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# Experimental Investigation to Identify the Effect of Oxide Based Suspension on Effectiveness of Automobile Radiator

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**Abstract**

**In this paper, aluminum silicate ($Al_2SiO_5$)-water based nanofluid is experimentally investigated as a coolant for automobile radiator to enhance the heat transfer performance. The thermal performance of radiator has been evaluated in terms of temperature of the fluid at the outlet of the radiator. Different concentrations of nanofluids have been prepared by the addition of $Al_2SiO_5$ nanoparticles into the pure water. The concentration of nano particles used in this investigation ranges from 0.1% to 0.4%. In all the experiments nanofluids make to flow through the radiator tubes with elliptical cross section. The results indicate that there is an increase in the heat transfer when compared with pure water. By increasing the flow rate of the working fluid, the heat transfer coefficient of both pure water and Nanofluid increases significantly. The results of the investigation are presented graphically in terms of heat transfer coefficient as a function of volume concentration, temperature and flow rate.**

*Keywords*: $Al_2SiO_5$ nanofluid, Radiator, Heat transfer coefficient, Laminar, Reynolds number

## 1. Introduction

Automotive industries continuously doing development for making high efficient and economical engines which consumes less fuel to attract the customers. The efficiency of engine is increased by various ways like by using optimized design of engine which reduce the weight of automotive and efficient engine cooling system which will increase the performance of vehicle. To increase the performance of radiator by using of optimized designed fins and micro size tube is most conventional way. Another way of enhance the cooling effect is use of efficient coolant in the vehicle radiator. Conventional coolant is the mixture of water and ethylene glycol. Ethylene glycol works as anti-freeze agent for increasing the boiling point of water. Water is used for wide range of temperature by adding anti-freeze agent but for that we have to compromise the heat transfer performance of the radiator as the heat capacity of mixture is less that of water. Solid particles having size less than 100 nm has different thermal properties than the conventional solid particles. As nanometer size particles has large surface area as compare to micro size powder which enhance heat transfer rate. Choi [1] has pioneered the use of nanofluids which are more efficient than regular fluids in terms of heat transmission. Many authors have conducted a thorough study of the physical and thermal properties of nanofluids [2–5]. Since its initial application in real-world engineering [6, 7] a number of applications have effectively employed nanofluid to enhance thermal transfer, including electronic components [8–10], nuclear reactors [11–13], heating & cooling systems [14–16] and hot water [17].

A nanofluid may be made by scattering metallic or non-metallic nanoparticles or nanofibers less than 100 nm on an average in the base liquid. The use of nanoparticles in foundation fluids enhances mixing compared with pure fluid and boosts heat conductivity. Nanofluids have been investigated for their possible application in the cooling system of car engines through advances in research. Nanoparticles were placed into the usual (water, ethylene glycol, and glycerol) coolants to boost the efficiency of the engine's heat removal and numerous researchers were acknowledged for their performance. However, several incoherence's exist in the reported results, notably as regards the optimum quantity of nanoparticles to be used, the percentage of improvement, the innovative type of nanoparticles and other experimental elements.

The radiator system is essential to reduce friction and overheating of the vehicle engine. An automobile radiator traditionally circulates water as the heat transfer medium passes through the chambers of the engine block, absorbs heat and disperses it away from other vital components. The louvered fins of a radiator permit an increase in heat transfer over the surface, therefore affecting the expansion of the boundary layer generated along the surface. Antifreeze is a chemical additive used to decrease the freezing point or increase the boiling point of the liquid in areas with extreme weather conditions. In recent decades, the performance of automotive engines has increased dramatically. Engine manufacturers are in competition with each other to meet customers' demands for high-efficiency engines at a reasonable price. However, the cooling efficiency of the radiator is limited due to the low thermal conductivity of the engine coolant, making it difficult to maintain the small size of the cooling system. Moreover, traditional cooling techniques (i.e. fins and micro-channels) have reached their limits.

Nano-coolant, which consists of nanoparticles mixed within a traditional coolant, has been tested for genuine usage since the early 2000s. Notably, it is reported in the literature that the vehicle radiator was the first difficult system to use cooling nano-coolant [18]. Choi and colleagues [18] employed a transient thermal-wire technique to assess metallic and oxide-based ethylene glycol nanofluids in thermal conductivity. They argued that the heat conductivity measured was much higher than anticipated. Its results are consistent with Maranville et al [19].'s approach to determine the thermal conductivity of nanofluids and metal oxide based on ethylene glycol/water, by using a transient planar source approach. The issues of aggregation and oxidation of metallic nanoparticles remain unresolved. Goldenstein et al. [20] showed that adding nanoparticles to water leads to high thermal diffusivity of the nanofluid. This excellent coolant quality can be applied to any system which requires a quick response to heat fluctuations, like a radiator for a vehicle. Tzeng et al. did an experimental investigation on the performance of nano-fluid in the cooling system of a real car engine [21]. The results of CuO, $Al_2O_3$, and antifoam nanoparticles added to the fluid were investigated. The engine rotated at four different velocities (400 rpm, 800 rpm, 1200 rpm and 1600 rpm), and the Mazda 4-wheel drive (4WD) gearbox system was added for the test car. They showed that CuO had the best heat transfer effect and the most restricted heat transmission of all nanoparticles and antifoam. Zhang et al. [22] studied the effect of nano graphite added to coolant for diesel heavy-duty engines. They found that 3 % by wt. nano graphite added to the refrigerant increased cooling capacity by 15 %. Saripella et al. [23] examined the effect of cooling nanofluid on a truck engine. A 50-50% combination of water and ethylene glycol was used as the base fluid and added 2 and 4 volume % of copper oxide (CuO) nanoparticles to evaluate engine power, temperature and pump speed. The authors concluded that the inclusion of nano graphite resulted in two pump speed reductions that needed heat rejection as without nano graphite. The result was a reduction in the power consumption of an engine. Ali and his associates carried out experiment on an actual automotive engine cooling system [24]. They tested the forced convection heat transfer capabilities of an $Al_2O_3$-water nanofluid-filled Toyota Yaris radiator. They observed that the coefficient of heat transmission was suprrior at a fraction of 1% by wt. immersion. The cooling mechanism of the radiators would be impaired by raising the volume fraction.

From the above literature survey, it is confirmed that the immersion of nanoparticles certainly enhance the heat transfer at radiator. However, water-based aluminum silicate ($Al_2SiO_5$) nanofluid has not been investigated for the possible improvement in the thermal performance of the coolant used at radiator. As a result, the current study investigated the application of $Al_2SiO_5$-water nanofluid as a radiator coolant. Additionally, other variables such as liquid flow rates, various nanoparticle concentrations, and coolant inlet temperatures were investigated to gain a better understanding of the radiator's cooling efficiency**.**

## 2. Methodology

### 2.1 Preparation of $Al_2SiO_5$ nanofluid

The nanofluid used in this study is made up of water containing varying concentrations of $Al_2SiO_5$ nanoparticles. $Al_2SiO_5$ nanoparticles with an average particle diameter of less than 100 nm were purchased from Intelligent Materials Pvt. Ltd., India. The quantity of nanoparticles required to achieve a specified percentage of volumetric concentration is calculated using Eq (1).

$$\text{Volume concentration, } \emptyset = \left[\frac{\frac{w_{Particle}}{\rho_{Particle}}}{\frac{w_{Particle}}{\rho_{Particle}}+\frac{w_{Fluid}}{\rho_{Fluid}}}\right] \text{x } 100$$

Nanofluid samples were prepared by taking 100 g of the base fluid and directly adding the estimated amount of $Al_2SiO_5$. To achieve uniform dispersion, the mixture of water and $Al_2SiO_5$ nanoparticle was sonicated continuously for approximately 8 hours. Besides, oleic acid and SDBS (Sodium dodecylbenzene sulfonate) were used as surfactants. For each 100 ml Nanofluid sample, 0.5 ml oleic acid and SDBS with a weight equal to one-tenth the weight of the nanoparticles was used. The present investigation used bulk volumetric concentrations of 0.1%, 0.2 %, 0.3 % and 0.4

% of a 5 l capacity.

The solid–fluid mixture formulas were used to approximate the Nanofluid's thermophysical properties. Density, specific heat, thermal conductivity and viscosity were estimated using the Pak and Cho [25] equations, which are presented below:

$$\rho_{nf} = \emptyset \rho_p + (1-\emptyset)\rho_{bf} \quad (2)$$

$$C_{pnf} = (1-\emptyset)\left(\frac{\rho_{bf}}{\rho_{nf}}\right) C_{pbf} + \emptyset\left(\frac{\rho_p}{\rho_{nf}}\right) C_{pp} \quad (3)$$

$$k_{nf} = \frac{k_p + (n-1)k_{bf} - \emptyset\,(n-1)(k_{bf} - k_p)}{k_p + (n-1)k_{bf} + \emptyset\,(n-1)(k_{bf} - k_p)} \quad (4)$$

$$\mu_{nf} = \mu_{bf}\,(1 + 2.5\emptyset) \quad (5)$$

Regarding the equality of Q in the above equations:

$$Nu = \frac{h_{exp} D_h}{k} = \frac{m\, C_p\,(T_{in} - T_{out})}{A\,(T_b - T_w)} \quad (8)$$

Nu is the radiator's average Nusselt number, m is the mass flow rate, which is obtained by the multiplication of fluid's density and volume flow

## 2.2 Estimation for Coefficient of heat transfer

The below mentioned steps were used to measure the heat transfer coefficient and corresponding Nusselt number.

According to Newton's law of cooling:

$$Q = h\,A\,(T_b - T_w) \quad (6)$$

Heat transfer rate can be calculated as follows:

$$Q = m\,C_p\,\Delta T = m\,C_p\,(T_{in} - T_{out}) \quad (7)$$

rate, Cp is the specific heat of fluid, A is the radiator tubes' peripheral area, $T_{inlet}$ and $T_{outlet}$ are the radiator tubes' temperatures respectively, and $T_b$ is the bulk temperature, which was presumed to be the average of the inlet and outlet temperatures of coolant. In this equation, k denotes the fluid's thermal conductivity and $D_h$ denotes the hydraulic diameter of the tube. Furthermore, all physical properties were calculated at the bulk temperature of the fluid.

## 2.3 Experimental Set-up

As illustrated in Fig.1, the test rig was developed to investigate the thermal performance of Nanofluids as a car radiator coolant. This test rig is equipped with a coolant storage tank, a heater, a pump, a flow measuring instrument, thermocouples of the J type, a pressure transducer, and a resistance temperature detector for the purpose of measuring the coolant's inlet and outlet temperatures. Table 1 summarizes the geometrical parameters considered for the radiator.

After heating the coolant in the tank to the desired temperature, the pump is activated, allowing the coolant to flow through the radiator, and the fan is activated to absorb and dissipate heat from the hot fluid. The temperatures at the radiator's inlet and outlet are recorded. The nanofluid is supposed to flow with a uniform Reynolds number in radiator channels, assuming a normal distribution. After heating the coolant in the tank to the desired temperature, the pump is activated, allowing the coolant to flow through the radiator, and the fan is activated to absorb and dissipate heat from the hot fluid.

**Fig. 1.** An image of experimental set-up used


**Table 1** Geometrical characteristics of radiator

| | |
|---|---|
| Length of radiator | 0.345 m |
| Height of radiator | 0.340 m |
| Depth of radiator | 0.022 m |
| Total tubes | 48 (24 in one row) |
| Outer diameter of tube | 0.007 m |
| Inner diameter of tube | 0.003 m |
| Surface area of tube | 0.5 $m^2$ |
| Hydraulic diameter | 0.004378 m |

The temperatures at the radiator's inlet and outlet are recorded. The nanofluid is supposed to flow with a uniform Reynolds number in radiator channels, assuming a normal distribution.

The coolant circulates through two rows of 24 tubes each with a 0.5 $m^2$ surface area. The radiator is allowed to circulate coolant at flow rates of 2, 4, 6 and 8 l/min. The aim for varying coolant and air flow rates is to replicate in-service operating conditions as closely as possible. The temperature of the air entering and exiting the radiator was determined. A heater set to a temperature range of 39 to 95 °C is used to simulate heat generation. When the required temperature is reached (95 °C), the high temperature durable coolant pump is activated, allowing coolant to circulate across the heat exchanger. Six J-type thermocouples (having range of 20 - 350 °C ) were used to measure the temperature of the coolant tank, the radiator's inlet chamber as well as exit chamber. Out of six thermocouples, one was placed close to the radiator's passage tubes, and two on the front and rear to record the temperature of the air. The temperature of a thermocouple located near the passage tube in the radiator's center is employed to calculate the amount of heat lost and the bulk temperature. Calibration of thermocouples, temperature recorder, and flow meter was performed prior to the start of the experiment.

## 3. Results and Discussion

The thermal performance of radiator has been measured by the temperature of the fluid at the outlet of the radiator. The fluid temperature at the radiator output ($T_{out}$) should be lower for a better cooling system. Figure 2 shows the graph of outlet temperature with respect to different flow rate of the coolant and pure water circulating in the radiator. In figure 2, different data series indicate different concentrations of $Al_2SiO_5$ and pure water. For each reading in the graph, the fluid inlet temperature was kept constant at 80°C.

It has been found from the Fig. 2 that, the outlet temperature drops significantly with increase in volume concentration of $Al_2SiO_5$. However, at all concentration, the thermal performance is better than pure water. This is also evident from Figure 3, which shows the effect of a variation in the $Al_2SiO_5$ concentration on the coefficient of convective heat transfer at different coolant flow rates. Figure 3 shows that the value of the heat transfer coefficient increases by increasing the coolant flow rate. The same trend observed for all nanofluids with different concentrations of $Al_2SiO_5$ nanoparticles. It can be demonstrated that as concentration increases, the heat transfer coefficient increases. By adding only 0.4 vol. percent of $Al_2SiO_5$ nanoparticles to pure water, a heat transfer coefficient of approximately 40–45 % greater than that of pure water was observed.

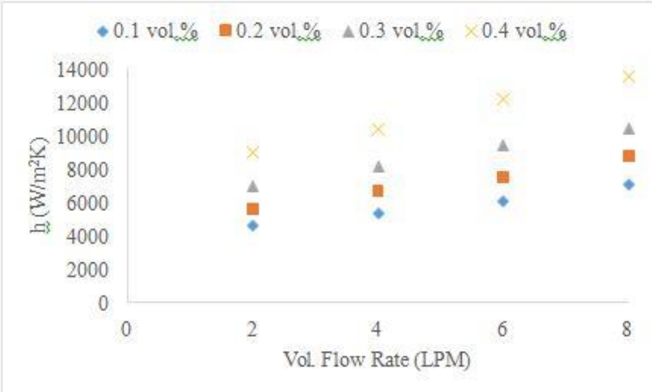


**Fig.2.** Effect on heat transfer coefficient due to different nanofluid concentration and fluid flow rate

The reason for the improvement in heat transfer coefficient by using nanofluid is attributed with the concept of Brownian motion. According to this concept, the presence of nanoparticle and their random motion affects the thermal boundary layer which plays important role in heat transfer [15].

Numerous experimental trials with pure water were made with the cooling system to analyze the experimental results. The experimental results for Nu compared with the equations of Shah- London Equation for laminar flow [26].

Fig. 4 describes the experimental results for the Nusselt number with various Reynolds numbers for pure water. It appears that the experimental results for pure water agreed with Shah-London Equation for laminar flow. The influence of nanoparticle concentration on the mean Nusselt number is shown in Fig. 5 for $Al_2SiO_5$-Water. It appears that the Nusselt number surges with growing Reynolds number and volume concentration. Fig. 5 also shows an assessment of the Nusselt number amid nanofluids and base fluids at laminar flow. This comparison shows that the nanofluid has invreased values of heat transfer than that of the base fluid. The other side shows the experimental results for the Nusselt number with curve-fitting data of Sieder-Tate correlation [27] and Shah- London Equation for $Al_2SiO_5$-Water.

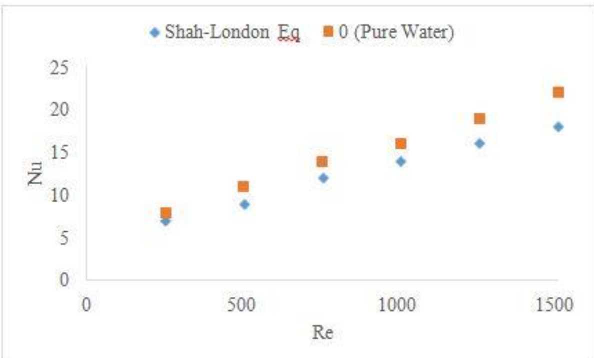


**Fig. 3(a).** Nusselt numbers at different Reynolds numbers: Pure water

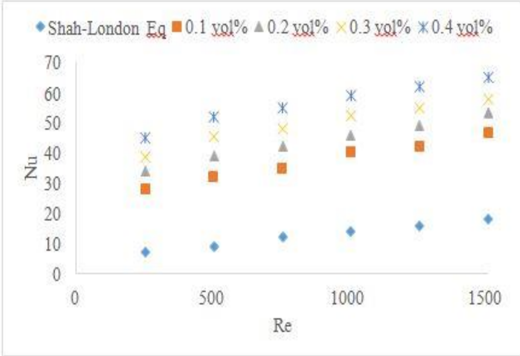


**Fig. 3(b).** Nusselt numbers at different Reynolds numbers: $Al_2SiO_5$-water

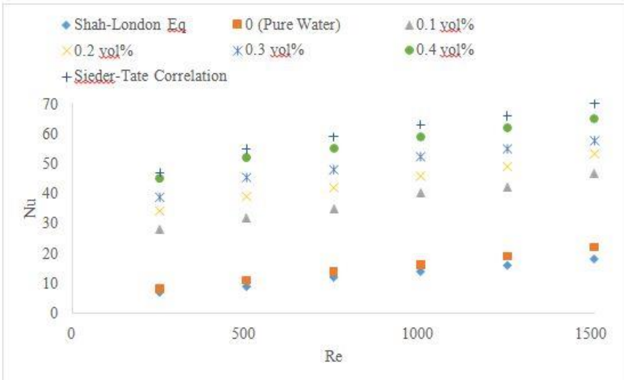


**Fig. 4.** Validation of the Nusselt number with equations and experimental data: $Al_2SiO_5$-water

**Conclusions**

In this article, thermal performance of the automobile radiator were investigated using two distinct coolants: pure water and a water-based nanofluid ($Al_2SiO_5$ nanoparticle suspended in water at various concentrations) and a constant inlet temperature (80 $^0$C). The following conclusions were drawn.

The presence of $Al_2SiO_5$ nanoparticles in water can improve the radiator's heat transfer rate. The amount of nanoparticle added to pure water determines the degree of heat transfer enhancement. Finally, at a concentration of 0.4 vol. percent, a heat transfer enhancement of 40-45 % was observed when compared to pure water.

It was observed that with increase in the flow rate of the coolant, the heat transfer coefficient of both pure water and Nanofluid increases significantly.

The improvement in the effective thermal conductivity observed in this study, as well as variations in the other physical properties, are not responsible for the significant improvement in radiator performance. Brownian motion of nanoparticles may be a factor in thermal performance improvement.

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