Numerical Analysis of Heat Transfer Improvement in Flat Tube Car Radiator by Using TiO$_2$/Water Nanofluids

B Kristiawan$^1$, A T Wijayanta$^1$, I Yaningsih$^1$, E P Budiana$^1$, S Hadi$^1$, D A Himawanto$^1$

$^1$ Mechanical Engineering Department, Faculty of Engineering, Universitas Sebelas Maret, Jl. Ir. Sutami 36A, Kentingan, Surakarta, Jawa Tengah, Indonesia 57126

Abstract. This research investigated two-phase heat transfer numerically using TiO$_2$/water nanofluids to enhance the thermal performance in a flat tube car radiator. Nanofluid is a colloid dispersion in a nano-sized which is a breakthrough in terms of the thermal devices. The radiator is widely used in the automotive industry as a heat exchanger. The enhancement of thermal accomplishment was studied numerically by analyzing in thermohydraulic characterizations. A numerical study was conducted by TiO$_2$/Water nanofluids using five concentrations consisting, that is, 0.05%, 0.5%, 1.0%, 3.0% and 5.0% and six Reynolds number variations. Nanofluids with volume concentrations of 0.05%, 0.5%, and 1.0% volume concentration indicated that the values of Nusselt number were lower compared to water. Meanwhile, the values of Nusselt number for nanofluids with volume concentration of 3.0% and 5.0% were higher than water. This occurs because the transfer coefficient enhancement was higher when compared to the increase of thermal conductivity.

1. Introduction

Radiators were an important part in automotive engine cooling systems. Because of the restricted space in front of the engine, basically, the limited radiator size cannot be enlarged. Hence, the radiator cooling was very important to improve the thermal capability of coolant fluids, that is, the coolant liquid of the engine radiator which consists of ethylene glycol due to its low thermal conductivity. The nanotechnologies have been developed recently, which is nanofluids having very superior in the field of heat transfer.

Nanofluid was a dispersion of nanoparticles that is currently becoming one of the new breakthrough technologies in heat transfer enhancement. Many literatures have studied nanofluids to enhance the thermal properties of heat transfer liquids. The value of thermal conductivity of working fluids can determine the quality of heat transfer. The low thermal conductivity in conventional heat transfer fluids such as water, ethylene glycol and mineral oil, is a limitation that needs to be improved its thermal properties. To improve performance and produce compact equipment requires strong effort to develop heat transfer fluids (HTFs) with thermal conductivity which substantially have better thermal properties. The use of advanced HTFs has become as the effort to increase the thermal capacity. Radiators are often utilized as the thermal devices to remove heat from the engine to environment [1]. In general, a mixture of ethylene glycol and water is used as a cooler in a car engine radiator. This HTFS has a poor heat transfer performance compared to water due to low thermal conductivity. Jang et al. [2] reports the limitations of the existing cooling system, that is, liquid side and air side. Traditional cooler and oil have
properties inherently poor heat transfer. In this view, new techniques are needed to improve the performance of existing heavy vehicle engines.

Nanofluid has been introduced by Choi [3] in which constitutes the dispersed phase involving nanoparticles normally less than 100 nm. Many researchers have reported the more advanced thermal properties of nanofluids. Nanofluid was the dispersed nanoparticles within a continuous phase such as, distilled water, glycol fluids, and engine oil. It has been observed that the thermal conductivity of nanofluids is significantly higher than that of base fluids [4]. Increasing convective heat transfer coefficient of nanofluids is quite promising. An important study of convective flow and heat transfer from nanofluids was carried out by Pak and Cho [5]. It is found that the enhancement is not only from thermal conductivity but also the design of thermal devices. The cost of producing a radiator is almost 20% of the total expense of the car engine [6]. Therefore, this work is needed to reduce costs and improve radiator performance. For higher cooling capacity of the radiator, the addition of fins is one technique to increase the cooling rate of the radiator. The usage of nanofluids was expected to be able to solve those problems.

Aloisius et al. [7] has conducted the numerical investigation on the application of nanofluids based on CuO and Al2O3 in automotive diesel engine radiators. Nanofluids containing particles from 0.05 vol.% to 1 vol.% were prepared with CuO and Al2O3 nanoparticles with nominal diameter less than 50 nm. The circulating nanofluids inside the flat tube radiator has 90°C in an inlet temperature. The work was performed with Reynolds numbers ranging from 100 to 850. The results indicated that heat transfer coefficient augmentation and the effectiveness of the radiator is according to the increasing Reynolds number and volume concentration. Ahmed et al. [8] examined experimentally the usage of nanofluids TiO2/water as a coolant liquid in automotive diesel engine radiators. Experimental investigations were performed by comparing water and TiO2 nanofluids with volume concentrations of 0.1; 0.2; and 0.3%. The volumetric rates are 0.097 and 0.68 m3/h at laminar flow regime in which Reynolds number variations are from 560 to 1650. The results indicated that the observed nanofluids containing TiO2 nanoparticles of 0.2 vol.% can enhance the effectiveness of car radiators by up to 47% compared to the volume fractions of 0.1 and 0.3% and water as a coolant.

A numerical investigations were performed by Bozorgan et al. [9] regarding to the usage of copper oxide nanoparticles into water flowing inside a car radiator. The observed nanofluids containing nanoparticles sized of 20 nm and volume concentration of 2.0% was carried out on a diesel radiator from Chevrolet Suburban at turbulent regime. The thermal relation between air flow and nanofluids was evaluated to determine the thermal and pumping power behaviour for nanofluids flowing inside a car radiator. The findings stated that the observed nanofluids containing 2 vol.% of CuO nanoparticles into water circulating through a flat tube with 6000 in Reynolds number and 70 km/h in velocity, the thermal and pumping power behaviors are about 10% and 23.8 %, respectively, greater than those of water with the same conditions.

Kristiawan et al. [10] reported the flow and thermal characteristics of nanofluids containing titania nanoparticles into water in which the observed nanofluids flow turbulently in a horizontal circular pipe under constant heat flux. The observed nanoparticles sized ~21 nm containing 0.1 vol.% to 0.5 vol.% dispersed into water were used in the previous work. In this work, a non-Newtonian approach and a time-independent behavior were used to evaluate TiO2/water nanofluids with the given n and K values. Where n and K are index power law and consistency coefficient magnitude, respectively. The empirical equations involving the effects of micro convection and micro diffusion aimed to predict Nusselt numbers. In this work, the reduction of drag phenomenon at turbulent regime was demonstrated naturally. This phenomenon may be an important key factor inducing an increase in the performance of thermal characteristics of nanofluids besides the thermal conductivity enhancement.

A numerical work on the thermal characteristics of TiO2/water nanofluids containing 0.24, 0.60, and 1.18 vol.% was experimentally investigated [11]. The observed nanofluids circulate laminarily through straight pipes with a uniform heating of 4000 W/m². Numerical simulations using the Eulerian and Lagrangian methods by comparing the single-phase model and the Euler-DPM model with two variations of Reynolds number of 900 and 1500. The finding was reported that Euler-DPM model is
slightly higher than single-phase model. The factor causing this difference is that the single-phase model did not take into consideration of the motion between particles as well as the interactions between fluid and nanoparticles were ignored.

This work focused numerically on the thermal characteristics of TiO$_2$/water nanofluids applied flat tube as a radiator channel model. The objectives of this work were to determine performance evaluation criterion (PEC) and compare with the numerical findings from the previous published results. Therefore, thermal characteristics and Nusselt numbers were observed in laminar flow. The magnitude of the thermal augmentation generated by the proposed working fluids was also investigated in different particle volume fractions.

2. Numerical Procedures
Designing 3-D model on horizontal flat tubes circulated by nanofluids was performed by using ANSYS Release 15.0 software code Fluent with 340 mm in length, 17.6 mm in width and 2.5 mm in height as shown in Fig. 1. The outside heat transfer coefficient based on the experimental result by Alosius et al. [7] was used as a reference value. The convection heat transfer coefficient was determined as the boundary conditions on the tube wall representing conditions outside of the flat tube from the actual radiator of 350 W/m$^2$K.

![Figure 1. Flat tube radiator design as test section.](image)

The optimized grid has been performed to obtain the optimal numerical results of validation. The selected grid as shown in Fig. 2 was applied in this work. The number of divisions was 100 with a bias factor of 20 in axial direction and number of nodes of 245,127. The maximum skewness was 0.499 and the skewness average was 0.04, therefore, this grid had the excellent category. The operating parameters associated with the numerical work were listed in Table 1.

![Figure 2. Flat tube 3-D grid configuration.](image)

| Parameter                  | Value  | Unit |
|----------------------------|--------|------|
| Length, $L$                | 0.34   | m    |
| Hydraulic Diameter, $D_h$  | 0.00448| m    |

Table 1. The operating parameters associated with the numerical study.
Nominal diameter of nanoparticles ~21 nm
Thermal conductivity of nanoparticles, \( k_{np} \) 13.7 Wm\(^{-1}\)K\(^{-1}\)
Nanoparticles concentration, \( \phi \) 0.05; 0.5; 1.0; 3.0; 5.0 Vol.%
Reynolds number 130 - 820

3. Results and Discussion

3.1. Numerical Validation
Prior to using nanofluids, hydrodynamic and thermal validations were conducted to assess the accuracy of the model. At laminar flow, the validations were performed by comparing with the results of numerical calculation and the established empirical equations. The empirical equations used as validation were Darcy-Weisbach and Shah-London equations for friction factor and Nusselt number, respectively. Hydrodynamic and thermal validations for pure water were demonstrated in Fig. 3 and 4, respectively.

Darcy-Weisbach equation

\[
f = \frac{64}{Re}
\]  

(1)

Shah-London correlation

\[
Nu = 4.364 + 0.0722Re \cdot Pr \frac{x}{D} \quad \text{for } Re \cdot Pr \frac{x}{D} \leq 33.3
\]  

(2)

\[
Nu = 1.953(Re \cdot Pr \frac{x}{D})^{1/3} \quad \text{for } Re \cdot Pr \frac{x}{D} \geq 33.3
\]  

(3)

![Figure 3. Hydrodynamic validation for water at Re = 136](image-url)
3.2. Thermal characteristics
Modeling laminar flow was performed by varying nanoparticles concentration. The volume fractions used in this work were 0.05%, 0.5%, 1%, 3% and 5%. The simulation was applied on a flat tube with various Reynolds number from 130 to 820. The heat transfer coefficient used as boundary condition was 350 W/m²K. In Fig. 4, the local Nusselt number was validated at Re = 136.

![Fig. 4. Local Nusselt number validation at Re = 136.](image)

**Fig. 4.** Local Nusselt number validation at Re = 136.

In Fig. 5, the thermal characteristics of the observed nanofluids flowing inside flat tubes were demonstrated.

![Figure 5. Thermal characteristics for several concentrations.](image)

**Figure 5.** Thermal characteristics for several concentrations.

It is clear in this figure that $Nu$ numbers of nanofluids numbers with volume concentrations of 0.05%, 0.5% and 1.0% are lower than that of the water, whereas, nanofluids with volume concentrations of 3.0% and 5.0% have higher Nusselt number. This phenomenon has a similar consistency with the reported results of previous experiment [7]. In spite of the thermal enhancement with increasing
nanoparticles concentrations, the augmentation of thermal rate was lower compared with the thermal conductivity enhancement. The increase in Nusselt numbers is demonstrated for nanoparticles concentration over 1.0%. The maximum enhancement in Nusselt numbers at 7% is found in nanofluids containing 5.0 vol.% at Re number of 816.

In Fig. 6, temperature distributions in a plane view for volume concentration of 5.0% and Re number of 816 are demonstrated. It is clear that the outlet side of heat decreases due to the releasing out of heat through the tube wall. Therefore, nanofluids coolant that comes out from the outlet side will circulate back into the engine in already cold conditions.

**Figure 6.** Temperature distribution profile at Re = 816 and volume concentration of 5%.

3.3. **Performance Evaluation Criterion (PEC)**

As an exhaustive valuation for the accomplishment of nanofluids regarding to the thermal augmentation, the system assessment namely the performance evaluation criterion (PEC) is performed. Considering with the usage of pumping power, this performance was defined as follows.
PEC = \frac{\text{Nu}_{nf}/\text{Nu}_{water}}{(f_{nf}/f_{water})^{1/3}} \quad (4)

Fig. 7 shows the value of the performance evaluation criterion for various nanoparticles concentrations. This figure demonstrates irregular PEC values in each Reynolds number. Nevertheless, not all performance values are higher than 1.0 in which it illustrates that adding nanofluids inside a flat tube with the aim of increasing heat transfer does not apply universally. The thermal performance decreases at volume concentrations 0.05%; 0.5%; and 1.0%. However, the PEC value indicates higher than 1.0 at volume concentration of 3.0 vol.% and 5.0 vol.%. The observed nanofluids at laminar flow regime flowing through a flat tube reach the optimal PEC values of 1.28 for volume concentration of 5% and Reynolds number of 136.

**Figure 7.** Comprehensive assessment for performance evaluation criterion of nanofluids

4. Conclusion
The improved thermal performance using TiO$_2$/water nanofluids has been investigated numerically. The findings denote that Nusselt numbers of the observed nanofluids enhance with increasing $Re$ numbers. Nu numbers of TiO$_2$/water nanofluids containing 3.0 vol.% and 5.0 vol.% indicate higher than that of water. The higher enhancement in thermal consideration might be responsible if compared to the thermal conductivity enhancement. At laminar flow, the optimum PEC value of TiO$_2$/water nanofluids flowing through a flat pipe is 1.28 for 5 vol.% and $Re$ number of 136. It is still possible to increase the heat transfer performance by adding insert devices which produce a swirl flow in the laminar flow regime.

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