International Journal of Engineering Research and Development
e-ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 12, Issue 8 (August 2016), PP.61-69

Experimental Investigation of Natural Convection Heat Transfer Along A Vertical Cylinder Using (Water + Ethylene Glycol) Fluids

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Abstract:- In the present study, the enhancement of natural convection heat transfer of Water, and mixture of (Water + Ethylene Glycol) fluids in a vertical Aluminium square enclosure has been experimentally investigated by placing the vertical cylindrical heating element in a stationary test fluid. The uniform heat flux has been has been applied to the large L/D ratio that has been performed in this experiment. The temperature distribution along the surface of the heating element has been recorded with respect to time within the uniform heat flux at different heat generation rates. The preparation of the fluid is done by mixing 3 litres of water with 1 litre of Ethylene Glycol, i.e, in the proportion of (75:25). The experimental results showed that the surface temperature of (Water + Ethylene Glycol) increases more than that of pure water in this narrow annular space heat sink which is the Aluminium square enclosure that enhanced the effective heat transfer in the Natural convection with respect to time. The local and average heat transfer coefficient, local and average Nusselt number at different Grashof numbers and Raleigh numbers have been presented for the required experimental data and the acquired relation is finally proposed.

Keywords:- Natural convection heat transfer, Temperature distribution, Heat transfer coefficient, Nusselt number, Raleigh number, Grashof number, Fluids, Water, (Water + Ethylene Glycol).

I. INTRODUCTION

Thermal properties of a liquid play a decisive role in heating as well as cooling applications in industrial processes. Thermal conductivity of a liquid is an important physical property that decides in heat transfer performances [comparing with nanofluids heat transfer performance have failed because particle sedimentation, corrosion of components of machine, particle clogging, excessive pressure drop]. With the increase of nanofluids concentration and temperature, the thermal conductivity also increases rapidly. Natural convection heat transfer is most applicable in the industrial aspects. It is usually seen as results of the movement of the fluids due to changes in the density by the process of heating (or) cooling. Natural Convection heat transfer obtained from vertical cylinders is pertinent to the engineering applications such as vertical tubes of Heating Ventilation and Air Conditioning [HVAC] systems, for imposing restrictions on the heating of electronic components, electric immersion heater in the process vessels, for the cooling purpose of the nuclear reactor core after the loss of coolant in accidents, and in a deep repository for nuclear waste rods storage, etc.

Chughtai and Inayat studied the annulus open from both ends. For large values of L/D the curvature effects cannot be ignored [1]. The experimental result showed that the surface temperature of water in a narrow annular space heat sink increases more than that in a wide annular space heat sink with respect to the time. Literature data considering natural convective heat transfer from vertical cylinders are very widespread. Zi-Tao Yu et al [2] numerically investigated the Transient natural convection heat transfer of nanofluids which are in aqueous state in a differentially heated square cavity. Nanofluids were usually treated as single-phase fluids with the effective thermophysical properties. A great number of models had been proposed, especially for predicting the thermal related transport properties, i.e., dynamic viscosity, and thermal conductivity of the nanofluids. Three different Rayleigh numbers and five different volume fractions of nanoparticles are considerably chosen. It is resulted that at constant Rayleigh numbers, the time-averaged Nusselt number is lowered by increasing the volume fraction of the nanoparticles.

Two different kinds of non-Newtonian nanofluids were prepared by dispersing Al2O3 and TiO2 nanoparticles in a 0.5 wt.% aqueous solution of carboxymethyl cellulose (CMC). Natural convection heat transfer of non- Newtonian nanofluids in a vertical cylindrical body that is uniformly heated from below and cooled from top was experimentally investigated by Mahmoud Reza Khadangi Mahrood et al [3]. The optimum concentrations of TiO2 and Al2O3 nanofluids are about 0.2 and 0.1 vol.%, respectively. It has also been observed that the enhancement of heat transfer in TiO2 nanofluids is higher than that of the Al2O3 nanofluids. Mathematical modeling had been performed to simulate natural convection of Al2O3/water nanofluids in a vertical square enclosure by using the lattice Boltzmann method (LBM) which was performed by Feng-Hsiang Lai et al [4]. Results have indicated that the average Nusselt number increases if the Rayleigh number and the particle volume concentration increases. The average Nusselt number with the use of the nanofluid is higher than the use of water under the same Rayleigh number. Mathematical modeling is performed to simulate the natural convection heat transfer of Al2O3/water nanofluids in a vertical square enclosure by using the lattice Boltzmann method (LBM). Hence, the results are well validated with the works available in the literature review and consequently LBM is completely robust and applicable for the practical applications. Natural convection in a square cavity filled with different nanofluids is studied numerically by Mohamed A. Teamah et al [5]. The numerical results are even reported for the effect of Rayleigh number, solid volume fraction and both Hartmann number and heat generation or heat absorption coefficient on the iso-contours of streamline and the temperature. The results showed that for the weak magnetic field; the addition of nanoparticles is immensely necessary to enhance the heat transfer but coming to the strong magnetic field there is no need for the nanoparticles because the heat transfer will be decreased. On the other hand for the augmentation of the heat transfer; volume fraction of nanoparticles must be increased whereas with a small value of heat absorption coefficient ($q < 0$) at constant Rayleigh numbers and Hartmann numbers.

Laminar mixed convection flow over a 2D horizontal microscale backward-facing step (MBFS) that was placed in a duct has been investigated numerically by A.Sh. Kherbeet et al [6]. Different types of nanoparticles such as Al2O3, CuO, SiO2 and ZnO, with volume fractions within the range of 1–4% are used. The results had revealed that the Nusselt number increases by increasing the volume fraction and Reynolds number. The nanofluid of SiO2 nanoparticles is observed to have the highest Nusselt number. It is also found that the Nusselt number increases due to the decrease of nanoparticle diameter. A numerical study of transient natural convection heat transfer of aqueous nanofluids in a horizontal annulus situated in between two coaxial cylinders is presented by Zi-Tao Yu et al [7]. The effective thermophysical properties of water in the presence of copper oxide nanoparticles with four different volume fractions have been predicted using the existing models. It is also shown that at constant Rayleigh numbers, the time-averaged Nusselt number will be gradually lowered as the volume fraction of the nanoparticles is increased. Experimental investigation on natural convection heat transfer has been carried out inside vertical circular enclosures that are filled with Al2O3 nanofluid with different concentrations namely; 0.0%, 0.85%, (0.21%), 1.98 (0.51%) and 2.95% (0.75%) by mass (volume) by Mohamed Ali et al [8]. The results finally show that the heat transfer coefficient increases as the concentration increases up to a specific value of the concentration and then it decreases as the concentration will continue to increase when compared to the base fluid of the pure water.

According to M. Turkyilmazoglu et al [9] Nanofluids or so-called smart fluids the research have attracted a considerable attention in the recent years owing to their significant applications in both engineering and technology. Derivation of exact analytical solutions are also aimed for different water-based nanofluids containing Cu, Ag, CuO, Al2O3, and TiO2. In terms of the presented solutions the effect of different nanofluids on the thermal and hydrodynamics response of the system such as the skin friction and heat transfer coefficients of physical importance are thoroughly investigated. S. Srinivas Rao et al [10] conducted an experimental study that has been aimed for understanding the heat transfer characteristics of dilute nanofluids under the natural convection environment by using the non-intrusive optical imaging techniques. Aluminium oxide (Al2O3) nanoparticles with volume concentrations in the range of 0.005–0.02% are dispersed in the base fluid to prepare the nanofluids of dilute concentrations. Results have been presented in the form of interferometric images of convective field in the vicinity of the flat plate,contours of the heat transfer coefficient as a function of nanofluid concentration, in quantitative terms, an enhancement of about 21% in the heat transfer coefficient was observed for 0.02% concentration of nanofluid as compared to the base fluid whereas the Nusselt number was observed to deteriorate with increasing concentration of the nanofluids. New nanofluids as dispersions of dry ZnO nanopowder in ethylene glycol + water of about (50/50% in volume) were investigated at three mass nanoparticle concentrations up to 5% by D. Cabaleiro et al [11]. Temperature and concentration dependences on these two properties were studied by analysing the base fluid and nanofluids at 1%, 2.5% and 5% mass concentrations within the temperature range from 283.15 to 343.15 K. The results were expressed in a dimensionless way through the form of Nusselt number and the effectiveness of different semi-empirical equations for laminar, laminar-to-turbulent or turbulent flow conditions was tested. M.F. Zawrah et al [12] have studied by synthesizing the Al2O3–H2O nanofluids using sodium dodecylbenzenesulfonate (SDBS) dispersant agent by ultra-sonication method. Different amounts of SDBS i.e. 0.1, 0.2, 0.3, 0.6, 1 and 1.5 wt.% were tested to stabilize the prepared nanofluids. The results revealed that the nanofluid containing 1% SDBS was the most stable one and settling was observed for the fluid contained 0.75 vol.% of Al2O3 nanoparticles that has given higher viscosity. Addition of nanoparticles into the base liquid enhanced the electrical conductivity up to 0.2 vol.% of Al2O3 nano-particles after which it has decreased. Therefore, as seen from the previous literatures of natural convection in rectangular and square cavities filled without nanofluids, in the present study the experiments were conducted on natural convection heat transfer in a vertical square enclosure by placing a cylindrical heating source at the centre of the square enclosure heated from the above using Water, (Ethylene Glycol + Water) and further research will be done using Al2O3 / (Ethylene Glycol + Water) with five various concentrations: 0.05, 0.08, 0.1, 0.15, 0.2 percentage by volume which will be discussed later in the next literature review that will be continued further. So, the present study involves only the experimentation of the natural convection heat transfer in a square cavity using (EG + Water) as fluids.

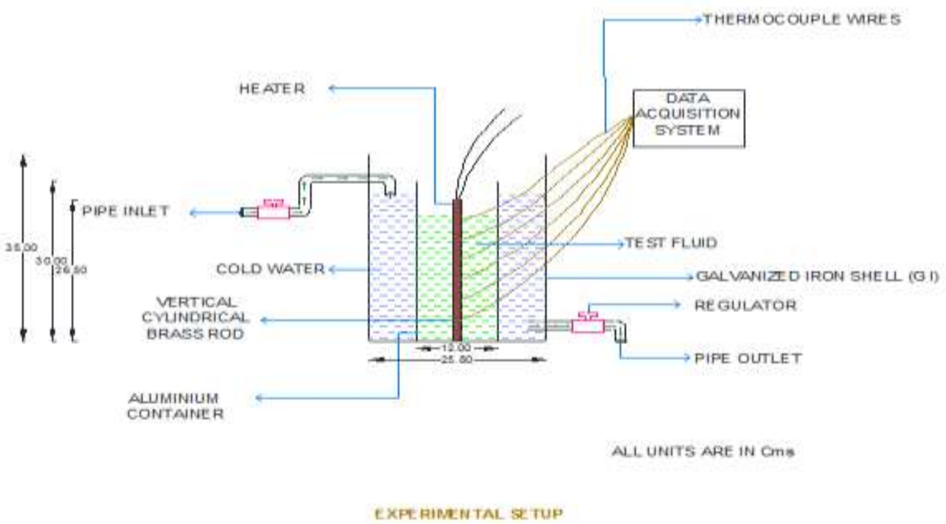

Figure.1: Schematic Diagram of Experimental Setup.

II. EXPERIMENTAL

The experimental setup mainly consists of a Galvanized Iron (GI) cylindrical container, Aluminium square enclosure, Brass cylinder, variable voltage power supply (Variac), Data Acquisition system (DAS) and also the instrumentations for temperature, voltage and current. A schematic view of the setup is illustrated as shown in Figure.1. The cylindrical GI container is of 258 mm outer diameter (OD), with a height of about 350 mm, the active heated length is about 248 mm of the total length of 265 mm. An Aluminium (Al) square enclosure of about 4mm thickness, 300 mm height and the l x b of the enclosure is about 120 x 120 mm respectively. Eight K-Type (Chromel / Alumel of 1.5 mm outer diameter) thermocouples were fixed firmly into the cavity (or) enclosure internally at six positions in an axial direction with the two thermocouples that are set diametrically in an opposite position, one on the top and the other on the bottom which were left open to the fluid in order to remove perturbations in readings. The thermocouples were attached to resist the temperature effects during the experimentation. A heater of tubular in shape of the same length of the cylinder that has been installed at the center of the cylindrical Brass rod. The internal gap between the heater and the Aluminium enclosure wall is filled with the (Ethylene Glycol + Water) fluids.

The Brass cylinder was vertically immersed in a stationary demineralized water Tank of 4 litres capacity with 300 mm height and l x b of about 120 mm x 120mm. Two holes on the opposite sides of the external GI cylindrical container were placed, so that two hose pipes of about 15 mm outer diameter (OD) and 12 mm inner diameter (ID) were passed through the holes of the external cylindrical container. The pipes are arranged in such a way that one is maintained to be fixed as pipe inlet and the other one to be as pipe outlet. In order to maintain different flow rates, a regulator valve is kept stable and fixed at the outlet of the pipe, so that different flow rates can be controlled through this regulator valve that has been fixed at one end of the outlet of the pipe. The Brass cylinder was internally heated by passing current through the heater by adjusting voltage. The Aluminium square enclosure is first inserted at the centre of the GI vertical cylinder. So that internally the GI vertical cylindrical container is completely filled with an active Bulk fluid (water) from the tap which was the cooling water that has to be filled until certain quantity that is equal to the height of Aluminium (Al) enclosure. This process of filling the water into the GI container is peculiarly done with varying mass flow rates during the experiment in order to extract the heat from the internal Aluminium (Al) enclosure continually of the fluid that is present in the vertical square (Al) enclosure. In the first condition only for water, later experiments were conducted for both [Water (H2O) + Ethylene Glycol (C2H6O2)] respectively.

The vertical Aluminium (Al) square enclosure is completely surrounded by an inactive test fluid that may be either water or (water + Ethylene Glycol) at constant temperature Tb heated in such a way that the uniform heat flux will be constant. After filling the enclosure with water in the presence of Brass cylinder and thermocouples, the water temperature is to be measure with the help of a digital thermometer in order to calculate the error in temperature of the test fluid. To determine the heat transfer characteristics of the Aluminium (Al) square vertical enclosure, the experiments were conducted using demineralized cooling water to avoid the scaling on the surface of the enclosure. Constant power has been supplied to the cylindrical heating element (or) cylindrical heater by adjusting the voltage at the same level by using the variable voltage regulator (Variac). The temperature changes at the surface of the Brass cylinder measured by the thermocouples are recorded at certain time by using the Data Acquisition system (DAS). The temperature of the test fluid at different depths was found to be constant throughout the experiment, which is mainly due to the large volume of Ethylene Glycol with more quantity of water in the vertical square enclosure. The temperatures of the surface were seemed to be at steady state after 40-50 minutes, but the data has got recorded for more than two (or) three hours. The verticality of the Brass cylinder had been set very accurately, so that the thermocouples will not get disturbed. Due to high thermal conductivity of (water + Ethylene Glycol) fluid, the electric power which was supplied to the heater was almost obtained with the thermal power at the surface of the vertical Brass cylinder. After the readings were taken at each heat input, of the test fluid that is situated in the Al vertical square enclosure contained with the thermocouples at certain distance on the Brass cylinder, the temperatures from top to bottom at different depths axially were measured and noted using the digital thermometer.

Here, in this natural convection heat transfer problem, the Grashof number is the major independent parameter of the experiment. The experiments have been performed for more than two hours to reach the steady state condition. When the steady state is attained, the average readings of the thermocouples and the input power was recorded to study the steady state natural convection heat transfer subjected to the constant heat flux boundary conditions that were appropriately analyzed.

Specifications of Water (H2O):
Chemical name: Dihydrogen monoxide
Appearance: Transparent
Density: 1 g/cm^3
Odour: Odourless

Specifications of Ethylene Glycol (C2H6O2):
Chemical name: Ethylene Glycol (Ethane-1,2-diol)
Colour: Green
Density: 1.1132 g/cm^3
Appearance: Clear liquid
Solubility in water: Miscible
Viscosity: 1.61 x 10^{-2} Ns/m^2

S. No	Properties	Water	Mixture of Water + Ethylene Glycol (25:75)
1.	Density (Kg/m^3)	1000	1065
2.	Specific Heat (J/KgK)	4178	3371
3.	Thermal conductivity (W/mK)	0.634	0.364

Table.1: Thermo Physical Properties of the Base Fluids.

It should be clearly noted that these given transport properties are the main functions of temperature. As a consequence all the properties of the fluids were calculated by using mean film temperature of the fluid that is present in the enclosure. The addition of small amount of Ethylene Glycol either less or more can change all the properties of the fluid in the heat transfer.

III. CALCULATIONS FOR HEAT TRANSFER COEFFICIENT

To obtain the heat transfer coefficient and the corresponding Nusselt number, the following procedure has been performed.

All the properties of water are calculated at mean film temperature (The average of surface and bulk temperature).

$$T = \frac{T_s + T_b}{}$$

2

The local Nusselt number is given by

$$Nu_L = \frac{h_x L}{k}$$

Where,

$$h_x = \frac{Q}{As\ \Delta Tx}$$

The average values of the Nusselt number can be calculated by

$$\overline{Nu_L} = \frac{\overline{h_L}\, L}{k}$$

Where,

$$\overline{h_L} = \frac{1}{L}\int_{x=0}^{x=L} h_x dx$$

The average values of the surface temperature, bulk temperature and mean film temperature can be evaluated as:

$$\overline{T_S} = \frac{1}{L}\int_{x=0}^{x=L} T_S dx$$

$$\overline{T_b} = \frac{1}{L}\int_{x=0}^{x=L} T_b dx$$

$$\overline{T_f} = \frac{\overline{T_S} + \overline{T_b}}{2}$$

The Grashof number and the Raleigh number can be calculated as

$$\overline{Gr_L} = \frac{g\beta L^3\,(\overline{T_S} - \overline{T_b})}{\upsilon^2}$$

$$\overline{Ra_L} = \overline{Gr_L}\ .\ \mathrm{Pr}$$

All the physical properties (Cp, ρ, β, μ and k) of Water and mixture of (Water + Ethylene Glycol) were evaluated at the average mean film temperature.

From the above equations, Nu is the average Nusselt number for the whole Aluminium square enclosure, C_P is the specific heat capacity of the fluid, A is the peripheral area of the Brass cylinder, T_b is the bulk temperature which was assumed to be the average values of the surface of the cylinder, K is the thermal conductivity of the fluid. It should also be mentioned that all the physical properties of the fluid were to be calculated at the bulk fluid temperature.

IV. RESULTS AND DISCUSSIONS

A. Pure water as Base Fluid (4 Litres):

Before conducting systematic experiments on the application of (Ethylene Glycol + Water) in the natural convection, some experimental tests with pure water were done in order to check the working nature of the experimental setup. Here, in this experiment the Brass cylinder was heated by immersing it vertically in a demineralized Aluminium water tank. This Aluminium square enclosure water tank area was about 120mm x 120mm x 300mm (l x b x h), so that the bulk temperature is constant throughout the experiment at different locations. The constant temperature of the fluid from the heating source at large distances have got satisfied. The heater is installed at the centre of the aluminium square enclosure which is to be calculated same at the surface of the cylinder, so the uniform heat flux is observed at the surface of the cylinder. The temperatures were recorded by the help of thermocouples to restrict the perturbations of the temperature distribution around the thermocouples measuring junction. The experiments have been performed for four different uniform heat fluxes that are in the range of 2838.22 watt per meter square to 4730.36 watt per meter square with an L/D ratio of 20.86.

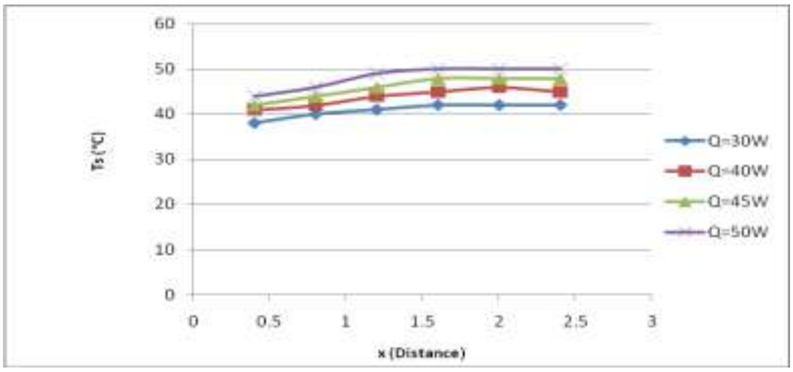

Figure.2: Temperature distribution of the surface along axial distance at different uniform heat fluxes.

Figure.2 shows the experimental results for the base fluid as pure water. The temperature variations along the vertical Brass cylinder at different axial distances from the lower side at different uniform heat fluxes and at different power levels the rise in temperatures can be observed along the axial direction. The surface temperature has been gradually increased for water with the consideration of the length. The fluid temperature rises as it is heated along the cylinder and the physical properties gradually changes with the rise in temperature. The T_S-x curve shows the variation of the surface temperature along the cylinder for different heat fluxes. Figure.2 reveals that the surface temperature increases to reach the maximum value due to some buoyancy forces.

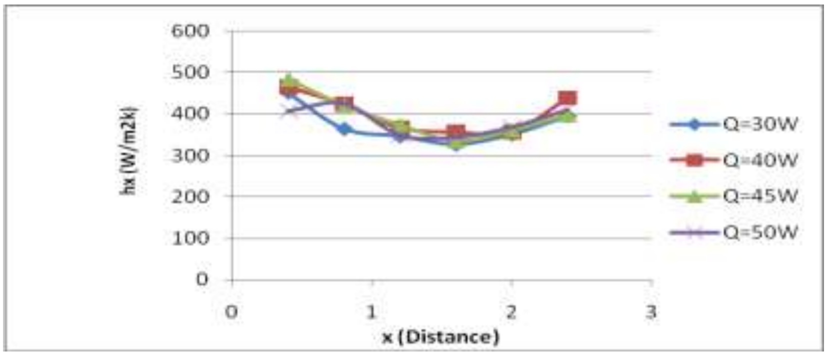

Figure.3: Local Heat Transfer Coefficient along axial distance at different heat inputs.

In Figure.3, it shows that the local heat transfer coefficient gradually decreases and then it has been increased due to the potential of the length of the cylinder and the confined improvement in the temperature due to high thermal conductivity of the water at different uniform heat fluxes.

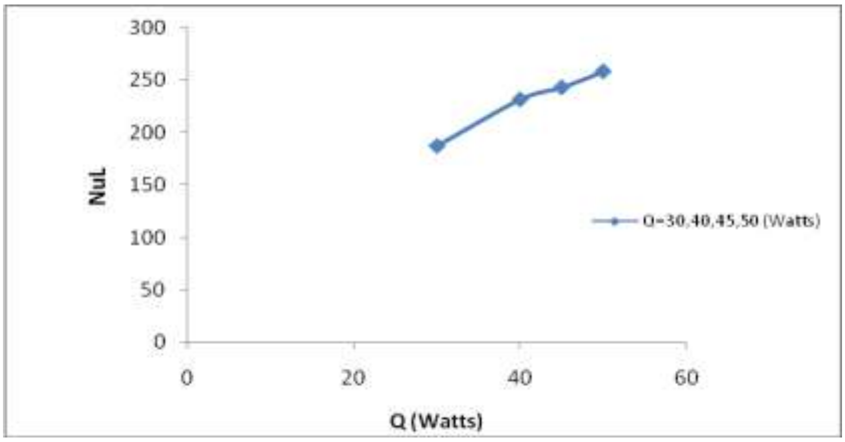

Figure.4: The experimental results for the average Nusselt number at different heat inputs for water.

Figure.4 shows the experimental values for the average Nusselt number at different uniform heat fluxes and heat inputs, the Nusselt number is going on increasing for the water as the heat supplied given is more for the vertical cylindrical surface.

B. Mixture of water + Ethylene Glycol (75:25):

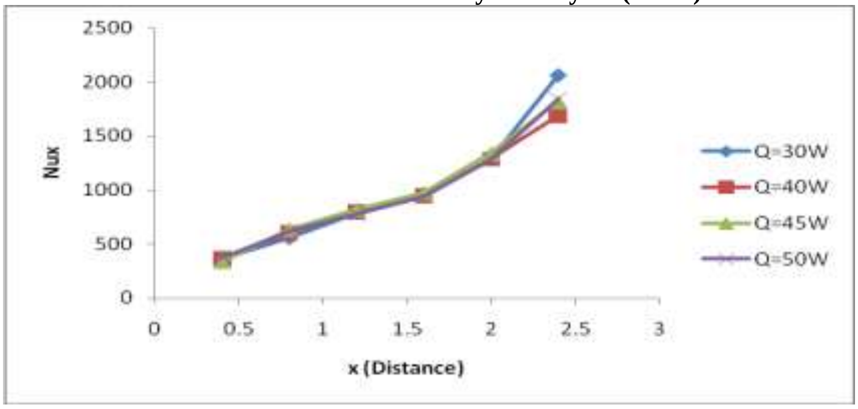

Figure.5: Local Nusselt number along the length of the cylinder along axial distance from bottom to top at different given heat inputs for (Water + Ethylene Glycol)

The Natural convection from uniformly heated surface of the cylinder of length (L) is directly exposed to the mixture of water and Ethylene Glycol. This variation in surface temperature is mainly used to calculate the local heat transfer coefficient at different axial lengths of the cylinder. The physical properties of the test fluid were calculated at the mean film temperature. The local dimensionless constants such as Nusselt number, Grashof number and Raleigh number were calculated to find out the correlation for natural convection heat transfer. The local Nusselt number increases gradually at different uniform heat fluxes with the length of the vertical cylinder at different power inputs. So, the Figure.5 shows the gradual increase in the Nusselt number along the length of the cylinder.

In Figure.6, it is clearly seen that the temperature of the mixture of (Ethylene Glycol + Water) is more than that of pure water, so the temperature has been increased intermittently on the surface of the vertical cylinder, this is because due to the changes in the physical transport properties of the fluid such as thermal conductivity, viscosity and density of the fluid indeed at certain considerate length and diameter of the cylinder.

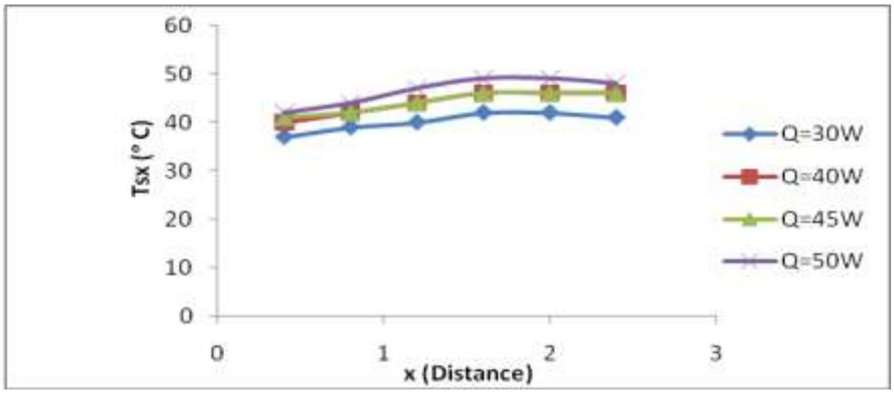

Figure.6: Experimental results for the surface temperature distribution along the axial distance at different heat generation rates.

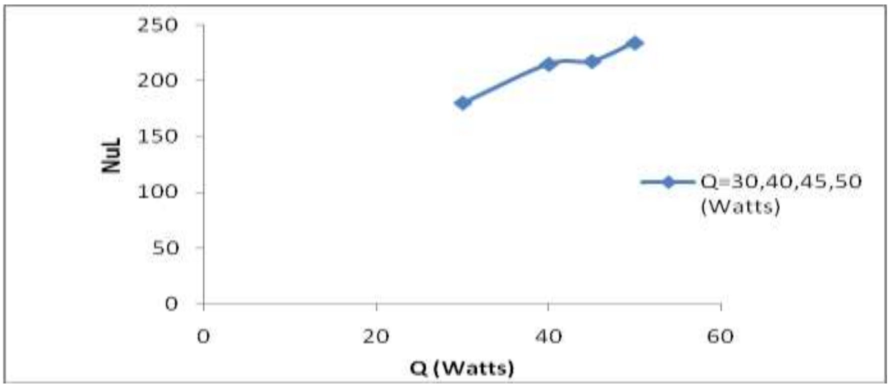

Figure.7: Experimental results for the average Nusselt number at different heat generation rates at given

dimensionless constants for the mixture of (Water + Ethylene Glycol) in the ratio of (75:25) of the total amount of fluid.

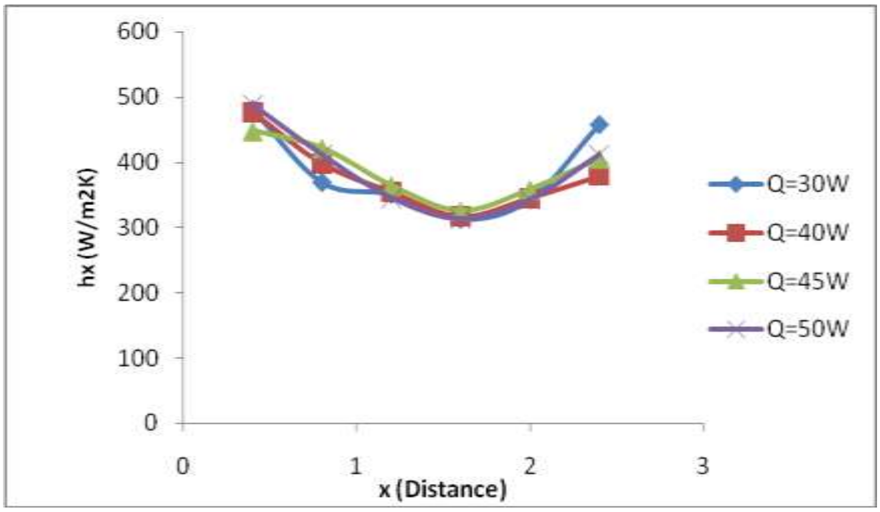

Figure.8: Local Heat Transfer Coefficient along axial distance of the vertical cylinder at different heat generation rates.

Figure.8 shows the local heat transfer coefficient that has been decreased consistenly and then it has got increased finally more than that of water, this has happened due to the sudden changes in the transport properties of the mixture of Ethylene Glycol into the water in this convection heat transfer problem.

The general equation can be obtained by the dimensional analysis for the natural convection heat transfer in the literature will be empirically correlated in this study. In this case of heat transfer from the vertical Brass cylinder, we can expect that there are combined effects of both length and diameter. In this study finally as the experimentations were done on the flat surface, i.e, aluminium vertical square enclosure, the characteristic dimensions which are linear in Nusselt number Grashof number can be taken as the length of the cylinder (L). Hence, the Nusselt number and Raleigh numbers are mainly dependent on the length parameter. The equation can be proposed as

$$Nu_L = a\,(Gr_L\ \mathrm{Pr})^{n}$$

V. CONCLUSION

The presence of mixture of [Water + Ethylene Glycol](25:75) can enhance the heat transfer rate of the vertical Brass cylinder in an Aluminium square enclosure. The degree of heat transfer enhancement mainly depends on the amount of the addition of the Ethylene Glycol to water in the ratio of (25:75).

The steady state natural convection heat transfer of the vertical cylinder which was heated throughout the uniform heat flux has been experimentally investigated for high Grashof numbers and Raleigh numbers. As a result, the local and average parameters have been presented at every state. It has also been negotiated that the increase in the effective thermal conductivity and in the variation of all the other transport properties were not responsible for the large enhancements of heat transfer, but also the buoyancy forces of the may also be one of the most important factor in the heat transfer enhancement in the Natural Convection applications.

VI. NOMENCLATURE

L Overall heated length of cylinder, m

x Local length of cylinder, m

D Diameter of cylinder, m

Q Rate of heat transfer, watt

q Heat flux, w/m^2

g Gravitational acceleration, m/sec^2

Ts Surface temperature, ^{o}C

Tb Bulk temperature of water, ^{o}C

k Thermal conductivity, $w/m^{o}C$

Cp Specific heat capacity of water, $J/kg^{o}C$

β Thermal expansion coefficient, $1/^{o}K$
ρ Density of water, kg/m^3
μ Dynamic viscosity of water, kg/m-s
ν Kinematic viscosity of water, m^2/s
h Local heat transfer coefficient, $w/m^2\ ^{o}C$
Nu Nusselt number
Pr Prandtl number
Gr Grashof number
Ra Raleigh number
x shows the local value in suffix
L shows the average value suffix

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