cavity was placed inside an insulating box with an insulating lid, to prevent heat loss as shown in plat 1. The cavity contains thirty-one thermocouples for taking temperatures in quick succession when the system is on.

This system is connected to a desktop with software that reads and records both the temperature and current of the thermocouples. The cavity capacity is 1200ml, well lagged and sealed to avoid heat loss. At the bottom of the cavity is a drain, well screwed. It is meant for draining used samples via a hose connected at the bottom of the box to a discharge container. Using the above described set-up, the cavity, being the test region was carefully washed with distilled water many times before filling with the test fluid. 1200ml of the basefluid was first measured using measuring Cylinder of 1000 ml and poured into the cavity and sealed. The hot bath was kept at a constant temperature of 55^{o}C while the cold thermal bath was set at 10^{o}C and the system was left to run for at least two hours for thermal equilibrium to be achieved between the sample and its environment. The software was then allowed to run for at least 5 minutes where data acquisition into Microsoft excel file takes place. The cold thermal bath temperature was then raised to 15^{o}C and the next reading was taken after two hours and the process continues in that order for every 5^{o}C increase of the cold thermal bath temperature. Readings were taken up to 25^{o}C of the cold thermal bath.



Plate 1: The cavity box for Determining Natural Convection

The data acquired were for the temperatures of the thirty-one thermocouples. Their averages were taken due to their bulky nature. This was then transferred to the master spreadsheet which contains all the parameters to be investigated. The figure below shows a schematic view of the experimental setup

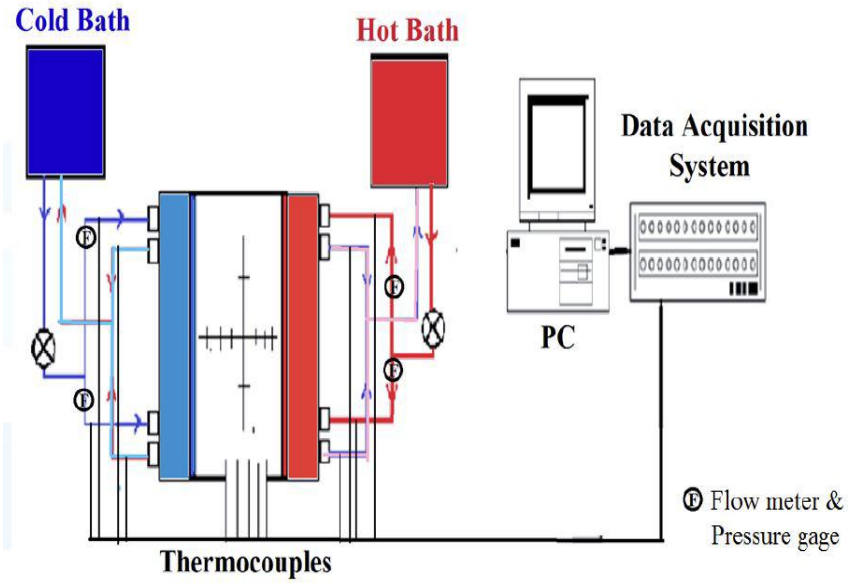


Figure 1: Schematic of Experimental Setup for nanofluid flow in a cavity by natural convection

The cold wall temperature was kept constant and the hot wall temperature was varied. Nanoparticles of mango leaves were used for this experiment. 0.1%, 0.5%, 1%, 2% and 3% volume of the nanoparticles were used for the experiment. The bulk density of mango leaves nanoparticles was used to determine the volume fraction. The weight of the nanoparticle was measured using RADWAG precision balance (as 220.R2). The mixture was sonicated using Q700 ultrasonicator (Q sonica, USA) for 1 hour for each volume fraction. 1.2 litres of 0.1% volume fraction of the nanofluid was poured carefully into the cavity after the cold and hot baths and a computer, where data was automatically recorded were switched on. The temperature of the cold bath was maintained as 5^0c while the temperature of the hot bath was varied for 55^0c, 50^0c, 45^0c and 40^0c respectively.

When the cold temperature was set at 5^0c and hot temperature 55^0c the flow was allowed to reach a steady state after 1 hour. The system was run for 5 minutes. Data obtained was exported to excel and saved. Then the cold and hot bath temperature ware regulated as shown in table 2 above and experiment repeated.

The experiment was also repeated for volume fractions of 0.5%, 1%, 2% and, 3%, data obtained were exported to excel and saved.

The experiment is assumed to be done in an adiabatic cavity with the following dimensions:

L (length of cavity) = 102.3mm
H (height of cavity) 96.3mm
W (width of cavity) 120.04mm

M (mass flow rate of hot water) = 0.0149 kg/s

$T_{ave\ w}$ = average temperature of water inlet and outlet of hot wall of cavity

$$T_{ave\ w} = \frac{T(CH_{00}) + T(CH_{23})}{2} + 273.15$$

To calculate the value of heat flux and Nusselt number for the hot wall

$Q = \dot{m} \times (C_p)_w \times [T(CH_{00}) - T(CH_{23})]$ J/s

The heat capacity of hot water for different temperatures are estimated with 2 polynomial function, each one for one range of temperature

If $T_{ave\ w} < 310k \longrightarrow (C_p)_w = 4178 + 0.44 \times (310 - T_{ave\ w})$

If $T_{ave\ w} > 310k \longrightarrow (C_p)_w = 4188 - 0.33 \times (340 - T_{ave\ w})$

The Nusselt number was calculated using equation below and tabulated in table below

$$Nu = \frac{QxL}{WxHx\,(T_H - T_C)x(K_{eff})_{.stagnation}}$$

T_H = average temperature on the hot wall.

T_C = average temperature on the cold wall.

ρ_{mango} leaves = 1.5396 g/cm^3

III. RESULTS AND DISCUSSIONS

Figure 2 shows the variation of heat flow (Q) with concentration for mango leaves based nanofluid in a cavity. For 0% volume fraction (de-ionized water) the effective heat transfer is 49.87W/m^2, the heat flow increased from 49.87 W/m^2 to 50.50 W/m^2 when 0.1% volume fraction of mango leaves nanoparticles was dispersed in the basefluid. The effective heat flow decreases to 44.89 W/m^2 for volume fraction of 0.5%. It decreased to 44.26 and 26.81 W/m^2 for 1.0 and 2.0% volume fractions respectively.

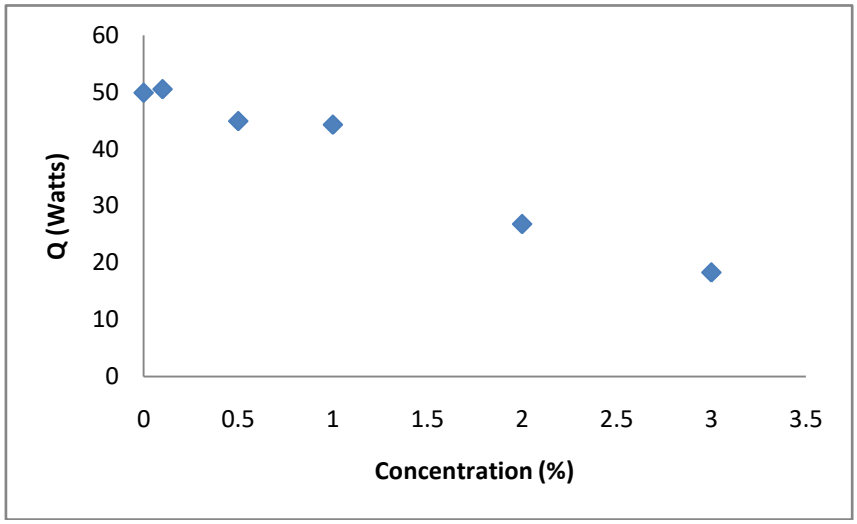


Figure 2: Variation of Heat Flow (Q) with Concentration

Increase in concentration of the nanoparticles affects the effective heat flow as it decreases as concentration increases. The present experimental results show that using nanofluid in cavity causes decrease in effective heat transfer coefficients.

The equation used by Parvin et al, [19] to determine the Nusselt number was used in this present work. Figure 3 shows the variation of Nusselt number (Nu) with concentration. The

result shows that the Nu at 0% volume fraction. i.e when de-ionized water flows under natural convection in a cavity is 3.313. Increasing the concentration by 0.1% volume fraction of the mango leaves nanoparticles increases the Nu to 3.293. Further increase of the nanoparticles to 0.5% volume fraction decreases the Nusselt number. In general, we can say that the Nusselt number decreases as the volume fraction increases during this present work.

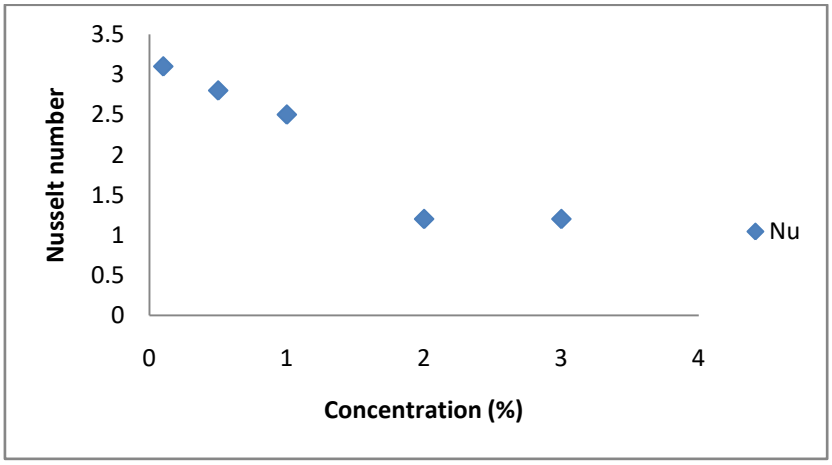


Figure 3: Variation of Nusselt number (Nu) with Concentration

The result is not in agreement with the work presented by Arefimanesh and Tavakoli[17]. They investigated the effect of Nusselt number, Raleigh number and the volume fraction of nanoparticles on the characteristics of the natural convection inside the cavity using three different nanoflinds, Al_2O_3-water, Cu-water and TiO_2-water and reported that the Nusselt number increases with increasing the volume fraction of the nanoparticles.

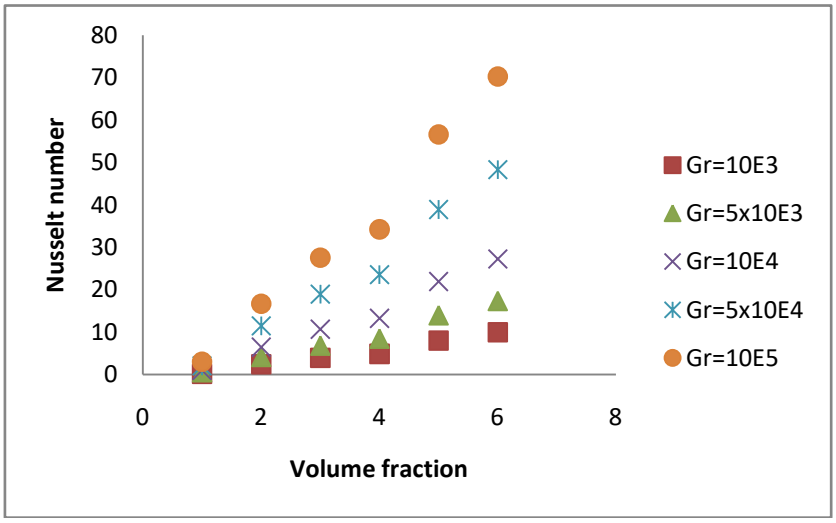


Figure 4: Variation of Average Nusselt Number with Volume Fraction of mango bark based nanofluid for different Gr Number

Figure 4 shows the variation of average nusselt number with volume fraction for different Gr number using the model of khanafer et al [32]. Nu for the present work is simulated using Khanafer et al correction for $10^3 \leq Gr \leq 10^5$ and $0 \leq \theta \leq 3.0$. The result show that Nu number increases with increase in Gr number and volume fraction. The trend for the average nusselt number verses volume fraction would have been downward if the nusselt number is based on the effective thermal conductivity and not the thermal conductivity.

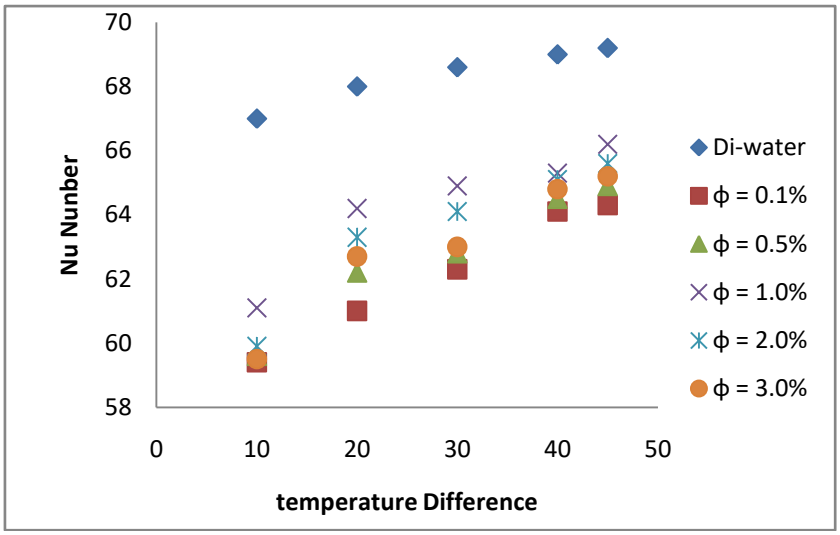


Figure 5: Variation of Nusselt Number with Concentration at the Cold Wall.

Figure 5 shows the variation of Nusselt Number with concentration of nanofluids in the Cold side of the cavity. Result shows that de-ionized water show a uniform rise in Nu number at varying temperature than the nanofluids. Increase in Nu number of the respective nanofluids volume fractions was also observed at varying temperature (i.e increase in temperature). Better performance of the nanofluidis at 1.0% volume concentration. The hot side of the cavity was also studied and observed that the Nu number decreases with increase in temperature as shown in figure 6.

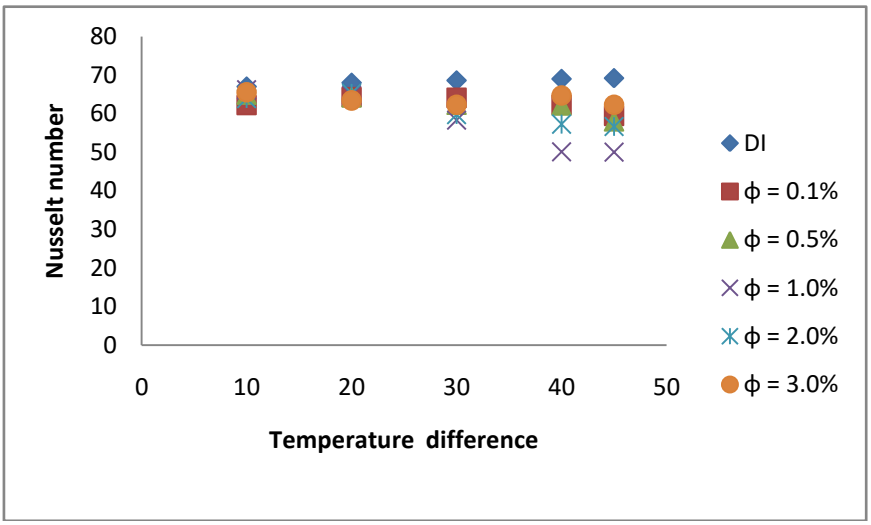


Figure 6: Variation of Nusselt Number with Concentration at the Hot Wall.

IV. CONCLUSIONS AND FUTURE SCOPE

It has been established by different researchers that *Mangifera indica* nanoparticles has the potential to enhance heat transfer when dispersed in basefluids. This work experiments on the behavior of *Mangifera indica* leaves nanoparticles in a cavity under natural convectiveheat transfer. The heat flow for 0.1% volume fraction was slightly enhanced but the heat flow kept decreasing as the volume fraction was increased. The Nu number also decreases with increase in volume fraction. However it was observed that the Nu number increased with increased in Grashof (Gr) number and volume fraction when simulated using Khanafer et al correction for $10^3 \leq Gr \leq 10^5$ and $0 \leq \theta \leq 3.0$.

Studies on the hot and cold sides of the cavity showed poor performance of the fluid inside the cavity. The work is in agreement with the work reported by Solomon et al [31]. Further works are recommended to determine the effect buoyancy on the respective nanofluid volume fractions

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