American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)
ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

Convective Heat Transfer Study of ZnO Nanofluids and a Comparison with the Conventional Coolant Water

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Abstract

In this era, the utilization of automobiles is increasing rapidly. So, it is a task for the automobile industries to yield well-ordered cooling system, which is actually responsible to carry waste heat of engine to atmosphere for effective working of an internal combustion engines. In this research, car radiator was tested by the water based Nano fluids to increase its heat transfer capacity and new experimental results were reported. Zinc Oxide nanofluids were prepared and tested by adding their nanoparticles in water with different volume fractions (0.1, 0.2, 0.3 and 0.4)%. Experimentally, effect of these concentrations were observed by varying a fluid flow rate from 4 liter per minute to 1 liter per minute and inlet temperature of fluid entering in radiator was kept constant at 80^{o}C and enhancement in heat transfer was observed from 46% to 70% by using ZnO Nano Fluid having volumetric concentration 0.2%. Increase in volumetric concentration had shown the enhancement of heat transfer but up to 0.2% and it was seen that further increase in concentration was been reduced the heat transfer capacity.

Keywords: Nanofluids; Volume Fraction; Nano-Particles; Heat Transfer Capacity.

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1. Introduction

Today, there is a demand of highly efficient engines with the ongoing development in automobile industries and cooling system of engine plays a vital role to increase efficiency and heat transfer. A measureable increase in heat transfer is achieved by adding fins that provides more heat transfer area and increases heat transfer capacity by increment in air convection heat transfer coefficient. But, this typical method to increase heat transfer has ultimately reached to their limit [1]. Consequently, there is a need of new and efficient coolants that can cause increase in heat transfer of car radiators. Traditional coolants like pure water and E.G reveals less thermal conductivity. So, with the growth of nanotechnology a new coolant named nanofluids have been made and researchers found that they shows more thermal conductivity that ultimately increases the heat transfer in comparison to the conventional coolants [2].Thermal Conductivities of Zinc oxide water based nanofluids was determined by Lee and his colleagues [3] by the help of transient hot wire method and it was clear from the results that thermal conductivity mainly depends upon particle size and shape. It was shown higher thermal conductivity instead of water and E.G. It was found by the Das and his colleagues [4] that the thermal conductivity was varying directly with the temperature gradient of fluid entering or leaving the radiator. It was also said that the heat conduction is more due to increased surface area for transferring heat and it was due to the greater number of particles present. According to the analysis of doubt in the results found, the percentage errors observed regarding Reynolds number and Nusselt number were almost 5.2% and 18% respectively [5]. reference [6] and a comprehensive articles regarding heat transfer by the nano fluids were published in articles by Godson and his colleagues [7,8,9].

2. Experimental Setup and Data Reduction

2.1. Experimental setup

In order to prove the higher heat transfer rate for the nanofluids experimental setup was developed as shown in figure 1 with schematic diagram in figure 2 and since it is research on car radiator so the setup resembles the car cooling system in which an artificial electrical heat source was installed having power of 4KW to higher the temperature of fluid to a specified limit and then the fluid was allowed to move to radiator by the help of centrifugal pump after maintaining a required temperature and flow rate have a great importance in this research so the fluid flow rate was controlled by the variable area flow meter in which the flow rate was controlled by the flow regulation valve and the extra fluid was sent back to the fluid tank by by-pass flow valve. The fluid was cooled down in the radiator by the forced convection done by the fan by exchanging the heat of fluid to atmosphere and the temperatures of the fluid entering or leaving the heat exchanger were observed by the digitally controlled thermometers that also have a capability of setting a temperature limit.

2.2. Data Reduction

An important factor named bulk temperature was calculated by taking the average of temperatures of fluid entering or leaving the radiator and it was used to determine the different properties.

Density and Specific heat of nanofluids were calculated by the relations given by [10,11].

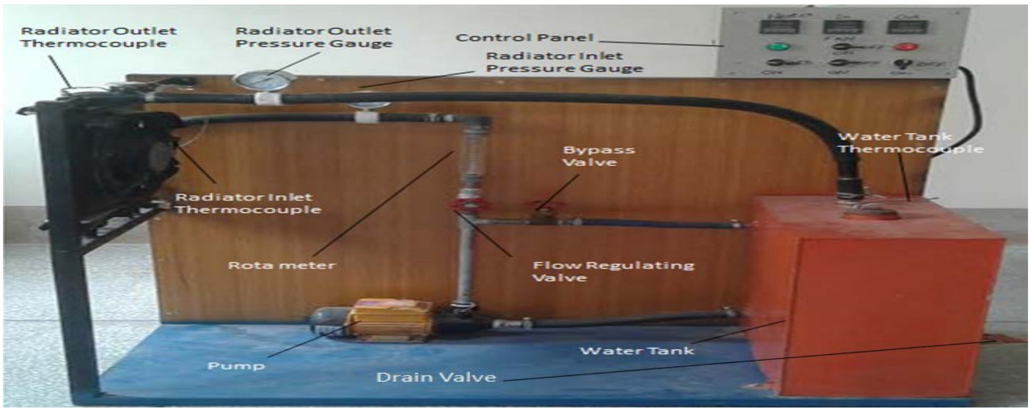

Figure 1: Experimental Setup

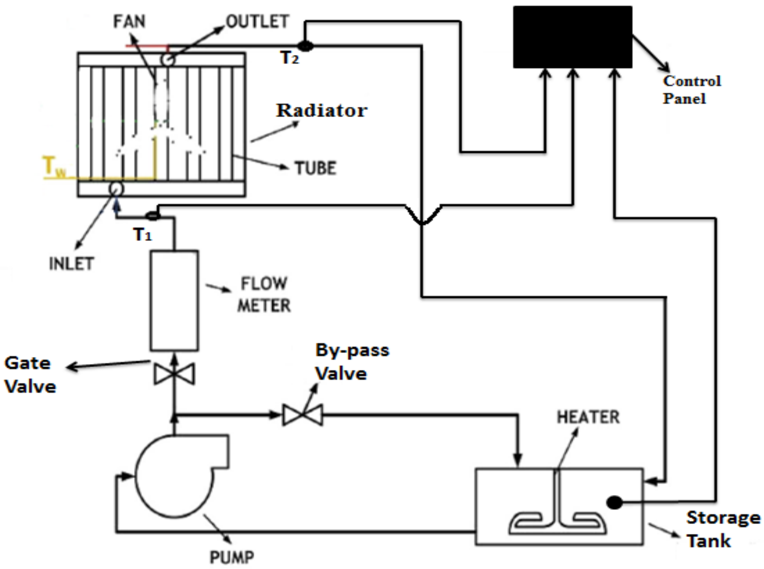

Figure 2: Line Diagram of experimental setup

$$\rho(n.f) = \theta * \rho(p) + (1-\Theta) * \rho(b.f) \quad (1)$$

$$Cp(n.f) = \theta * Cp(p) + (1-\Theta) * Cp(b.f) \quad (2)$$

Where the parameters ρ, Θ and Cp were showing density, volumetric concentration of nanoparticle and specific heat at constant pressure respectively and in addition the parameters n.f, b.f and p are for the nanofluid, base fluid and particle respectively.

Calculation of heat transfer was done by the relation

$$Q = \dot{m}Cp(T1 - T2) \quad (3)$$

Where Q is for Heat Transfer, ṁ is mass flow rate of the fuid and T1 and T2 are for the Radiator inlet and Outlet temperature respectively.

Dimensionless numbers (Reynolds number and Nusselt number) holds an enough importance in that research and was determined by the relation

$$Re = \frac{\rho * v * Dh}{\mu} \tag{4}$$

Where Re is showing Reynolds number, v is for fluid flowing velocity, Dh is the hydraulic diameter of radiator tubes along which nano coolant is flowing and μ is showing dynamic viscosity.

The dynamic viscosity for the nanofluids was calculated by the relation purposed by Wang and his colleagues [12]

$$\mu(n.f) = \mu(b.f) * (1 + 7.3\theta + 123\theta^2) \tag{5}$$

Thermal Conductivity of nanofluids were determined according to Hamilton and Crosser [13], by the relation

$$K(n.f) = \frac{K(p) + (\omega-1)*K(b.f) - \Theta(\omega-1)(K(b.f)-K(p))}{K(p) + (\omega-1)*K(b.f) - \Theta*(K(b.f)-K(p))} * K(b.f) \tag{6}$$

K is the thermal conductivity and ω is representing empirical shape factor of nano-particle added to base fluid and its value for the spherical shaped particle is considered as 3.

Coefficient of heat transfer H was calculated by the formula

$$H = \frac{\dot{m}Cp(T1-T2)}{A(T-Tw)} \tag{7}$$

Where A, T and Tw are representing Peripheral area of tubes, average bulk temperature and tube wall temperature respectively.

Nusselt number was calculated by the relation

$$Nu = \frac{H * Dh}{K} \tag{8}$$

Dh the hydraulic diameter was found by formula

$$Dh = \frac{4 * A}{p} \tag{9}$$

And the relations for A the peripheral area and P the perimeter of radiator tubes having cylindrical cross section were

$$A = \frac{\pi}{4} * d2^2 + (d1 - d2) * d2 \tag{10}$$

$$p = \pi * d2 + 2 * (d1 - d2) \tag{11}$$

Where d1 is the major diameter and d2 is the minor diameter of cylindrical tube.

U the heat transfer coefficient overall was determined by the relation

$$U = \frac{Q}{A*LMTD} \quad (12)$$

LMTD for the radiator was determined using formula

$$LMTD = \frac{(T1-T2)}{\ln(\frac{T1}{T2})} \quad (13)$$

3. Results and Discussions

To prove the experimental results authenticated nusselt number for pure water and for ZnO at 0.2 % volumetric concentration was found and was compared with the previously investigated results of water being tested in a car radiator by Peyghambarzadeh and his colleagues [14] as shown in figure 3.

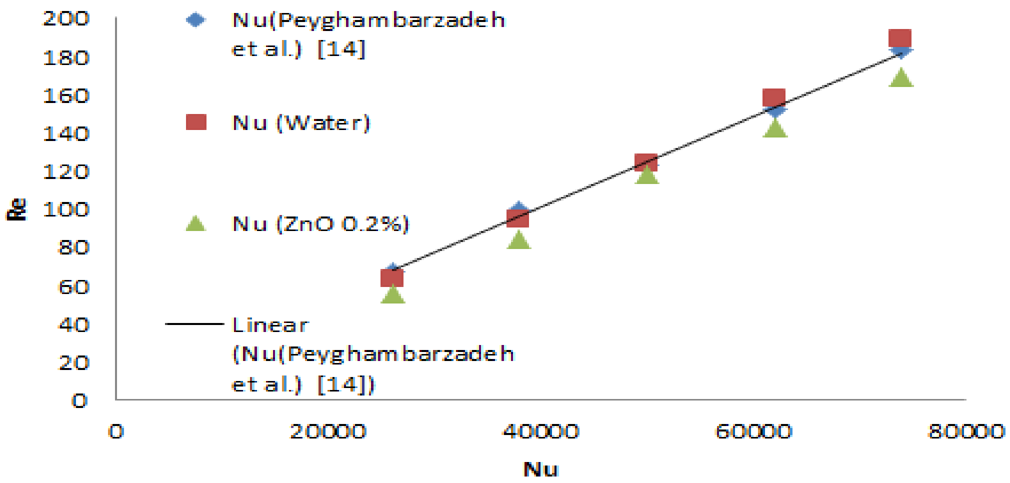

Figure 3: Comparison of Experimental Results of pure water and ZnO at 0.2% with the Peyghambarzadeh and his colleagues [14].

Figure 3 was showing good comparison between the experimental results and previous results for pure water by the Peyghambarzadeh and his colleagues [14] and it is clearly shown from figure 3 that water gives higher Nusselt number as compared to the ZnO.

Heat transfer have a great importance in this study so heat transfer for different concentrations of ZnO nanofluids (0.1%, 0.2%, 0.3% and 0.4%) was determined in variation with the flow rate and compared with the heat transfer of water as shown in figure 4.

It is clearly shown from the figure 4 that water gives less heat transfer as compared to ZnO nanofluid and maximum heat transfer was given by ZnO at 0.2% volume fraction it is because of solid particles added to base fluid in nano size to make it nanofluid. As the particle is added the thermal conductivity of fluid is increased and it shown more heat transfer.

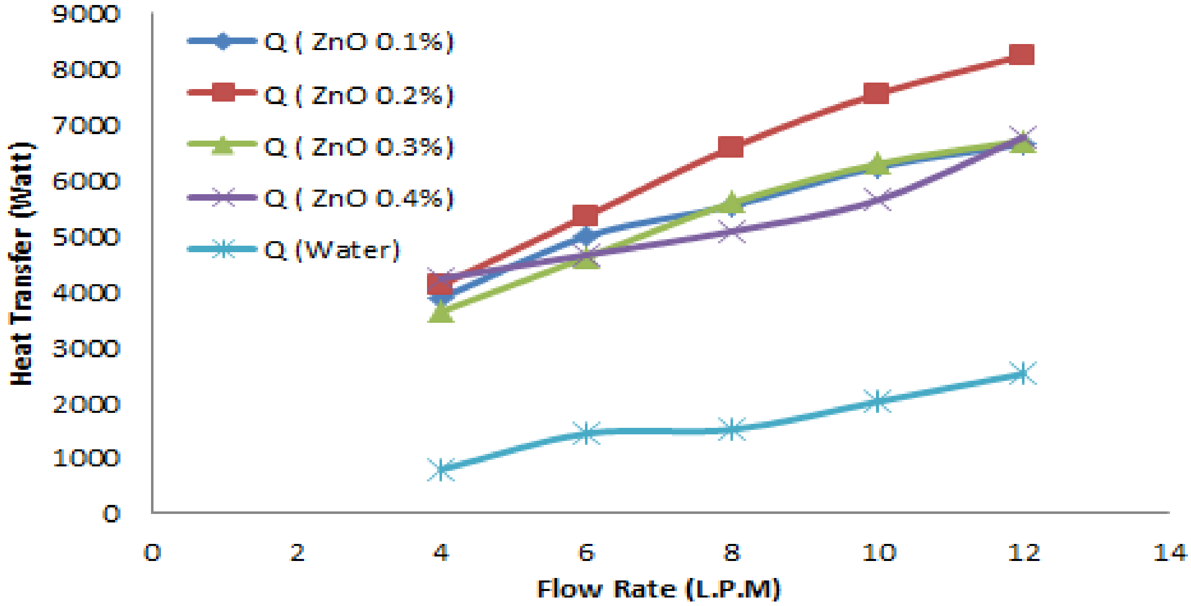

Figure 4: Heat Transfer comparison between water and different concentrations of ZnO Nanofluid

Log mean Temperature difference (LMTD) is a key factor to define the efficiency of a heat exchanger so the overall coefficient of heat transfer was determined for all the concentrations of ZnO discussed earlier and compared with that of of pure water determined from the LMTD as shown in figure 5

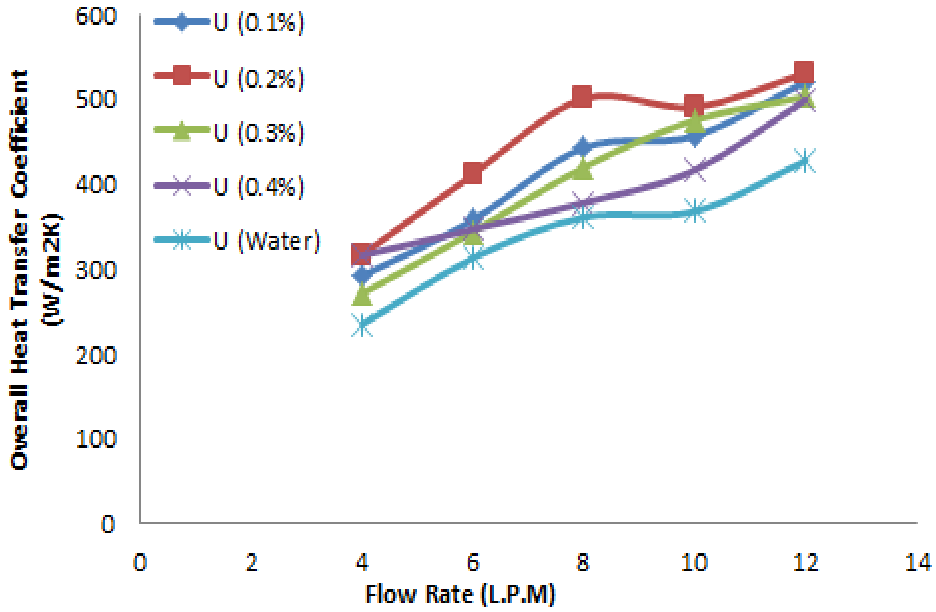

Figure 5: Overall Heat Transfer Coefficient and Flow Rate

ZnO gives higher overall heat Transfer Coefficient at 0.2% and a good comparison was seen between water and a nanofluid results showing that radiator works more efficiently by using nano coolants instead of water.

4. Conclusions

From the results of this research, some important conclusions were drawn.

- Nanofluids can be utilized as an efficient coolant for automobile industries.
- Enhancement in heat transfer using nanofluids in comparison to the base fluid has shown the promising future of nano coolants in automotive industries.
- Increment in heat transfer has also been observed by increment in flow rate of fluid corresponding to Reynolds number.
- Measureable amount of increase in heat transfer using ZnO nano coolants have been observed and 0.2% volumetric concentration have shown the maximum increment in heat transfer from 40% to 60%.
- Increase in heat transfer have been observed by increasing volumetric concentration but up to 0.2% and after that heat transfer is going to decline by increasing particle fraction.
- Automobile radiators size can be reduced due to improvement in heat transfer because of which drag force can be reduced results in decreasing fuel consumption and in addition the weight can also be reduced.

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