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# Study of forced convection nanofluid heat transfer in the automotive cooling system

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ABSTRACT

The heat transfer enhancement for many industrial applications by adding solid nanoparticles to liquids is significant topics in the last 10 years. This article included the friction factor and forced convection heat transfer of $SiO_2$ nanoparticle dispersed in water as a base fluid conducted in a car radiator experimentally and numerically. Four different concentrations of nanofluids in the range of 1–2.5 vol% have been used. The flowrate changed in the range of 2–8 LPM to have Reynolds number with the range 500–1750. The results showed that the friction factor decreases with an increase in flowrate and increase with increasing in volume concentration. Furthermore, the inlet temperature to the radiator has insignificantly affected to the friction factor. On the other side, Nusselt number increases with increasing in flowrate, nanofluid volume concentration and inlet temperature. Meanwhile, application of $SiO_2$ nanofluid with low concentrations can enhance heat transfer rate up to 50% as a comparison with pure water. The simulation results compared with experimental data, and there is a good agreement. Likewise, these results compared to other investigators to be validated.



## 1. Introduction

In the last 10 years, there has been more attention paid to enhance the convective heat transfer performance of nanofluids [1], due to the recognition that in practical applications nanofluids. Experimental studies of friction factor and nanofluids heat transfer enhancement with the flow velocity and nanofluid volume fraction inside heated tube under laminar flow condition has been presented by [2–5]. There are many different applications of thermal-fluid systems, including automotive cooling systems [6]. Base fluids, such as water, ethylene glycol and glycerol, have been used as conventional coolants in automobile radiators for many years; however, these fluids have low thermal conductivities. The low thermal conductivities have thus prompted researchers to search for fluids with higher thermal conductivities than that of conventional coolants. Therefore, nanofluids have been used instead of the commonly used base fluids [7–9]. A numerical study on laminar heat transfer using CuO– and $Al_2O_3$–ethylene glycol and water inside a flat tube of a car radiator was performed by Vajjha et al. [10]. A CFD model of the mass flowrate of air passing across the tubes of a car radiator was presented by Peyghambarzadeh et al. [11]. The air flow was simulated using the commercial software ANSYS 12.1, where the geometry was created in the software SOLID WORKS, followed by creating both the surface mesh and the volume mesh accordingly. The results were compared and verified according to the

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**Nomenclature**

| | |
|---|---|
| $C$ | specific heat [W/kg °C] |
| $D$ | diameter [m] |
| $E$ | energy [W] |
| $f$ | friction factor |
| htc | convection heat transfer coefficient [W/m$^2$ °C] |
| $k$ | thermal conductivity [W/m °C] |
| Nu | Nusselt Number [htc$D/K_{nf}$] |
| $P$ | pressure [N/m$^2$] |
| Pr | Prandtl number [$C\mu/K_{nf}$] |
| Re | Reynolds number [$\rho_{nf}D_h u/K_{nf}$] |
| $u$ | velocity [m/s] |
| $\mu$ | viscosity [N s/m$^2$] |
| $\rho$ | density [kg/m$^3$] |
| $\tau$ | shear stress [N/m$^2$] |
| $\phi$ | volume concentration |

*Subscripts*

| | |
|---|---|
| $f$ | liquid phases |
| $p$ | solid particle |
| $nf$ | nanofluid |
| $h$ | hydraulic |

known physical situation and existing experimental data. The results serve as a good database for future investigations. New correlations for the viscosity and thermal conductivity of nanofluids as a function of volumetric particle concentration and temperature developed from the experiments were used in this paper. The convective heat transfer coefficient and shear stress of the nanofluid showed marked improvement over the base fluid, showing higher magnitudes in the flat regions of the tube. The results showed that increasing the nanofluid volume fraction increased the friction factor and convective heat transfer coefficient; however, there was also an increase in pressure loss as the particle volume fraction increased. A numerical study that analyzed mixed convection flows in a U-shaped grooved tube “in a radiator” was conducted by Park and Pak [12]. A modified SIMPLE algorithm for the irregular geometry was developed to determine the flow and temperature field. The results have been used as fundamental data for tube design by suggesting optimal specifications for radiator tubes. Two liquids, water and an ethylene glycol/water mixture, used as the coolant fluid in a meso-channel heat exchanger were studied numerically by Dehghandokht et al. [13]. The predicted results (heat transfer rate, pressure and temperature drops in the coolants) from the numerical simulation were compared with the experimental data for the same geometrical and operating conditions and showed good agreement. Additionally, the results showed the heat exchanger was enhanced, with heat transfer rate approximately 20% higher than that of a straight slab of the same length; the enhanced heat exchanger has a good potential to be used as a car radiator with reasonably enhanced heat transfer characteristics using an ethylene glycol/water mixture as the coolant. The application of a copper–ethylene glycol nanofluid in a car cooling system has been studied by Leong et al. [14]. The friction factor has been evaluated experimentally by [15–17], but heat transfer enhancement using water and ethylene glycol water in a multi-port serpentine meso-channel heat exchanger has been determined as [18]. The overall heat transfer coefficient of CuO/water nanofluids investigated experimentally under laminar flow regime in a car radiator by Naraki et al. [19]. The results showed that the overall heat transfer coefficient with nanofluid was more than the base fluid. The overall heat transfer coefficient increased with the enhancement in the nanofluid concentration from 0 to 0.4 vol%. Conversely, the overall heat transfer coefficient decreased with increasing the nanofluid inlet temperature from 50 to 80 °C. The implementation of nanofluid increases the overall heat transfer coefficient up to 8% at nanofluid concentration of 0.4 vol% in comparison with the base fluid. Theoretical results of nanofluid heat transfer of Maiga et al. [20] have been verified with the correlations of Seider–Tate [21] for base fluid only. Forced convection heat transfer of both CuO and $Fe_2O_3$ nanofluids flow through the car radiator has been studied experimentally by Peyghambarzadeh et al. [22]. An experimental investigation for the determination of heat transfer coefficient with $SiO_2$ nanofluid under cooling and heating conditions at fluid inlet temperatures of 20, 50 and 70 °C for Reynolds number range from 200 to 10,000 and 22 nm size diameter particles suspension in water has been conducted by Ferrouillat et al. [23]. The heat transfer coefficients at particle volume concentrations of 2.3% and 19% have been determined as 10% and 50% respectively greater than the values obtained with water.

In this paper, an experimental and computational study of forced convection heat transfer in a car radiator with $SiO_2$ nanoparticles suspension in water under laminar flow is presented. The test rig is setup to measure temperatures and pressure drop between inlet and outlet of the radiator. Furthermore, the CFD model is simulated by finite volume method and using FLUENT software to solve governing equations. The range of Reynolds number is 250–1750 and the volume fraction of nanofluid is from 1% to 2.5%. The aim of this study is to enhance heat transfer in the car cooling system. The comparison among experimental and simulation results are carried out then validated with other researchers data.

## 2. Experimental work

### 2.1. Experimental setup and procedure

The test rig shown in Fig. 1a has been used to measure heat transfer coefficient and friction factor in the automotive engine radiator. This experimental setup includes a reservoir plastic tank, electrical heater, a centrifugal pump, a flow meter,