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Experimental investigation on natural convective heat transfer coefficient of silver/water nanofluid in an enclosure

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Abstract: *Heat transfer enhancement by natural convection in vertical cylindrical enclosure using Silver/water nanofluids is reported in the present study with one end heated, and the other end, cooled. Cylinder of 50mm diameter and 152mm height is used as the test section. Silver nanoparticle with an average size of 54nm is used to study the heat transfer characteristics. The experiment is carried under the test matrix of three volumetric concentrations as 0.005%, 0.01% and 0.03% for different heat inputs. The results showed an increase in heat transfer coefficient with increase in concentration of the nanoparticle. The effect of Rayleigh number on Nusselt number and heat transfer coefficient is analysed. The results revealed an enhancement in heat transfer coefficient of 47% with 0.01% and 54% with 0.03% has been observed.*

Keywords: *Nano fluid, Natural Convection, Dispersion, Convective Heat Transfer.*

Nomenclature

A	Area, m^2
C	Constant
d	Diameter, m
g	Gravity, m/s^2
h	Convective heat transfer coefficient, $W/(m^2K)$
k	Thermal conductivity, W/(mK)
L_c	Length of cylindrical enclosure, m
Nu	Nusselt number
Pr	Prandtl number
Ra	Rayleigh number
Q	Heat flow, W
T	Temperature, K
ΔT	Temperature difference, K

Greek symbols

α	Thermal diffusivity, m^2/s
β	Thermal expansion coefficient, 1/K
μ	Dynamic viscosity, Ns/m^2
ν	Kinematic viscosity, m^2/s
ρ	Density, kg/m^3
□	Particle concentration, %

Subscript

nf	nanofluid
w	water
f	film
p	particle

I. Introduction

Miniaturization has become a trend in the modern world as the saying “Bigger is better” pave way to “Smaller is better”. Industries are in need of compact equipments that reduce space consumption and also work efficiently in heat transfer applications. Heat transfer in a closed chamber finds many engineering applications such as automobile, aerospace, boiler plants, cooling of electronic components, heat exchangers and many more. Accumulation of heat at a particular place will cause discomfort and leads to poor performance. Many methods and experiments are conducted to drive away the excess heat generated. Natural convection is a heat transfer mechanism that is employed in several applications. Suspensions of one phase dispersed as a small particle in base liquid phase plays a vital role in food and beverages, pharmaceuticals as well as refrigeration industry [1]. Years ago, it was observed that enhancement of thermal properties of liquids could be carried with one of the features of the suspensions [2]. Many micro and mini sized particles were introduced for heat reduction purpose. Though it worked well, each one had their drawbacks. Lee et al [3] showed that the recent advancement in generating nanoparticle can be an alternative with good effect during the study. Choi in 1995 [4] was the first person who coined the term nanofluid and showed that the thermal conductivity of the nanofluid –particle is substantially increased.

This plays a vital role in many engineering diligences. Examples can be of cooling electronic devices, boiler plants, etc., In many situations mechanical devices for coolant circulation were not given any preference in design of heat transfer equipments. It is because of noise, space consumption and power consumption, reducing problems in repairing of the equipments which becomes a tedious process. These systems can be eliminated by introducing an innovative technique, involving nanofluid as working fluid. The modern growth depicts that the things that are of smaller are better as it is said earlier. Therefore the aim of this work is to study the convective heat transfer coefficient of Ag (silver)/water nanofluid in a closed enclosure with varying heat inputs and low volume concentrations.

II. Fabrication of experimental setup

The schematic layout of the experimental test section is shown in fig.1. The essential components to fabricate the experimental setup are an acrylic cylinder, brass piston, a base cup, thermocouples (K-type), cold temperature bath, and a submersible pump, copper bottom, O-ring, hoses, heater, data logger and a computer system. Acrylic cylinder of 60mm diameter and 152mm height is used as a test section. To mount it on a base a Teflon material is used where it is machined in lathe to the dimension thereby the cylinder can be fixed on it. The copper that is fixed at the bottom serves as a hot surface and the brass piston at the top serves as a cold surface. This copper is fixed to the bottom by m-seal and araldite. The brass piston of diameter 49.5mm is provided with three valves wherein two of the valves are used for the cold water inlet and outlet and one is used for fixing of thermocouples on surface of the piston. Thermocouples are fitted on three parts of the set up. Three are of on the hot plate, three on the cylinder, and three on cold surface. All are arranged in proper manner with equal spacing between each of the thermocouples. For the cooling effect, an insulated bath is used where the water is maintained at a very low temperature of 15^{o}C. The water that is maintained at a very low temperature is pumped by submersible pump.

III. Experimental Procedure

The current study is dealt by keeping the test section vertically. This is because that the heating effect at the bottom makes the particles completely to move in the upward direction that makes the heat transfer effective. Heat dissipation through the walls of the cylinder is arrested by proper insulation with glass wool. Three fourth of the insulated tank is filled with water in which a submersible pump is also fitted for the flow of water through the hollow piston. Water in this bath is maintained at a very low temperature of 15^{o}C. Then the data logger is switched on to send the required information's for the experiment to proceed. Once everything gets ready, first two readings are noted down then the heater is switched on by setting the desired heat input. The experiment is carried for a period of time until it reaches steady state. The steady state refers to that beyond certain temperature limit no heat transfer takes place. This procedure is repeated for different heat inputs of 5W, 10W, 15W and 20W. The heat transfer takes place due to buoyancy effect. Once water molecules get heated up it loses its density and becomes a lighter particle. As the lighter particles cannot stay in the lower levels it goes upward and due to the cooling effect it regains its property and comes down. Again the process continues to carry the heat and loses it at the cold surface area thereby the natural convection takes place. The same procedure is then followed with the nanofluid with different levels of concentrations (0.005%, 0.01% and 0.03%) for various input power.

IV. Experimental Layout

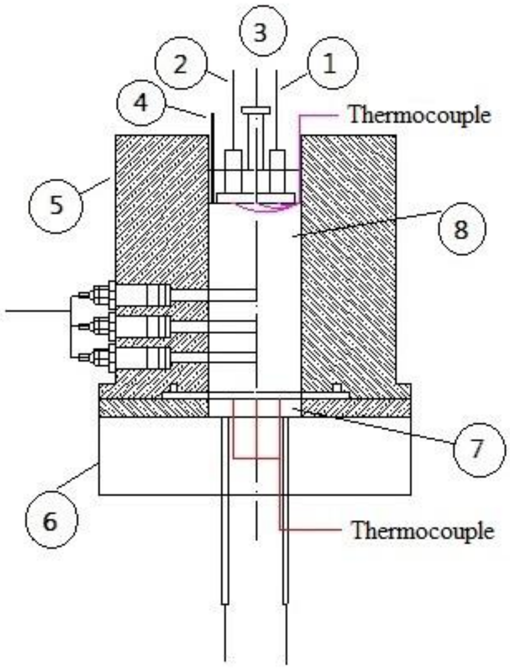

Fig.1 Schematic layout of experimental setup

1. Cold water inlet 2. Cold water outlet 3. Slot to fix thermocouple 4. Draft tube 5. External pipe with insulation 6. Teflon base 7. Heater 8. Acrylic test section

V. Data Reduction

The experiment is initiated by supplying the required heat load using the voltage regulator. The temperature variation due to the applied heat is sensed by the thermocouple and recorded using data logger. This temperature variations and recorded till it reaches a steady state. The amount of heat supplied is calculated based on the applied voltage and current and is given below in equation (1).

$$Q = V.I \tag{1}$$

Where, V is input voltage in volts and I represents the current to the heater.
The Rayleigh number is calculated from the following equation (2)

$$Ra = \frac{g\beta\Delta TL^3\rho^2}{\mu^2} \tag{2}$$

where, g – acceleration due to gravity, β – thermal expansion coefficient, ΔT – Temperature difference, L – length of the test section, ρ – density of the nanofluid and μ - kinematic viscosity of the nanofluid. The thermo-physical properties such as density, viscosity and thermal conductivity are calculated using the following relations given in equation (3), (4) and (5). The density is calculated using Pak & Cho equation [5] and the viscosity is calculated using Einstein's equation [6] and the thermal conductivity is calculated based on Maxwell's relation [7]

$$\rho_{nf} = (1-\phi)\rho_f + \phi\rho_p \tag{3}$$

$$\mu_f = \mu_w(1+2.5\phi) \tag{4}$$

$$k_{nf} = \frac{k_p + 2k_l + 2(k_p - k_l)\phi}{k_p + 2k_l - (k_p - k_l)\phi} k_l \tag{5}$$

The convective heat transfer coefficient is calculated from equation (6)

$$h = \frac{Q}{A\Delta T} \tag{6}$$

where, A – surface area of the test section.

Similarly, the Nusselt number is calculated using the equation (7)

$$Nu = \frac{hL}{k} \tag{7}$$

where, L – length of the test section, h – convective heat transfer coefficient and k – Thermal conductivity.

VI. Results and Discussion

The range of the Rayleigh number, volume concentration are Ra = 10^7 – 10^9, 0.005<□< 0.01 and L/D ratio is of 75mm. The fig. 3a & 3b presents the variation of temperature with respect to time for water and nanoparticles, which also explains that water takes much of time to attain steady state. In other words water has lesser conductivity than that of the nanofluid used. On contrary nanoparticles have more conductivity than the base liquid (water) which shows the levels in different volume concentrations for different heat inputs (Q). As the concentration level of the nanoparticle increases, increase in the heat transfer is also observed.

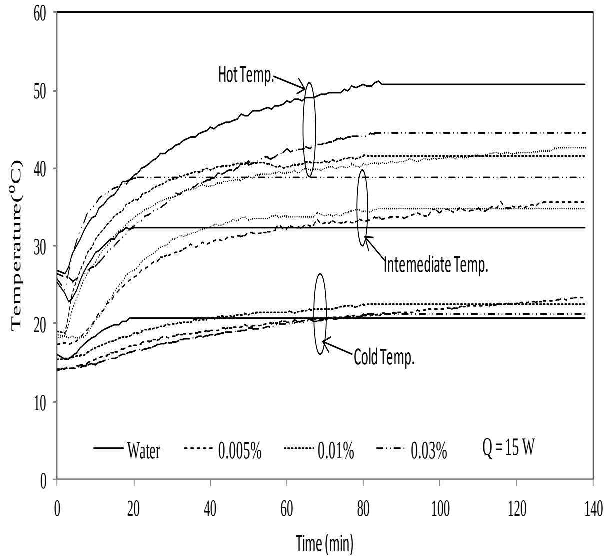

Fig. 3a Variation of temperature with respect to time

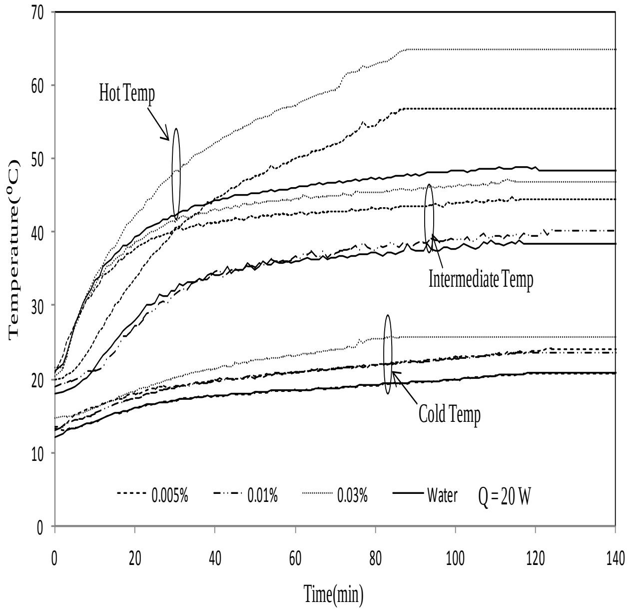

Fig. 3b Variation of temperature with respect to time

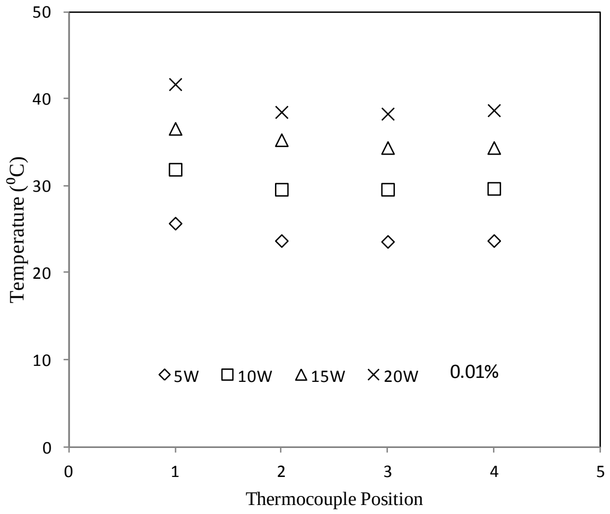

Fig.4a. Variation of temperature with respect to thermocouple position

Fig.4a and 4b reports the variation of temperature with respect to thermocouple positions. As the heater gets heated up, test fluid (Silver/Water nanofluid) inside the enclosure carries heat from one side to the other side of the test section. The thermocouples placed at equal distances indicate the temperatures at that particular point. The graph shows the record of intermediate and end temperature at different concentration levels on various heat inputs that are measured at the axis of the cylinder.

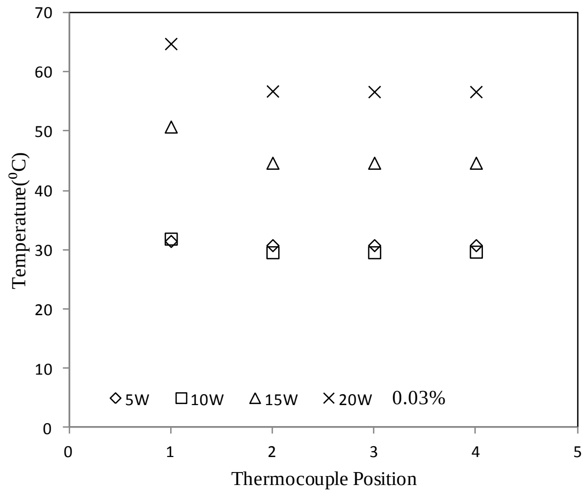

Fig.4b Variation of temperature with respect to thermocouple position

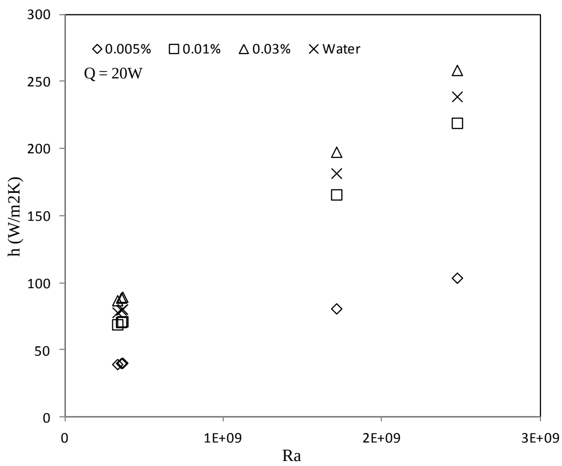

Fig. 5 Variation of heat transfer coefficient with respect to Rayleigh number

Fig.5 shows the variation of heat transfer coefficient with respect to Rayleigh number. The fig.5 shows the effect of nanofluid on heat transfer rate for a heat input of Q = 20 Watts. As Rayleigh increases, Nusselt number increases which in turn gives rise to heat transfer coefficient. In this case, highest heat transfer rate at $Ra=10^9$ and L/D=75mm is observed. The graph gives a clear account of higher heat transfer at higher concentration level of the nanoparticle.

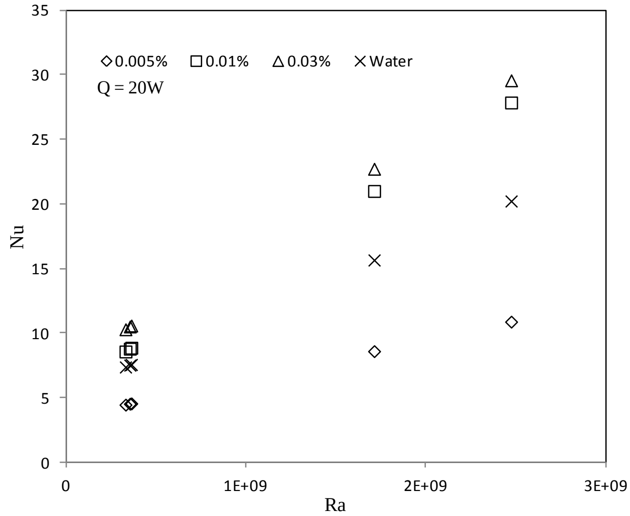

Fig. 6 Variation of Nusselt number with Rayleigh number

As the temperature difference increases, Rayleigh number also increases. Due to which the Nusselt number gets increased. It is shown that for $Ra\geq10^9$, there is a good increase in the Nusselt number which is taken at each thermocouple positions. It is evident that an increase in the natural convection heat transfer is shown after the increase in the concentration level of the nanoparticle.

VII. Conclusion

The convective heat transfer enhancement on water based nanofluid in a cylindrical enclosed chamber is experimentally studied in the present study. The observed results show that silver/water nanofluid poses better heat transfer characteristics than water. With the given heat inputs, nanoparticles have shown increase in heat transfer as 47% in 0.01% concentration and 55% in 0.03% concentration.

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