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ORIGINAL ARTICLE

Thermal performance of natural circulation loop filled with Al_2O_3/ Water nanofluid

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Abstract
Natural Circulation Loop (NCL) which is also called as a thermosyphon system is the heat transfer loop which uses no pump or external device to drive the loop fluid. In the present paper, a comparative study on thermal characteristics of two loop fluids viz. water and Al_2O_3/water nanofluid is made. Experiments are conducted on in-house designed test rig. Thermo-hydraulic behaviour of loop fluid is presented. Two parameters such as heat input, nanofluid concentration are varied in order to study their individual and combined effects. It is concluded that Al_2O_3/water nanofluid as loop fluid results in higher mass flow rates as compared to the water. Different derived quantities such as Nusselt number and Grashof number are calculated. Quantitative comparison is made between water and Al_2O_3/water nanofluid. Time to reach steady state is reduced by 22 % using Al_2O_3/water nanofluid as loop fluid when compared with water. Mass flow rate and Grashof number of the Al_2O_3/water nanofluid based NCL are enhanced by 6.75% and 26% respectively, when compared with water-based NCL at 1000W heat input. At the heater, the temperature gradient is reduced by 30.2% due to the improved thermal and transport properties of Al_2O_3/water nanofluid when compared with water at 1000 W heat input. As particle concentration increases from 1% to 5%, Nusselt number increases from 10.1 to 20.1, for the heat input of 1000W.

Keywords: *Grashof Number; Heat Transfer Enhancement; Nanofluid; NCL; Nusselt Number; Thermal Performance.*

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INTRODUCTION

Transferring heat transfer is an important process in many industries. Depending on application, reliability and cost, type of heat transfer method may be adopted while designing energy-efficient heat transfer equipment. Forced convection and natural convection are two commonly available methods. Thermal conductivity of heat transfer fluid plays an imperative role in designing of the heat transfer system. It is known that conventional heat transfer fluids such as water, ethylene glycol (EG), oil etc, have not shown sufficient competence to meet the present day industrial demand due to their poor thermal performance. Natural Circulation Loop (NCL) is a thermal system in which flow is driven by thermally generated density gradient so that pump is not required. In NCL, simultaneous heating and cooling cause the density gradient which results in buoyancy that drives the fluid. Heat is transferred to the loop fluid at heat source thereby fluid temperature raises which causes less density and the same fluid raises upwards and reaches the heat sink through the riser (a vertical connecting pipe between heat source and heat sink). This fluid loses heat at the heat sink thereby its temperature decreases and density increases so that the same fluid comes back to the heater through the downcomer (another vertical connection between heat sink and heat

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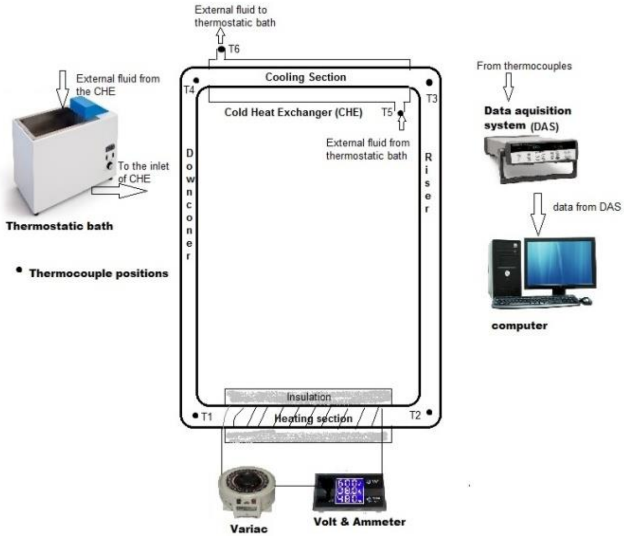

Fig. 1. Schematic of test rig.

source). Usually a heat source is located below the heat sink to promote natural circulation. There is a considerable amount of research carried out in the past by many researchers to investigate the thermo-hydraulic behaviour of the NCL. Vijayan [1] developed a correlation based on experimental results for flow rate in terms of Reynolds number, Grashof number and a dimensionless loop parameter. The developed correlation suggests that the simulation of the steady-state flow in single-phase NCL's can be attained by simulating the non-dimensional parameter (Gr/Ng). A general review paper on nanofluids in thermosyphon loops was presented by Mahdi Ramezanizade [2]. It was suggested that there exists an optimum nanoparticle concentration for the nanofluids used in thermosyphons. Enhanced effective thermal conductivity can increase the efficiency of nanofluidic thermosyphons. Nayak et al. [3] studied the circulation behaviour with Al_2O_3/water nanofluid and water as working fluids in a rectangular loop. From this study, the author observed that the flow instabilities were minimized and also the mass flow rates were improved with nanofluids. These are dependent on the nanoparticle concentration in water. Kamyar *et al.* [4] depicted that heat transfer enhancement is 1.23 times and reduction in thermal resistance is 65% for Al_2O_3 water based nanofluid compared to water. Similar studies on Al_2O_3/water nanofluid were carried out [5, 7]. Praveena *et al.* [10] studied the suitability of nanofluid in NCL. Aghayari *et al.* [11] experimentally investigated the thermal performance of Fe_2O_3/Water nanofluid in a double pipe heat exchanger. Kheram [12] numerically studied the convective heat transfer phenomena with alumina based nanofluids. Sheikhzadeh *et al.* [13] reported the effect of heat transfer and pressure drop with nanofluids in a three-dimensional microchannel. Ramezani Azghandi *et al.* [14] conducted experimental analysis using multi-walled carbon nanotubes. Asadikia *et al.* [15] studied the properties of copper oxide nanoparticles and carbon nanotubes in order to achieve better heat transfer properties.

The general trend observed from the literature on nanofluid based NCL is such a way that its heat transfer performance increases. Application of nanofluid in NCL is a promising area of research. Though, few studies were available on Al_2O_3 water based nanofluid as loop fluid in NCL, there exists an ambiguity among the research findings regarding the amount of enhancement. Thus, in the present work Al_2O_3/water nanofluid at five different nanoparticle concentrations is used as working fluid in the NCL to understand its heat transfer performance. The heat input is varied from 250 W to 1000 W with a step size of 250 W. The heat transfer performance of nanofluid is compared with pure distilled water.

EXPERIMENTATION

Schematic diagram of the test rig is shown in Fig. 1. Test rig consists of four parts, a heater (heat

Table 1. Geometrical specifications and operating ranges of Natural Circulation Loop.

Parameter	Value
Pipe diameter of the loop	0.012 m
Inner diameter of the annulus at CHE	0.0215 m
Width of the loop	0.75 m
Height of the loop	1m
Loop length	3.5 m
Length of heater	0.5 m
Length of cold heat exchanger	0.6 m
Heater power supply	250 W to 1000W
Mass flow rate of cold fluid	10 LPM
Particle volume concentration *(Ø)*	1% to 5% V/V

source) which is placed horizontally at the bottom; tube-in-tube cold heat exchanger (heat sink or CHE) which is placed at top; and two vertical pipes connecting the heater and CHE. Two vertical pipes are connected to the heat source and heat sink at the two ends there by closing the loop. Dimensional details of the test facility are given in Table1. Kiran Kumar and Ram Gopal [16] suggested an optimum loop diameter of 10-15 mm for natural circulation loop. They quoted that as the loop diameter increases the mass flow rate increases and reaches optimum value. As suggested by Kiran Kumar and Ram Gopal [16], 12mm is chosen as loop diameter. Entire loop is thoroughly insulated with foam. To tap the temperature of loop fluid at different locations, ten K-type thermocouples (TCs) are placed. Location of each thermocouple is shown in the schematic (fig. 1). Another two thermocouples are used to measure inlet and outlet temperatures of external fluid in cold heat exchanger. All these thermocouples are well calibrated. All these thermocouples are connected to a computer integrated NI (National Instruments Ltd.) data acquisition system. HTC made digital differential manometer is used for measurement of pressure difference between different sections in the loop. Nichrome wire is wound around the heater section and is connected to variac (dimmerstat). Amount of heat supplied to the heater section is calculated by measuring voltage and current. Rotameter is used to measure the mass flow rate of external fluid. Rotameter and thermocouples are calibrated. All precautions are taken to eradicate dissolved gases and air bubbles inside the loop while filling the NCL.

The steady state mass flow rate $(\dot{m}_s)$ is calculated after system reaches the steady state using equation 1. Here, T_1 and T_2 are the temperatures of loop fluid at the heater inlet and outlet respectively.

$$\text{Heat input to the heat source } Q = \dot{m}_s \cdot C_{p,f} \cdot (T_2 - T_1) \quad (1)$$

Steady state Reynolds number is calculated by:

$$Re_s = \frac{4\dot{m}_s}{\pi d \mu} \quad (2)$$

By known heat input and wall and fluid bulk mean temperatures, the average heat transfer coefficient is calculated by:

$$h_f = \frac{Q}{A_s\left(\bar{T}_{wall,in} - T_{b,f}\right)} \quad (3)$$

Nusselt number can be calculated by eqn. 4

$$Nu = \frac{h_f d}{k_f} \quad (4)$$

The Grashof number (Gr) can be estimated by using eqn. 5:

$$Gr = \frac{\left(g\beta d^3 \rho^2 Q H\right)}{\left(A\mu^3 C_p\right)} \quad (5)$$

Required thermo-physical properties are calculated through the reliable correlations at bulk fluid temperature

RESULTS AND DISCUSSION

The experiments are conducted with water and then with Al_2O_3/water nanofluid of different particle concentrations. The steady state mass flow rate is measured at different power inputs (250 - 1000 W) maintaining the cold water (secondary fluid of cold heat exchanger/heat sink) flow rate constant (10 lpm).

Fig. 2 shows the thermal behaviour of water

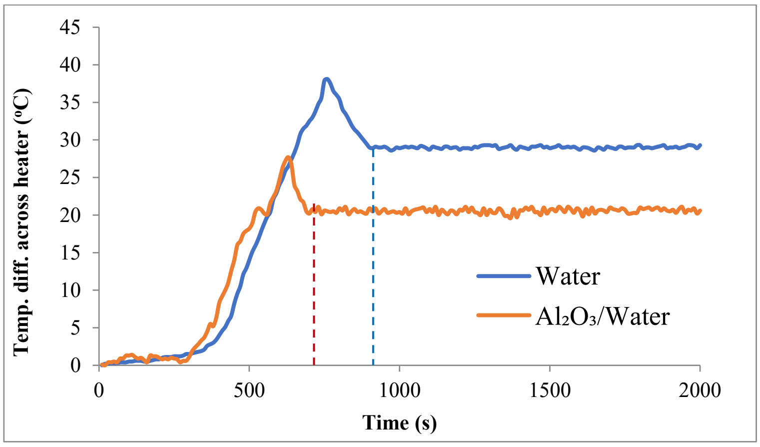

Fig. 2. Variation of temperature difference across the heater (Q = 1000W, Φ= 5%).

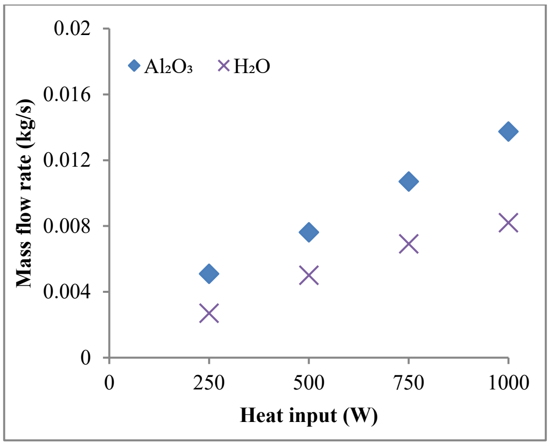

Fig. 3. Effect of heat input on mass flow rate of nanofluids (Φ= 5%).

and Al_2O_3/water nanofluid with respect to time. Temperature difference of loop fluid across the heater is taken as ordinate and time as abscissa for power input of 1000W and 5% particle concentration. From Fig. 2 one can observe that fluid thermal behaviour is similar for both the fluids. However, the steady state reaching time for Al_2O_3/water nanofluid is quicker compared to the water. It took 900 seconds for the loop to reach steady state while water is taken as loop fluid, whereas, it took only 700 seconds for Al_2O_3/ water nanofluid to reach steady state. It is to be noted that similar trend was observed by Ramesh Babu Bejjam *et al.* [6]. Ramesh Babu Bejjam *et al.* [6] reported that steady state reaching time is reduced by 12% to 27% for different fluids and different concentrations of nanofluid.

Figs. 3 and 4 present the effect of heat input on mass flow rate and temperature difference across heater. Loop mass flow rate is higher while loop is operating with Al_2O_3/water nanofluid. This is due to the fact that specific heat of nanofluid is less than that of water, which results in higher temperature for the same heat input. As bulk fluid temperature increases, its density decreases. Decrease in the density creates more buoyancy force. At the same time, change in the viscosity by adding nanoparticles to the base fluid is marginal. Hence, mass flow rate increases for nanofluid compared to water. Fig. 3 represents 6.75% of enhancement in the mass flow rate of Al_2O_3/water nanofluid when compared with water at 1000W heat

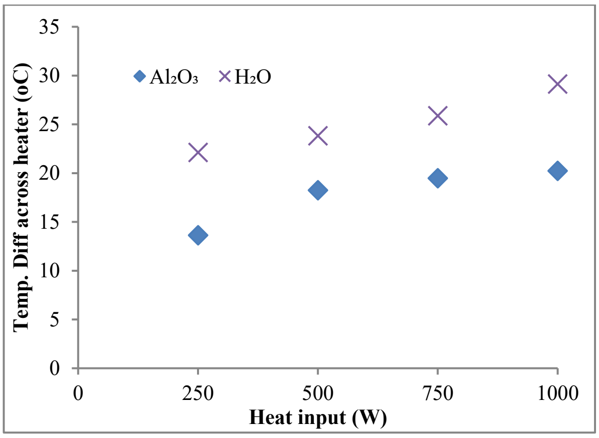

Fig. 4. Effect of heat input on temperature difference across heat input (Φ= 5%).

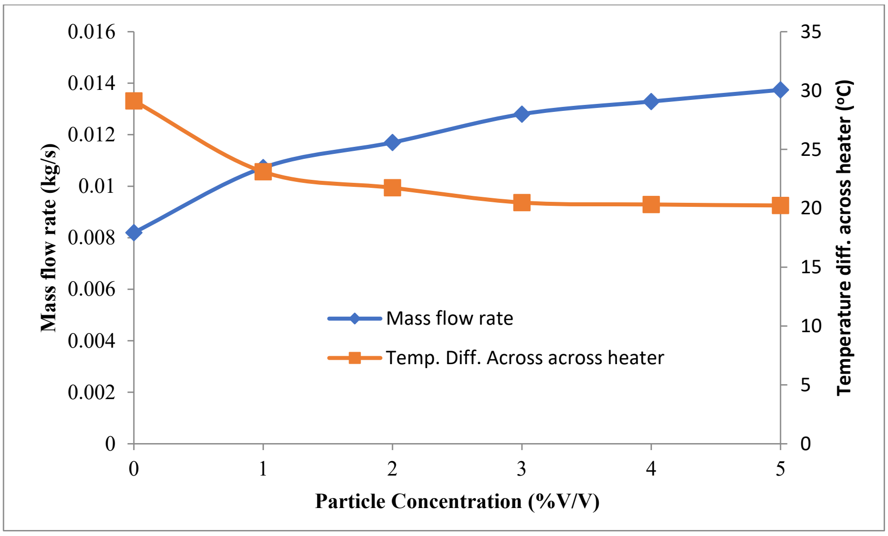

Fig. 5. Variation of mass flow rate and temperature difference across the heater with nanoparticle concentration (Q =1000W).

input. Fig. 4 depicts the temperature difference across the heater for different heat inputs, at 5% particle concentration at fixed external fluid inlet temperature. It is observed from fig. 4 that the temperature gradient of the loop fluid increases with power input. As heat input increases, temperature rise across the heater is steeper for water compared with nanofluid. At the heater, the temperature gradient is reduced by 30.2% due to improved thermal and transport properties of Al_2O_3/water nanofluid when compared with water at 1000 W heat input.

Fig. 5 elucidates that mass flow rate increases and temperature difference across the heater decreases with nanoparticle concentration. In Fig. 5, origin on abscissa represents pure water. Mass flow rate increases from 0.0082 kg/s to 0.010721 and 0.01374 kg/s while concentration increases to 1% V/V and 5% respectively. At higher concentration, the rate of increase is not high due to higher viscous forces. In addition to the increase in mass flow rate, temperature difference across the heater decreases with particle concentration.

Variation of Grashof number (Gr) with respect to heat input and particle concentrations are presented in Figs. 6 and 7 respectively. It is to be noted that, Grashof number is the important non-dimensional number considered in natural circulation systems. Increasing the Grashof number depicts higher buoyancy forces at higher

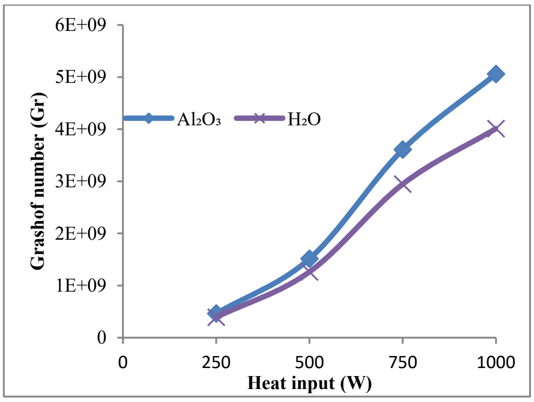

Fig. 6. Grashof number variation with heat input (Φ= 5%).

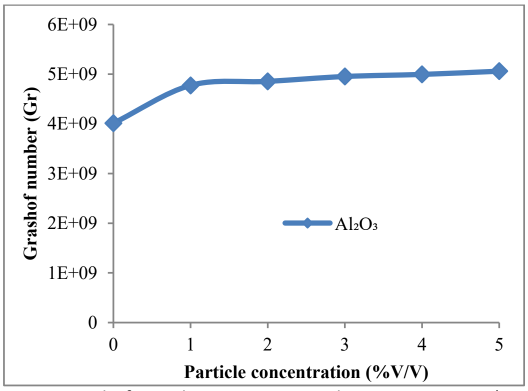

Fig. 7. Grashof number variation with Concentration (Q = 1000W).

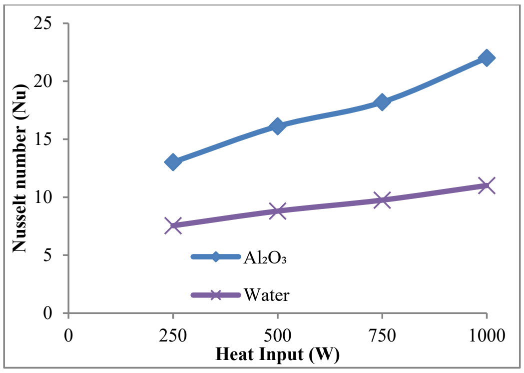

Fig. 8. Nusselt number variation with heat input (Φ= 5%).

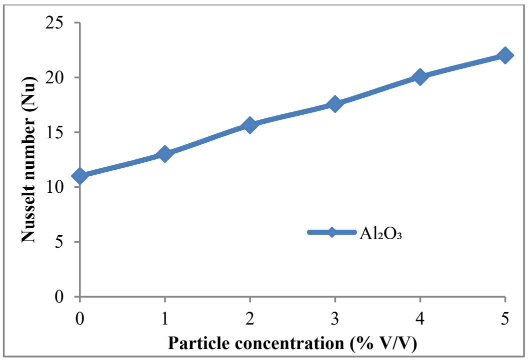

Fig. 9. Nusselt number variation with Concentration (Q = 1000W).

heat inputs and higher concentrations. However, it is worth noting that, as concentration increases, the rate of increase in Grashof number is marginal. This can be attributed to higher viscosity at higher concentrations. Misale et. al [8] and Doganay et. al [9] have conducted similar experiments on NCL and presented results in terms of Grashof number. However, both the studies were done on the mini-loop for fixed concentration of nanofluid.

Fig. 8 and 9 shows the Nusselt number (Nu) variation with heat input and particle concentration respectively. Due to the better heat transfer characteristics, Al_2O_3/water nanofluid exhibits higher Nusselt number. As concentration increases to 5%, Nusselt number increases from 10.1 to 20.1, for the heat input of 1000W.

CONCLUSIONS

Thermal performance of a rectangular Natural Circulation Loop (NCL) with heat source and heat sink is experimentally studied for a heat input of 250-1000 W. The use of Al_2O_3/water nanofluid in NCL depicts the improved heat transfer performance compared to pure distilled water. The buoyancy induced flow in a NCL can be increased either by increasing the driving buoyancy force or by reducing the viscous resistance force. The following specific conclusions are made from the current study:

- Steady state reaching time for NCL with Al_2O_3/water nanofluid as working fluid is reduced.
- Mass flow rate increases with heat input and particle concentration.
- Temperature difference across the heat sink decreases with particle concentration.
- Grashof number and Nusselt number increases with particle concentration. Nu is almost doubled by increasing concentration from 0% to 5%.

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CONFLICT OF INTEREST

Authors have no conflict of interest.

NOMENCLATURE

CHE	Cold Heat Exchanger
NCL	Natural circulation loop
$m^{\bullet}_{s}$	Steady state mass flow rate(kg/sec)
T_1	Fluid temperature at heater inlet
T_2	Fluid temperature at heater outlet
Q	Heat input(W)
$T_{Wall,in}$	Mean wall inner surface temperature
$T_{b,f}$	Mean bulk fluid temperature
h_f	Average heat transfer coefficient
$C_{p,f}$	Specific heat of fluid(J/kg K)
k_f	Thermal conductivity of fluid(W/m-K)
Nu	Nusselt number
Re	Reynolds number
Gr	Grashof number
A_s	Surface area
β	Thermal expansion coefficient(K^{-1})
Φ	Particle Volume Concentration
µ	Dynamic viscosity (kg/m s)
ρ	Density of fluid(kg/m^3)

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