Int. J. Ind. Chem. 2026; 17(1): 1-6

International Journal of Industrial Chemistry (IJIC)

https://doi.org/10.57647/ijic.2026.1701.01

Research Article

TiO_2 and Al_2O_3 - Water Nanofluids as Coolants in a Car Radiator

Ahmad Esmaeeli, Mahmoudreza Khadangi Mahrood*, Hossein Ghahremani

Department of Chemical Engineering, Qu.c., Islamic Azad University, Quchan, Iran

***Corresponding authors:** khadangi@iauq.ac.ir

Article History:

Received:
17 January 2026

Revised:
22 February 2026

Accepted:
19 March 2026

Published in Issue:
31 March 2026

Abstract

In recent decades, extensive research has been conducted on the use of nanoparticles with high thermal conductivity in automotive cooling systems. In this study, the performance of a radiator cooling system using nanofluids containing TiO_2 and Al_2O_3, in comparison with distilled water as the coolant, was investigated experimentally and through neural network modeling. The experiments were performed using different concentrations of TiO_2 and Al_2O_3 nanofluids at various engine speeds. Our results showed that the Al_2O_3 and water nanofluid with a 0.1% concentration and the TiO_2 and water nanofluid with a 0.05% concentration can improve the cooling system performance by 50% and 25%, respectively, compared to pure deionized (DI) water. The data obtained in this experiment were analyzed using the GMDH neural network algorithm, and the model showed strong agreement with the experimental results, with deviations of only 6.8% and 8.2% for TiO_2 and Al_2O_3 nanoparticles, respectively. These findings demonstrate the significant potential of low-concentration TiO_2 and Al_2O_3 nanofluids to enhance automotive cooling efficiency, highlighting their applicability as promising alternatives to conventional coolant fluids.

Keywords: Al_2O_3; Car radiator; Nanofluid; Neural network; TiO_2

Cite this article: Esmaeeli A, Khadangi Mahrood M, Ghahremani H. TiO_2 and Al_2O_3 - Water Nanofluids as Coolants in a Car Radiator. Int. J. Ind. Chem. 2026; 17(1): 1-6. https://doi.org/10.57647/ijic.2026.1701.01

1. Introduction

Conventional heat transfer fluids generally possess significantly lower thermal conductivity compared to metals, which restricts their effectiveness in heat exchange applications [1]. This intrinsic limitation has prompted extensive research efforts aimed at enhancing the thermal performance of working fluids used in heat transfer systems.

In recent decades, nanofluids have emerged as advanced heat transfer media due to their improved thermophysical properties. The suspension of high-thermal-conductivity nanoparticles in base fluids has attracted considerable attention from researchers across various engineering and scientific disciplines, owing to their potential to enhance heat transfer performance [2][3], [4]. In automotive cooling systems, the radiator plays a critical role as the primary heat exchanger responsible for removing excess thermal energy from the engine. Radiator design and placement are among the most important factors in vehicle engineering, as they directly affect fuel consumption, engine efficiency, and acceleration performance. An efficient cooling system with enhanced heat transfer capability enables higher coolant flow effectiveness, reduces the required volume of coolant, and decreases the energy consumption of circulation pumps, thereby contributing to improved aerodynamic and energy efficiency in vehicle design [5].

A number of studies have explored the application of nanofluids in automotive radiators. Singh et al. [5] demonstrated that replacing conventional water with nanofluids possessing higher thermal conductivity can lead to a reduction of approximately 10% in radiator frontal area and fuel savings of up to 5%. Saripela et al. [7] performed numerical simulations on the use of CuO nanoparticles dispersed in a water–ethylene glycol mixture and reported improvements in coolant pump performance, engine power output, and air-side radiator efficiency.

Experimental work by Putra and Maulana [8] showed that Al_2O_3-based nanofhuids significantly increase the convective heat transfer coefficient compared with the corresponding base fluid. In a theoretical investigation, Vasu et al. [9] confirmed that Al_2O_3–water nanofluids exhibit higher thermal conductivity than conventional coolants. Further studies on Al_2O_3–ethylene glycol–water nanofluids indicated that enhancements in thermophysical properties are temperature-dependent, and the predicted Nusselt number correlations were found to be in good agreement with previously reported experimental results [9][11].

Peyghambarzadeh et al. [12][13] experimentally examined pure water, pure ethylene glycol, and their mixtures containing various concentrations of Al_2O_3 nanoparticles and reported up to a 40% improvement in heat transfer performance relative to the base fluids. In another investigation, Xie analyzed the enhancement of convective heat transfer of nanofluids under laminar flow conditions in a circular copper tube and observed a notable increase in heat transfer coefficients. Additionally, nanofluids containing MgO, Al_2O_3, and ZnO nanoparticles have been reported to achieve heat transfer coefficient enhancements of up to 252% at a Reynolds number of 1000, with MgO demonstrating the highest level of performance enhancement [14].

Based on the existing literature, the present study aims to experimentally investigate and model the thermal performance of a car radiator using Al_2O_3–water and TiO_2–water nanofluids as coolants, with the objective of comparing the thermal performance and effectiveness of each nanofluid at different volume concentrations.

2. Experimental

2.1. Materials and methods

2.1.1. *Preparation of TiO_2 and Al_2O_3 Nanofluid*

Nanofluid preparation was carried out using a two-step method. TiO_2 and Al_2O_3 nanoparticles (US Research Nanomaterials, Inc.) with an average particle diameter of approximately 20 nm were obtained from NANOSONY Company. The physicochemical characteristics of the materials are presented in Table 1 . XRD analysis confirmed the mean particle size of both nanoparticles (data not shown). Initially, the nanoparticles were dispersed in distilled water using mechanical stirring, followed by an ultrasonication process. The ultrasonication step was performed for 30 min at a power of 100 kW and a frequency of 40 kHz to ensure uniform dispersion and prevent agglomeration.

2.1.2. *Experimental Set Up and Procedure*

In this investigation, the cooling system of a Peugeot 405 equipped with an XU7 engine was evaluated. A photograph of the experimental setup is shown in Figure 1. The system consists of a car radiator, an electric fan, two thermometers, a heater, a circulation pump, a flowmeter, connecting tubes, valves, and fittings. A schematic representation of the cooling system configuration is provided in Figure 2.

To ensure the stability and accuracy of the experimental apparatus, the system was initially tested using pure water. After verification, the setup was charged with TiO_2 and Al_2O_3 nanofluids at various concentrations (0, 0.05, 0.1, 0.15, and 0.2 vol.%). Experiments were conducted at three different engine speeds: 1000, 2000, and 2500 rpm.

For each test, two key temperature measurements were recorded:

1. The inlet temperature of the coolant before entering the radiator
2. The outlet temperature after passing through the radiator.

All experiments were repeated at least three times to ensure repeatability, and the corresponding data were systematically recorded.

Table 1. Some properties of TiO_2 and Al_2O_3 nanoparticles

Parameter	TiO_2	Al_2O_3
Color	White	White
Density	4.62	3.97
Molecular weight	79.87	101.96
Size	20 nm	20 nm
Purity	99%	99%
SSA	10-45 m^2/g	138m^2/g

Figure 1. Photo of actual experimental setup (Engine for Peugeot-405 XU7)

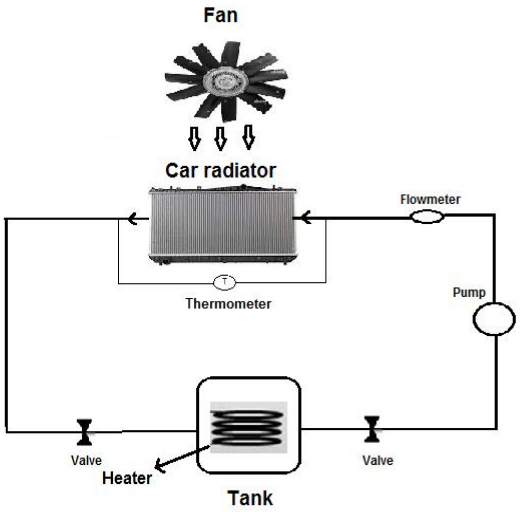

Figure 2. The schematic representation of test setup

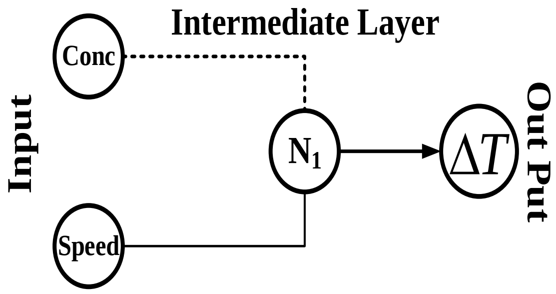

Figure 3. Schematic diagram of the GMDH model for TiO_2

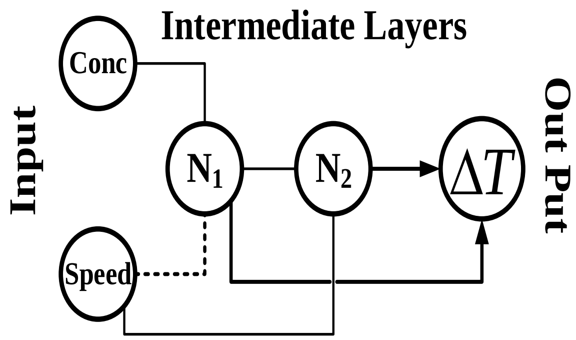

Figure 4. Schematic diagram of the GMDH model for Al_2O_3

2.1.3. *Design and Training of an Artificial Neural Network (ANN)*

Artificial neural networks (ANNs) are widely used tools for nonlinear modeling and can approximate complex functions with a high degree of accuracy. Owing to their flexibility in approximating nonlinear relationships, ANNs possess strong capabilities for modeling intricate correlations among variables [15].

The Group Method of Data Handling (GMDH) is a neural-network-based statistical learning technique commonly employed for data identification, prediction, and classification. GMDH provides a systematic approach to addressing certain statistical limitations of traditional neural networks. This method was first introduced by Professor Ivakhnenko for modeling complex systems characterized by multivariable input datasets and a single output.

The primary objective of a GMDH-type network is to construct a model based on a quadratic transfer function. During the training process, the most influential input variables, as well as the neurons in the hidden layers, are automatically selected. This allows the algorithm to determine the optimal architecture for the predictive model [16]. GMDH has been widely applied in modeling nonlinear systems and forecasting multivariable processes due to its robustness and efficiency.

The general mathematical relationship between input and output parameters in the GMDH network can be expressed using the following equation:

$$y_0 = a_0 + \sum_{i=1}^{m}\sum_{j=1}^{m}\ldots\sum_{k=1}^{m} a_{ij\ldots k} x_i^n x_j^n \ldots x_k^n \qquad (1)$$

n=0, 1, …, 21

Where xi, xj, and xk represent the input parameters, y0 denotes the output parameter, i corresponds to the number of layers, and a0 and aijk are the polynomial coefficients. The schematic structures of the GMDH models developed for TiO_2 and Al_2O_3 nanofluids are presented in Figs. 3,4, respectively.

Furthermore, for the developed models, the relationships between the input parameters, the neurons, and the target output parameter were established. These relationships are expressed by Equation (2) for the TiO_2 nanofluid model and Equation (3) for the Al_2O_3 nanofluid model.

N1 = 8.88062 – Conc. × Speed × 1.66077

ΔT = -343.687 + N1 × 81.0055 – N12 × 4.65499 (2)

N1 = 16.0105 + Conc. × Speed × 7.27485 – Speed × 3.27027

N2 = 6.96622 + Speed2 × 0.0753422 – N1 × 0.363514 + N12 × 0.0623288

ΔT = -6.70973 + N1 × 2.14482 – N1 × N2 ×13.025 + N12 × 6.41174 + N22 × 6.56434 (3)

In this model, the experimental data were partitioned into training and evaluation sets, with 65% allocated for training and the remaining 35% for evaluation.

3. Results and Discussion

3.1. The Check Point Temperatures

Based on the experimental results, the addition of both TiO_2 and Al_2O_3 nanofluids enhanced the heat transfer rate through the car radiator (Fig.5) .The evaluation criterion was the temperature difference of the coolant fluid before and after passing through the radiator. For pure water, the temperature difference ranged between 6 and 8 °C. After incorporating TiO_2 and Al_2O_3 nanoparticles as coolants, the temperature differences increased to 8–10 °C and 8–14 °C, respectively.

It was observed that increasing the TiO_2 concentration beyond 0.05 vol.% did not significantly affect the heat transfer rate. In contrast, the addition of Al_2O_3 nanoparticles up to 0.1 vol.% resulted in a substantial enhancement of the heat transfer rate compared with pure water. Overall, the inclusion of TiO_2 nanoparticles increased the heat transfer from the radiator by approximately 25%, whereas Al_2O_3 nanoparticles improved the heat transfer rate by more than 50%.

It was also observed that the presence of TiO_2 and Al_2O_3 nanoparticles had no significant effect on fuel consumption. Further investigations under different operating conditions and using various engine types are necessary to validate these findings.

Regarding the potential industrial applications of nanofluids, future studies should assess long-term effects, including corrosion, sedimentation, and other possible impacts on engine components. A limitation of the present study is that all experiments were conducted solely with water-based nanofluids. It is recommended that similar tests be performed using a mixture of water and ethylene glycol (anti-freeze and anti-boil coolant) to evaluate the performance and effectiveness of the nanoparticles under more realistic coolant conditions.

3.2. Neural Network Analysis

According to Figs.6 ,7 , the experimental results show good agreement with the predictions obtained from the neural network models. The average prediction errors for TiO_2 and Al_2O_3 nanoparticles were 6.8% and 8.2%, respectively. The results of this study show that adding TiO_2 and Al_2O_3 nanoparticles to the coolant can noticeably improve the radiator's heat transfer performance. This enhancement is mainly due to the higher thermal conductivity of the nanoparticles and the increased micro-convection created by their motion within the fluid. Among the two nanofluids, Al_2O_3 performed better, especially at concentrations up to 0.1 vol.%, likely because of its stronger thermal properties and more effective interaction with the base fluid. In contrast, TiO_2 showed limited improvement beyond 0.05 vol.%, which may be related to particle agglomeration or the rise in viscosity at higher concentrations. The increase in temperature drop, from 6–8 °C for pure water to 8–10 °C with TiO_2 and 8–14 °C with Al_2O_3, highlights the practical impact of using nanofluids. Even at low concentrations, TiO_2 improved heat transfer by about 25%, while Al_2O_3 achieved more than a 50% increase. Importantly, these enhancements did not lead to noticeable changes in fuel consumption, suggesting that nanofluids can improve cooling performance without adding mechanical stress to the engine. However, long-term considerations such as corrosion, sedimentation, and fouling were not included in this study and should be investigated before industrial use.

Additionally, because experiments were carried out with water-based nanofluids only, future research should evaluate mixtures containing ethylene glycol to better reflect real coolant conditions. The strong agreement between experimental data and the GMDH neural network predictions, showing small deviations of 6.8% for TiO_2 and 8.2% for Al_2O_3, also confirms that data-driven models can reliably predict the behavior of nanofluids and may serve as useful tools for optimizing automotive cooling systems

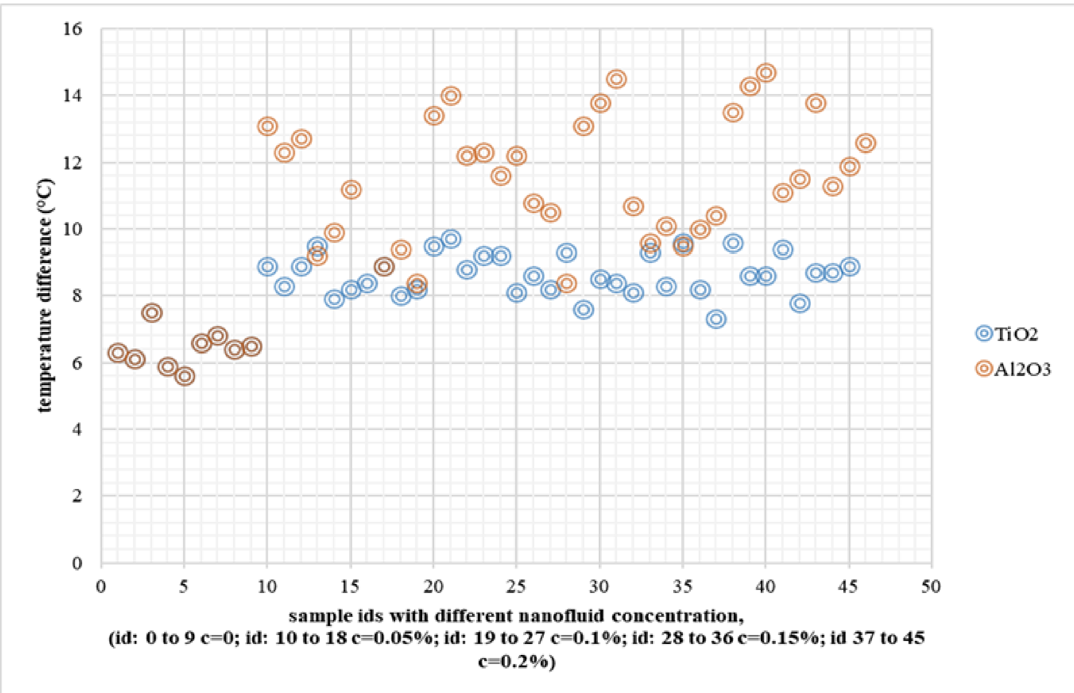

Figure 5. Temperature difference between outlet and inlet car radiator in different concentrations of TiO_2 and Al_2O_3

10.57647/ijic.2026.1701.01

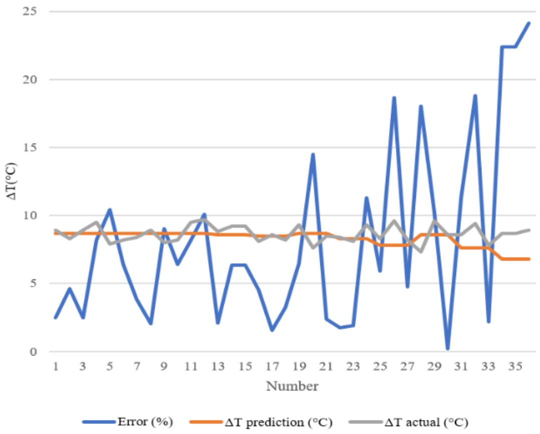

Figure 6. Graph of actual data set and estimated data for TiO_2 nanoparticle

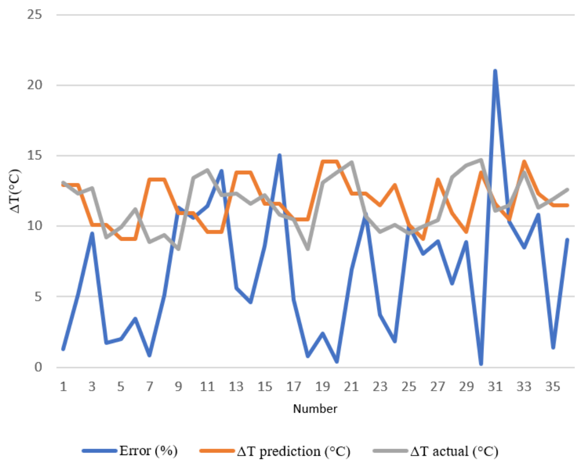

Figure 7. Graph neural network of original dataset and predicted data for Al_2O_3 nanoparticle

4. Conclusions

In the present study, the performance of Al_2O_3-water and TiO_2- water nanofluids as coolants in a car radiator was evaluated both experimentally and theoretically. The experimental results demonstrated that the addition of alumina and titanium dioxide nanoparticles significantly enhanced the heat transfer rate compared with the base fluid (pure water). Among the two nanofluids, Al_2O_3-water exhibited superior overall heat transfer performance relative to TiO_2–water. Furthermore, the experimental data showed excellent agreement with predictions obtained from the neural network models, confirming the reliability of the developed ANN approach. The findings indicate that TiO_2 and Al_2O_3 nanofluids have strong potential for heat transfer enhancement and are highly suitable for practical and industrial applications in automotive cooling systems.

Acknowledge

This work is part of the Ph.D. thesis of Ahmad Esmaeeli at Islamic Azad University, Quchan Branch. The authors thank the staff of the Chemistry Laboratory of Islamic Azad University, Quchan Branch, for technical support and access to instrumentation and facilities.

Authors Contribution

Conceptualization, A.E. and M.K.M.; Methodology, M.K.M and HG.; Software and modeling, A.E. and H.G.; Validation and Formal analysis, A.E. and M.K.M..; Writing – original draft, A.E.; Writing – review and editing, M.K.M. and H.G.; Supervision and Project administration, M.K.M and H.G. All authors have read and approved the final version of the manuscript.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interests

The author states that there is no conflict of interest.

References

[1] Saidina DS, Abdullah MZ, Hussin M. Metal oxide nanofluids in electronic cooling: a review. J Mater Sci Mater Electron. 2020; 31(6): 4381-4398. https://doi.org/10.1007/s10854-020-03020-7

[2] Hussein AM, Bakar RA, Kadirgama K, Sharma KV. Heat transfer enhancement using nanofluids in an automotive cooling system. Int Commun Heat Mass Transf. 2014; 53: 195-202. https://doi.org/10.1016/j.icheatmasstransfer.2014.01.003

[3] Ganvir RB, Walke PV, Kriplani VM. Heat transfer characteristics in nanofluid: a review. Renew Sustain Energy Rev. 2017; 75: 451-460. https://doi.org/10.1016/j.rser.2016.11.010

[4] Cheng L. Nanofluid heat transfer technologies. Recent Pat Eng. 2009; 3(1): 1-7. https://doi.org/10.2174/187221209787259875

[5] Hafeez MB, Amin R, Nisar KS, Jamshed W, Abdel-Aty AH, Khashan MM. Heat transfer enhancement through nanofluids with applications in automobile radiator. Case Stud Therm Eng. 2021; 27: 101192. https://doi.org/10.1016/j.csite.2021.101192

[6] Singh D, Toutbort J, Chen G. Heavy vehicle systems optimization merit review and peer evaluation: annual report. Argonne National Laboratory. 2006; 23: 405-411.

[7] Saripella S, Yu W, Routbort J, France D. Effects of nanofluid coolant in a class 8 truck engine. SAE Tech Pap. 2007; 2007-01-2141. https://doi.org/10.4271/2007-01-2141

[8] Putra N, Maulana S. Heat transfer enhancement of nanofluids in car radiator. In: Proceedings of the 7th JSME-KSME Thermal and Fluids Engineering Conference (TFEC 2008); 2008.

[9] Vasu V, Krishna KR, Kumar ACS. Thermal design analysis of compact heat exchanger using nanofluids. Int J Nanomanufacturing. 2008; 2. https://doi.org/10.1504/IJNM.2008.018949

[10] G. A. Sheikhzadeh GA, Fakhari MM. Investigation of heat transfer in a flat tube of an automobile radiator using Al2O3

nanofluid. In: Proceedings of the 7th International Conference on Computational Heat and Mass Transfer; 2011; Istanbul, Turkey.

[11] Li Q, Xuan Y. Convective heat transfer and flow characteristics of Cu-water nanofluid. Sci China Technol Sci. 2002; 45(4): 408-416. https://doi.org/10.1360/02ye9047

[12] Peyghambarzadeh SM, Hashemabadi SH, Hoseini SM, Jamnani MS. Experimental study of heat transfer enhancement using water/ethylene glycol-based nanofluids as a new coolant for car radiators. Int Commun Heat Mass Transf. 2011; 38(9): 1283-1290. https://doi.org/10.1016/j.icheatmasstransfer.2011.07.001

[13] Peyghambarzadeh SM, Hashemabadi SH, Jamnani MS, Hoseini SM. Improving the cooling performance of automobile radiator with Al_2O_3/water nanofluid. Appl Therm Eng. 2011; 31(10): 1833-1838. https://doi.org/10.1016/j.applthermaleng.2011.02.029

[14] Xie H, Li Y, Yu W. Intriguingly high convective heat transfer enhancement of nanofluid coolants in laminar flows. Phys Lett A. 2010; 374: 2566-2568. https://doi.org/10.1016/j.physleta.2010.04.026

[15] Goh G, Cammarata N, Voss C, Carter S, Petrov M, Schubert L, et al. Multimodal neurons in artificial neural networks. Distill. 2021; 6(3) :e30. https://doi.org/10.23915/distill.00030

[16] Barzegar Gerdroodbary M. Application of neural network on heat transfer enhancement of magnetohydrodynamic nanofluid. Heat Transf Asian Res. 2020; 49(1): 197-212. https://doi.org/10.1002/htj.21606