CONVECTION HEAT TRANSFER WITH WATER BASED MANGO BARK NANOFLUIDS

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ABSTRACT

Numerous studies reveal that the heat transfer capability of thermal systems has been significantly enhanced with the use of nanofluids. On the other hand, the hazardous nature of the nanoparticles is evident. Recent studies clearly indicate that the nanoparticles affect the human health as well as the environment. Therefore environmentally safe bio-nanofluids are currently under investigation. In this study, a novel heat transfer fluid with bio-nanomaterial is prepared and its natural convection heat transfer characteristics are studied. The bio-nanomaterial considered in this study is powdered mango bark. A two-step process is employed to prepare stable nanofluids. The effect of particles concentration, the temperature difference between the hot and cold side, and Rayleigh number on the natural convection heat transfer process is studied. The experimental results show that the natural convection process is deteriorated with the addition of mango nanoparticles in de-ionized water.

INTRODUCTION

Nanofluids have been under research in many areas such as heat transfer, energy, biomedical, pollution control etc., since the nanofluids have considerable advantages over the traditional fluids. After the introduction of nanofluids, research in the direction of heat transfer enhancement is revitalized as the fluid possesses significant enhancement in thermo physical properties over traditional fluids. It is well-known that the nanofluid is a high performance fluids and a mixture of traditional fluids with nano-sized solid particles [1]. The exceptional thermo-physical properties such as thermal conductivity, viscosity, surface tension and density are the biggest advantage of using nanofluids. A wide range of research has been done in the past few decades concerning the preparation, stability and measurement of thermo-physical properties [2, 3], which showed encouraging factors in the nanofluids which is useful for thermal systems. Also known that the nanofluids play a major role in enhancing the fundamental heat transfer process such as conduction and convection (both natural and forced) since the heat transfer is related to the thermo-physical properties. Among the heat transfer processes, natural convection is the important heat process since it plays a key role in many industrial applications.

NOMENCLATURE

C_p	[J/kg K]	Specific heat
D	[m]	Diameter
g	[m/s^2]	Gravitational acceleration due to gravity
h	[W/m^2 K]	Heat transfer coefficient
k	[W/m K]	Thermal conductivity
K	[m^2]	Permeability
l	[m]	Characteristics length
m	[kg/s]	Mass flow rate
Nu	[-]	Nusselt number
Ra	[-]	Raleigh number
T	[K]	Temperature
Special characters		
μ	[kg/m s]	Viscosity
β	[-]	Thermal Expansion coefficient
ρ	[kg/m^3]	Density
Subscripts		
bf		Base fluid
c		Cold
f		Fluid
h		Hot
i		Inlet
nf		Nanofluids
o		Outlet

To study the natural convection process experimentally, Putra et al. [4] studied the heat transfer characteristics of nanofluids using water-based Al_2O_3 and Cu nanofluids in a cylindrical enclosure. A horizontal cylinder with one end is heated and another end is cooled was used to examine the heat transfer characteristics. They found that the heat transfer is decreased systematically and it depends on the particle density, concentration and aspect ratio. Nnanna [5] conducted an experimental study with water-based Al_2O_3 nanofluids in a differentially heated square cavity in order to estimate the range of volume fraction that improves the heat transport and to study the effect of volume fraction on the Nusselt number. Their results show that the nanoparticle volume fraction $0.2 \leq \phi \leq 2\%$ augments the heat transfer and $\phi \geq 2\%$ reduces the heat transfer. Wen and Ding [6, 7] performed a natural convection heat transfer study in a cavity made up of two cylindrical shape aluminum disc using aqueous Titanium Oxide nanofluids. The transient Raleigh number and the concentration of nanofluids were varied in the range $1 \times 10^4 \leq Ra \leq 3.5 \times 10^4$ and $0.3 \leq \phi \leq 0.8$ respectively. They found that the heat transfer coefficient was decreased systematically with increase in volume concentration in both transient and steady state. Ho et al. [8] conducted a natural convection experiment with different size of cavities using alumina nanofluids. The Raleigh number and volume fraction of the experiment are varied in the range of $6.21 \times 10^5 \leq Ra \leq 2.56 \times 10^8$ and $0.1 \leq \phi \leq 4$ respectively. It was shown that the heat transfer is deteriorated systematically for the nanofluids concentration above 2 Vol% in the entire range of Ra number. However, the nanoparticle concentration of 0.1 Vol% nanofluid enhanced the heat transfer about 18% at high Ra number in the larger size cavity.

Mahrood et al. [9] developed a cylindrical cavity with a provision to adjust the aspect ratio of the cavity and tested with water-based Al_2O_3 and TiO_2 nanofluids stabilized with carboxymethyl cellulose. The Raleigh number and volume fraction of nanoparticle are varied in the range of $4 \times 10^6 \leq Ra \leq 3 \times 10^7$ and $0.1 \leq \phi \leq 1.5$ respectively. Their results show that the heat transfer was enhanced significantly with low concentration of nanofluids. However, nanoparticle concentration $\phi \geq 1$vol% showed an inferior heat transfer ability compared to the base fluid. Also an existence of optimum concentration for maximum heat transfer for the Al_2O_3 and TiO_2 nanofluids was found and it lies in between 0.2 and 0.1 vol% respectively. Heris et al. [10] developed a cubic cavity to study the effect of inclination angle and nanoparticles on the natural convection heat transfer of turbine oil. In this study, three kinds of nanoparticles namely Al_2O_3, TiO_2, and CuO were tested with the weight fractions of 0.2, 0.5 and 0.8% at an inclination angle of 0^o, 45^o and 90^o. The Ra number was varied in the range of $3 \times 10^7 \leq Ra \leq 3 \times 10^8$. Their results showed that the turbine oil performs better than the nanofluids at all inclination angles. Hu et al. [11] investigated the natural convection heat transfer of a water based TiO_2 nanofluids in a square enclosure. The Raleigh number in this study is varied in the range of $4 \times 10^7 \leq Ra \leq 2.4 \times 10^8$ and the volume concentration is varied from $0 \leq \phi \leq 7.4\%$. Their results show that the heat transfer with nanofluids is no better than water and worse when the Ra is too low. In another study, Hu et al. [12] analysed the natural convection heat transfer process in a square cavity using Al_2O_3 nanofluids. The volume concentration of nanoparticle and Ra number are varied in the range of $0.25 \leq \phi \leq 0.77$ and $3\times 10^7 \leq Ra \leq 6.3 \times 10^7$ respectively. Their results indicates that the heat transfer is enhanced at lower concentration ($\phi = 1\ and\ 2\ wt\%$) of nanofluids and decreased at higher concentration ($\phi = 3\ wt\%$) compared to pure water.

Moradi et al. [13] studied the effect of geometrical variation on the natural convection heat transfer process using Al_2O_3 and TiO_2 Newtonian nanofluids in a cylindrical enclosure. It was noticed that the natural convection is enhanced with the use of Al_2O_3 nanofluids at an optimum volume concentration of 0.2% of Al_2O_3. However, there was no heat transfer enhancement found when TiO_2 nanofluids is used. In another study, Moradi et al. [14] analyzed the effect of inclination angle ($0 \leq \theta \leq 90$), Ra number ($1\times 10^{-8} \leq Ra \leq 4 \times 10^{-8}$) and volume concentration ($0.1 \leq \phi \leq 1.5\%$) on the natural convection heat transfer and obtained a similar trend of results reported in previous study [13]. Li et al. [15] measured the thermophysical properties of Ethylene glycol and water mixture with ZnO nanoparticles along with the study of natural convection heat transfer process in a square cavity. The mass concentration of nanofluids and the range of Ra numbers studied is 5.25% and $5\times 10^{-7} \leq Ra \leq 11 \times 10^{-8}$. Their experimental result reveals that the heat transfer enhances with increase in heat input. Also they found that the increase in the quantity of ethylene glycol leads to adverse heat transfer. Recently, Ghodsinezhad et al. [16] performed an experimental investigation to study the natural convection heat transfer process in a square cavity filled with Al_2O_3/water nanofluids. The volume concentration of nanofluid was varied in the range of $0 \leq \phi \leq 0.6\%$ and the Raleigh number was varied in the range of $3.49 \times 10^8 \leq Ra \leq 1.08 \times 10^9$. The maximum heat transfer enhancement of 15% was obtained at a volume concentration of 0.1% of Al_2O_3. Very recently, Cadena-de la Pe~na et al. [17] investigated the natural convection heat transfer in a vertical annuli filled with AIN and TiO_2 / mineral oil suspension. The Prandtl number in the study was varied between $70 \leq Pr \leq 300$ and the Ra number was greater than 10^7. Three different weight concentrations of 0.01, 0.1 and 0.5% nanoparticles was under investigation. Their results suggests that the heat transfer was deteriorated in most of the conditions while few cases showed an enhancement. Also TiO_2 nanofluids performed better than AIN nanofluid.

Apart from the above experimental studies, considerable amount of numerical studies related to natural convection heat transfer is also reported in literatures [18-44], which includes numerical analysis of natural convection in rectangular cavities with various kinds of nanofluids [18-28], natural convection in different shape of cavities [29-37] and natural convection under MHD effects with magnetic sensitive nanofluids [38-44] etc. Though the numerical studies have few advantages over experimental studies, the numerical studies are clearly indicates that experimental studies are the only solution to capture the complete effects in natural convection since all the numerical models use assumptions and boundary conditions to simplify the analysis. Also it is found that there is not enough experimental results to validate those numerical results reported.

From the experimental studies [4-17] it is known that there are different kinds of nanoparticles used in the studies and namely those are Al_2O_3, TiO_2, AIN, ZnO_2 and CuO. Though many positive effects were found with the use of nanofluids in heat transfer applications, it is believed that the proliferation of nanoparticles to the environment is not safe for humans and environment. Recent studies reveal that the nanoparticles affect the human pulmonary cells [45], human health [46-48], pregnant Mice [49], aquatic organisms [50], animals [51], bacterial growth [52] and environment [53]. Therefore environmentally safe bio-nanofluids are currently under investigation. In this direction, limited studies are reported. Bio-nanoparticles which are originated from the wood, char, seeds and leaves could be environmentally friendly since naturally humans are exposed to these nanoparticles. Therefore in this study, a new kind of nanofluid consists of bio-nanoparticle is prepared and the natural convection heat transfer process is studied. The effect of nanofluid concentration, the temperature difference between the hot and cold surface and bio-nanofluid on the natural convection heat transfer process is also studied.

PREPARATION, CHARACTERIZATION AND THERMO-PHYSICAL PROPERTIES OF NANOFLUIDS

In this study, nanofluid is prepared using a two-step method. In the first step, the nanoparticle is prepared from the mango bark and leaves by ball milling. Before ball milling, the raw material is dried in the sunlight. The average size of the nanoparticle is found to be 100 nm. In the second step, the prepared nanoparticles are suspended in the De-ionized water (DI water) by using an ultrasonic process. The required volume of nanoparticles is taken and mixed with a necessary amount of water. Then the mixture is subjected to an ultrasonic cavitation (Qsonica-Q700) process for 1 hour to prepare a uniform and stable fluid. After the preparation of nanofluid, the stability of the nanofluid is accessed using UV-Visible spectroscopy (Jenway-7315) and verified with viscosity measurements at a constant temperature. The thermal conductivity and viscosity of the nanofluids are also measured and presented in a previous study [55]. Other properties such as density and thermal expansion coefficient are calculated using theoretical models as follows.

The mixing theory is used to calculate the density as reported in Ho et al [8] as

$$\rho_{nf} = \phi_{nf}\rho_p + (1-\phi_{nf})\rho_{bf}, \quad (1)$$

The density of the mango wood particle ρ_p is 1589 kg/m^3 and the density of water is taken from the ASRAE hand book [56].

The properties of nanofluids such as specific heat and thermal expansion coefficient are accessed from the equation (2) and (3) as

$$\rho_{nf}C_{P,nf} = \phi_{nf}\rho_p C_{P,p} + (1-\phi_{nf})\rho_{bf}C_{P,bf}, \quad (2)$$

$$\rho_{nf}\beta_{nf} = \phi_{nf}\rho_p\beta_p + (1-\phi_{nf})\rho_{bf}\beta_{bf}, \quad (3)$$

The coefficient of thermal expansion of water is 2.14 x 10^{-4}. The thermal expansion coefficient of mango bark is not available in the literature, therefore, the coefficient of thermal expansion of wood is considered. In general, the coefficient of thermal expansion of wood is varied between 3.1 to 4.5 × 10^{-6} K^{-1} in all directions [57] and therefore, an average value is used in the present study.

EXPERIMENTAL SET-UP AND PROCEDURE

The schematic of the experimental set-up for the natural convection heat transfer study is shown in Figure 1. The experimental system consists of a cavity, data logger unit, hot and cold bath and data recording system. The cavity is made up of epoxy material with a dimension of 120 (W) x 96 (H) x103(L) mm. Two heat exchangers made up of copper material are kept vertically side by side at a distance of 120 mm and other sides of the cavity are covered with epoxy material. Each heat exchanger is connected with hot and cold bath respectively. The cavity is positioned at zero inclination angle. Thermocouples are fixed along the width of the cavity to measure the temperature distribution inside the cavity. Also, three thermocouples were fixed on the each hot and cold wall to measure the surface temperature of the cavity. In order to avoid heat loss to ambient the entire cavity is insulated with polyurethane foam and then kept inside the insulation filled box. Thermocouples were connected to the data logger and temperature signals were monitored and recorded with the use of a computer.

The cavity is filled with 1200 ml of prepared nanofluid. The temperature difference between the hot and cold side are varied from 15 to 50 ºC and this is achieved by maintaining the hot side temperature as constant (55 ºC) and varying the cold side temperature (5, 10, 15, 20 and 25 ºC). The temperature evolutions of the hot and cold walls as well as fluid are recorded. The steady state of the system is assumed when the temperature signals are constant for about 40 mins. After 50 mins of differential heating, the natural convection system reaches steady state afterward the data's are recorded for about 40 min.

The recorded temperature data's at a different position of the cavity is used to estimate the heat transfer, heat transfer coefficient, Nusselt and Raleigh number. The Newton's law of cooling is used to calculate the heat transferred by the heat exchangers to and from the cavity which is denoted in equation (4) and (5) respectively.

$$\dot{q}_h = \dot{m}_h\, C_p\, (T_{h,i} - T_{c,o}), \quad (4)$$

$$\dot{q}_c = \dot{m}_c\, C_p\, (T_{h,o} - T_{c,i}), \quad (5)$$

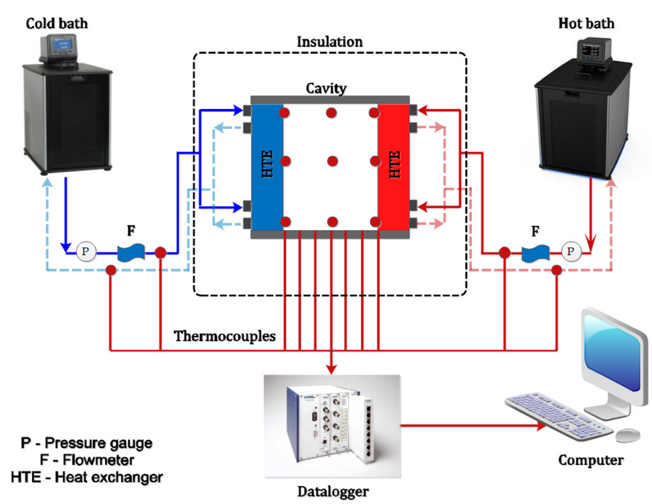

Figure 1 Experimental set-up

The heat transfer coefficient at the hot and cold wall is calculated using equation (6) and (7) respectively.

$$h_h = \frac{\dot{q}_h}{(T_h - T_f)}, \quad (6)$$

$$h_c = \frac{\dot{q}_c}{(T_f - T_c)}, \quad (7)$$

where, T_h and T_c are the average temperature of the hot and cold surface.

The Nusselt number is calculated as,

$$Nu = \frac{h\,l}{k}, \qquad (8)$$

The average heat transfer coefficient of hot and cold side ($h = (h_h + h_c)/2$) is used to calculate the Nusselt number in equation (8). The Raleigh number of the cavity is calculated using equation (9) as

$$Ra_L = \frac{g\,\beta_{bf}\,\rho_{bf}^2\,C_{p,bf}(T_h - T_c)\,L^3}{k_f\,\mu_f}, \qquad (9)$$

Finally, the uncertainty present in the heat transfer rate, heat flux, heat transfer coefficient and Nu are estimated. The uncertainty present in the estimation of heat transfer coefficient of Nu is found to be between 2 to 5 %.

RESULTS AND DISCUSSION

The nanofluid is tested in the cavity with the variable temperature boundary condition as discussed earlier, and the heat transfer capacity of the cavity, Nusselt number at the hot and cold wall as well as the Raleigh number variations are investigated. Figure 2 shows the heat transfer capacity of the cavity in which the heat transfer is within ±10% of the heat supplied except few points at low heat input. It is found that the maximum heat transfer by the cavity is about 93 W with the use of water. Also, it reveals that the heat transfer capability of the cavity is increased as the heat input increases.

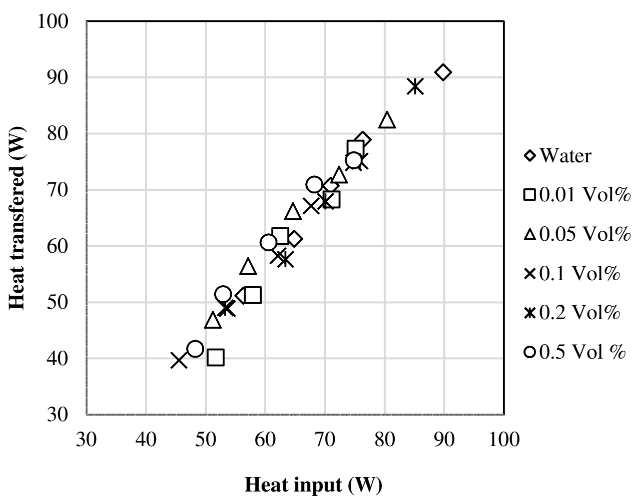

Figure 2 Heat transfer capability of cavity

Nusselt number variation with a temperature difference of cavity at the hot side is shown in Figure 3. It shows that the water is outperformed nanofluids in terms of heat transfer. Also, shows that the Nu of water is more or less uniform with temperature variation while the nanofluids show a slight decrease in Nu when the temperature difference increases. Though the performance with nanofluids deteriorated, there is an optimum concentration for maximum heat transfer with nanofluids. In this study, nanofluid with 0.2% volume concentration showed a better performance compared to other concentration of nanofluids.

Figure 4 shows the Nu number variation on the cold side with respect to the variation in temperature difference at the cavity. The Nusselt number at the cold side also behaves as same as in the hot side. However, the Nu in the hot side is decreasing trend whereas on the cold side increasing with the temperature difference. As similar to the hot side, the cold side also shows the maximum Nu for the 0.2% volume concentration of nanofluids. In both hot side and cold side, 0.5% volume concentration showed a low Nu.

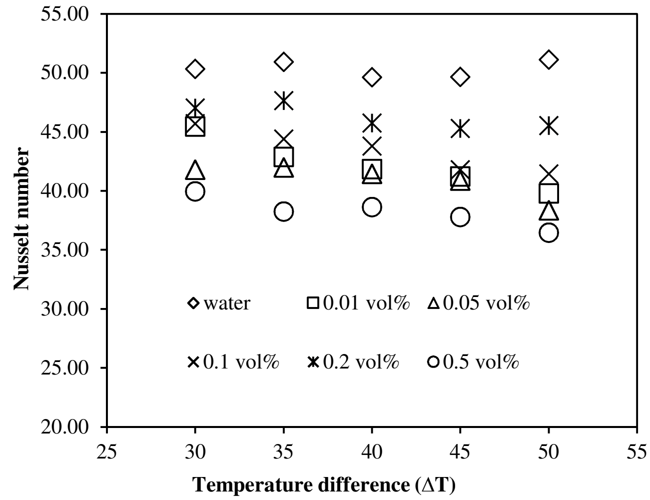

Figure 3 Nusselt number variations with concentration of nanofluids in hot side of the cavity

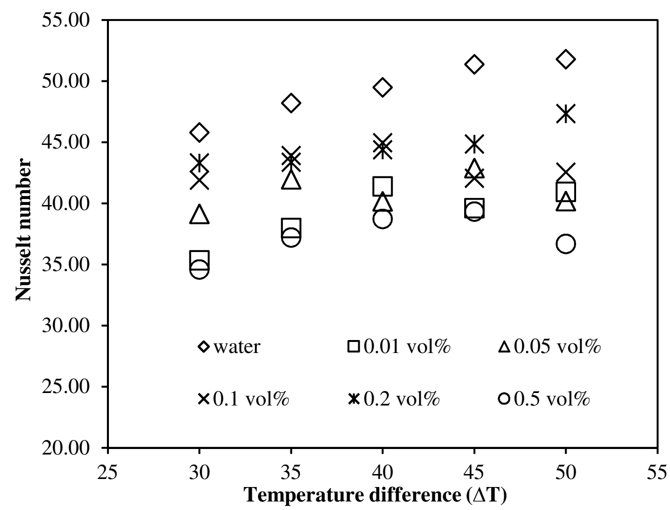

Figure 4 Nusselt number variations with concentration of nanofluids in cold side of the cavity

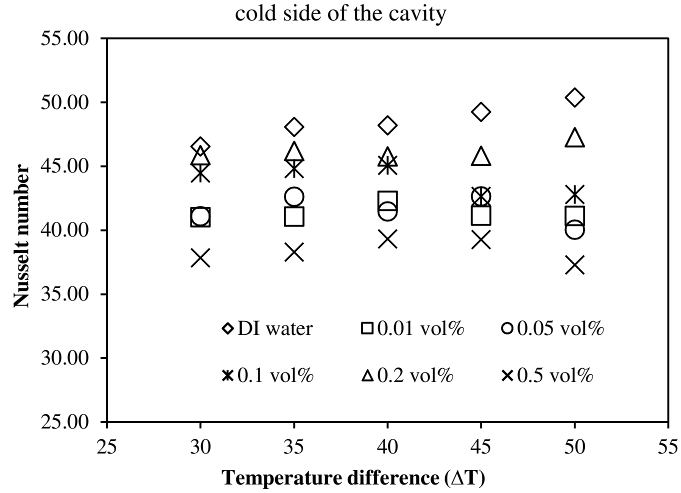

Figure 5 Nusselt number variations of nanofluids with at various temperatures

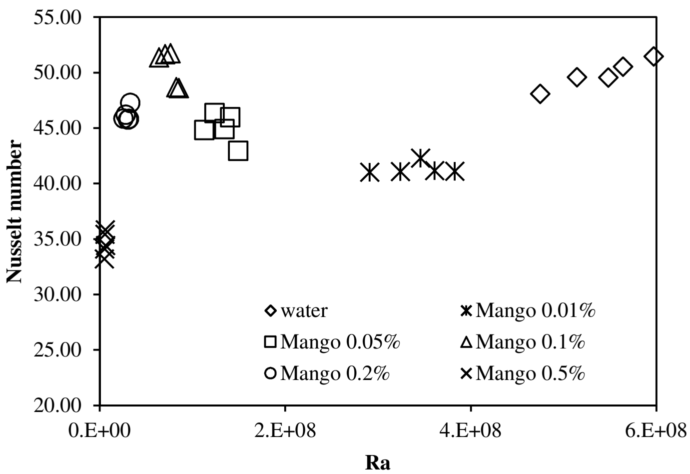

Figure 6 Variation of Nu at various Ra number

The average Nu of the cavity is calculated from the average heat transfer coefficient. The average Nu of the cavity is presented in Figure 5, which shows the same trend of Nu of the hot and cold side. Figure 6 shows the variation of Nu with the variation Ra number and it reveals that the Ra for Water is higher than the nanofluids. Also as the concentration increases the Ra decreases that suggests the water has highest buoyancy effect than the same effect in nanofluids.

CONCLUSION

An environmentally safe nanofluid is prepared and its natural convection heat transfer ability is studied. The optimum concentration of nanoparticle for the maximum heat transfer is identified as 0.2% for the present mango powder. Though the heat transfer is deteriorated with the use of mango nanopowder in the cavity, this study will be the first step to further studies in this direction.

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