International Journal of Innovative Research in Technology and Science

ISSN: 2321-1156 www.ijirts.org Volume 12 Issue 2, March 2024

# Computational Fluid Dynamics Investigation of Heat Transfer Efficiency in Automotive Radiators Using Nanofluid Coolants

Ravi Sahu, Vineet Kumar Dwivedi
Faculty of Engineering and Technology
SAM Global University, Bhopal, India

Selection and peer review of this article are under the responsibility of the scientific committee of the International Conference on Current Trends in Engineering, Science, and Management (ICCSTEM-2024) at SAM Global University, Bhopal.

Abstract - Nanofluids represent a novel class of thermal fluids with enhanced thermophysical properties capable of improving heat transfer performance across various applications. Integrating nanoparticles with superior thermal conductivity into a car radiator's coolant can elevate the coolant's effective thermal conductivity, thereby enhancing the cooling system's efficiency. This study employs alumina, silica, and copper oxide nanoparticles in conjunction with an ethylene glycol-water mixture (60:40) in three-dimensional simulations of car radiators to analyse fluid flow patterns and heat transfer performance. Assessment of heat transfer performance for nanofluids based on ethylene glycol-water mixtures at varying nanoparticle concentrations provides insights into heat transfer coefficients through numerical simulations at different coolant velocities. The findings indicate an overall enhancement in heat transfer performance when utilising nanofluids with increased effective thermal conductivity. Furthermore, the results demonstrate a significant improvement in coolant heat transfer performance in car radiators with higher particle loading.

Keywords: Nanofluids, Heat Transfer Performance, Car Radiator, Coolant, Thermal Conductivity, Numerical Simulations, Nanoparticle Concentration

## 1. INTRODUCTION

The car radiator is a pivotal component within the intricate machinery of modern vehicles, playing a paramount role in maintaining optimal engine performance and preventing catastrophic overheating. As a type of heat exchanger, the radiator serves as a critical link in the vehicle's cooling system, tasked with dissipating excess heat generated by the combustion processes within the engine. This introduction delves into the fundamental importance of the car radiator, elucidating its structural characteristics, operational mechanisms, and indispensable role in the seamless functionality of automotive propulsion systems. At its core, the car radiator embodies the principles of heat transfer and thermal management. It embodies a sophisticated engineering solution designed to regulate and dissipate the massive heat generated within the vehicle's internal combustion engine. With its intricate network of channels and fins, the radiator serves as a conduit for the circulation of coolant fluid, facilitating the efficient transfer of heat from the engine and into the surrounding environment. This pivotal function is indispensable in safeguarding the engine against overheating, which can lead to irreversible damage and compromised vehicle performance. As depicted in Figure 1, a typical car radiator comprises a series of interconnected components meticulously engineered to facilitate the efficient exchange of thermal energy. The radiator's core consists of a dense array of narrow tubes through which the coolant fluid flows, augmented by many thin metal fins that increase the surface area available for heat exchange. This intricate arrangement maximises the efficacy of heat transfer, allowing for the rapid dissipation of excess thermal energy into the ambient air passing through the radiator grille. The genesis of the substantial heat load confronting the car radiator lies in the relentless combustion processes unfolding within the heart of the vehicle's internal combustion engine. As air-fuel mixtures combust within the combustion chamber, a torrent of thermal energy is unleashed, propelling the pistons and driving the rotational motion of the crankshaft. This constant cycle of combustion and mechanical motion generates prodigious amounts of heat, necessitating the intervention of the radiator to prevent the engine from overheating. Engineered to withstand the demands of automotive operation, the car radiator stands as a testament to materials science and mechanical design, integrating a diverse array of robust materials optimised for thermal conductivity and durability. Typically constructed from high-grade aluminium or copper alloys, the core tubes and fins exhibit exceptional thermal conductivity and resistance to corrosion. Complementing these structural components is the coolant fluid, often comprising a meticulously formulated mixture of water and antifreeze additives engineered to endure extreme temperatures and minimise the risk of freezing or boiling. The car radiator exemplifies the symbiotic relationship between form and function, serving as a cornerstone in the intricate ecosystem of automotive propulsion systems. By effectively dissipating excess heat from the engine, the radiator plays a pivotal role in ensuring modern vehicles' smooth and reliable operation, guarding against the detrimental effects of engine overheating and extending the lifespan of critical engine components.

## 2. LITERATURE SURVEY

The demand for precision equipment with high performance, extended service life, and accurate operation has increased significantly alongside social progress, particularly in the realm of automotive engineering. Car engines, in particular, generate substantial heat during operation. Consequently, maintaining engine performance and preventing overheating are the primary functions of automotive radiator systems. High engine power, emissions compliance, and energy efficiency are all linked to the effectiveness of car radiators. While enlarging the radiator and increasing its heat exchange area have traditionally been employed to enhance performance, these approaches invariably result in heavier and costlier radiators.

Moreover, these conventional methods have reached their practical limits. Therefore, a novel strategy has emerged: augmenting the thermal conductivity of the vehicle engine coolant to bolster the radiator's cooling capabilities. The primary coolants in automobile radiator systems are typically water, ethylene glycol (EG), or a combination. Due to its high boiling and low freezing points, EG is particularly suitable for regions or countries experiencing extreme weather conditions. However, its relatively low thermal conductivity exceeds engine designers' expectations. Choi revolutionised the field of automotive engine coolants by introducing the concept of nanofluids as a solution to this challenge. Nanofluids, a novel class of homogenous, stable coolants with enhanced thermal conductivity, are created by dispersing nanoparticles (approximately 100 nm in size) into conventional heat transfer fluids (HTFs). Research by Leong and colleagues revealed that adding two weight percent of EG-based copper nanofluids could improve the heat transfer efficiency of car radiators by 3.8%. When $Al_2O_3$ nanoparticles were disseminated in automobile engine coolants by Kole et al. [8], a maximum increase of 10.41% was seen at room temperature. The viscosity of these nano-coolants was then investigated [9]. The thermo-physical characteristics of CuO-$Al_2O_3$ nanofluids as a coolant for car radiators were examined by Tijani et al. [10]. They discovered that the nano-coolants may efficiently increase the heat transfer coefficient. The MWCNTs/$H_2O$ nanofluids were created by Filho et al. [11] as a novel type of automotive coolant. The outcomes showed that the radiator's improved heat transmission was closely connected to the nanofluid concentration. ZnO nanofluids were employed by Muhammad Ali et al. [12] as coolants in automobile radiators. A about 46% improvement in heat transport was realised. Zou et al. [13] observed a 53.81% increase in TC on SiC nano-coolants based on an EG/$H_2O$ mixture.

Furthermore, Yu et al.'s analysis [14] examined the composition of MWCNT nanofluids used in automobile radiators. A 14.1% efficiency factor was discovered. Nonetheless, it is easy to discover that single-component nanoparticle nano coolant was utilised in most car radiator studies. Many studies have been done on dispersing various nanoparticle combinations. to get around some of the drawbacks of single-component nanofluids into heat-conducting fluids; these were subsequently dubbed "hybrid nanofluids". Hybrid nanofluids, created by dispersing two or more types of nanoparticles in various HTFs, are considered an extension of single-component nanofluids. The TC of CNTs-Cu hybrid nanofluids appears to have been reported for the first time by Jana et al. [15]. An improved TC of 26.9% was observed by Akilu et al. [16] on $SiO_2$-CuO/C hybrid nanofluid, whose base fluid was a combination of EG and glycerol. The heat-conductive oil-based SiC-$TiO_2$ nanofluids were synthesised by Zou et al. [17], and the TC increase was approximately 8.4%. At 50 °C, Esfe et al. [18] observed a 35% rise in the thermal conductivity of hybrid nanofluids containing 60% CNTs, 40% MgO, and EG. An experimental study on the thermo-convection performance of hybrid nanofluids of aluminium oxide ($Al_2O_3$)-MWCNTs was conducted by Giwa et al. [19]. Toghraie et al. [20] investigated the impact of temperature and concentration on the TC of ZnO-$TiO_2$ nanofluids.

## 3. METHODOLOGY

This study aims to investigate heat transfer in automobile radiators using coolant composed of nanofluids. Three types of nanofluids are examined: silica ($SiO_2$), copper oxide (CuO), and alumina ($Al_2O_3$). The performance of car radiators employing a base fluid mixture of ethylene glycol and water (60:40) is analysed at three different nanoparticle concentrations: 1 vol%, 3 vol%, and 5 vol%. The project will be numerically investigated using ANSYS Fluent 15.0 to develop a three-dimensional numerical model that examines fluid flow and heat transfer within automobile radiators under various coolant flow conditions. The study investigates nanofluids as coolants across different Reynolds number settings (ranging from laminar to turbulent), where $100 \leq Re \leq 10000$. Design Modeller is initially utilised to input the chosen design parameters, producing a three-dimensional model of various solid fin shapes with geometric variations. Four distinct mesh sizes will be employed to mesh this design based on different surfaces and sections of the vehicle's radiator, spanning from coarse to fine mesh sizes. Boundary conditions will be set according to the flow type and the selected nanofluid. The chosen model will be run continuously until convergence is achieved. This process will be repeated for each nanofluid, nanoparticle concentration, and flow regime. For analytical purposes, the investigation considers a three-dimensional model of a radiator, as depicted in Figure 1, comprising a serpentine finned-tube exchanger and an airflow duct.

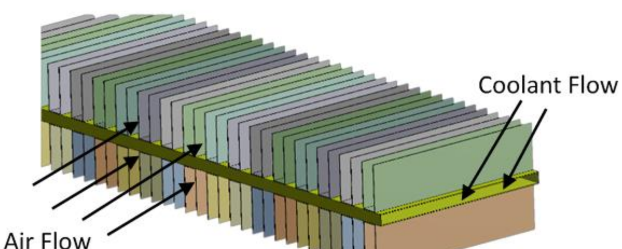


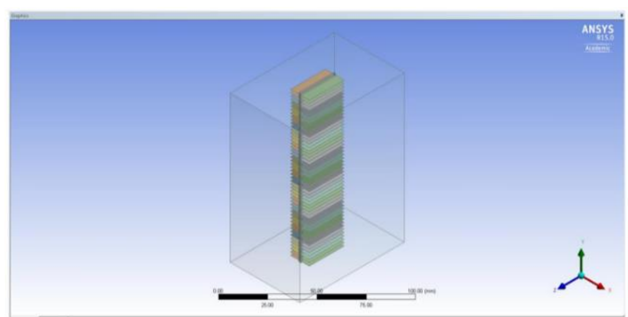

Figure 1. Car Radiator Model under Consideration with Dimensions

Table 1 summarises the precise measurements of the radiator. In this investigation, a section of a radiator with dimensions, as seen in Figure 2, consists of a single long rectangular tube with 25 fins attached to either side of the tube. The airflow over the car's radiator during motion is considered when constructing the airflow domain. Each nanofluid in the simulation will have the same shape and size throughout. The fins of the automobile radiator are designated as solid, while the tube is defined as fluid. Once the geometry is finalised, it will be loaded into the mesh.

Table 1. Core geometry of flat tubes, continuous fins, and operating conditions of a radiator

| **Description** | **Dimension** |
|---|---|
| Tube height | 0.0015 m |
| Tube length | 0.105 m |
| Tube width | 0.025 m |
| Fin height | 0.006 m |
| Fin width | 0.025 m |
| Fin Thickness | 0.0001 m |
| Distance between fins | 0.002 m |
| Number of fins | 25 |
| Air side hydraulic diameter, $D_h$ | 0.0247 m |
| Coolant side hydraulic diameter, $D_h$ | 0.04038 m |
| Air Temperature ($T_a$) | 303 K |
| Coolant Temperature ($T_c$) | 363 K |
| Material | Aluminum |

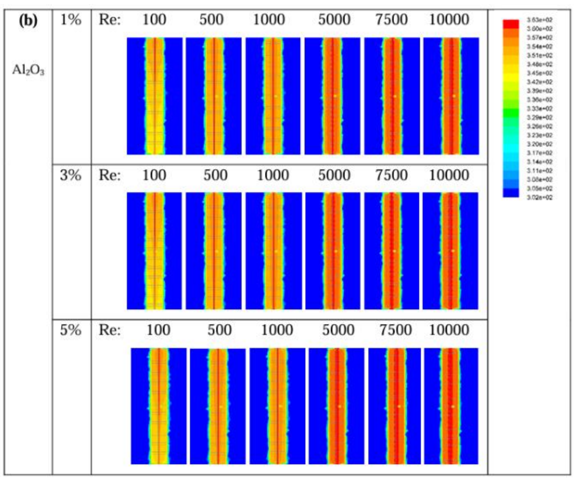
Figure 2. Geometry Modeling Using Design Modeler

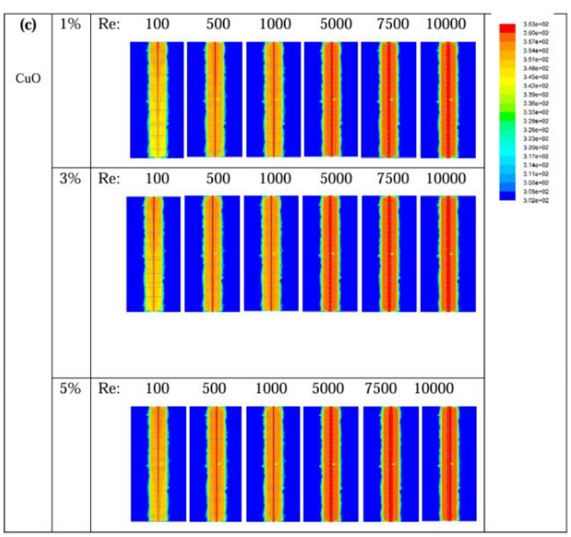


The open areas within a network or net are commonly called mesh. The mesh quality is crucial in achieving fast convergence, accurate results, and faster mesh generation times. ANSYS Mesh's automated meshing approach initiates the project and evaluates its quality. As depicted in Figure 2, a constant body size of 0.003 m is established for meshing the air domain in this study, while 0.0004 m is set for the tube and fins. Finer mesh quality is allocated to complex regions like fins for optimal results. The final mesh comprises 314,728 elements in the geometry. The ideal mesh size is determined after several tests, and the same mesh size is utilised for each simulation. After mesh development, the air domain and the intake and outlet faces of the automobile radiator are identified and allocated for further research using FLUENT.

## 3. RESULT AND DISCUSSION

Enhancing the thermal conductivity of nanofluids is crucial to ensure the optimal performance of an automobile radiator. Analysing the impact of coolant flow conditions in automobile radiators during hot weather is vital for assessing performance transmission.



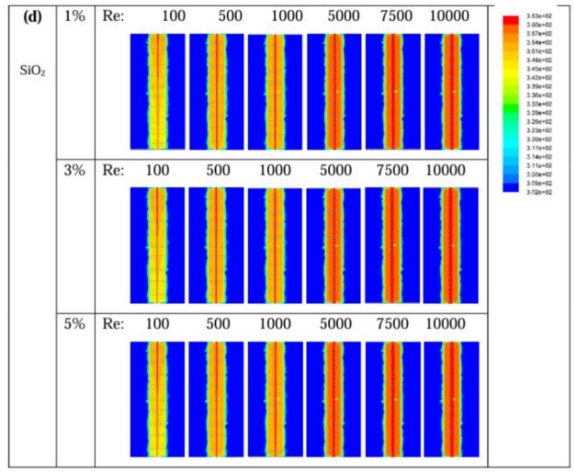




Figure 3. Contours of Temperature on the Iso-Surface at z=0.025 (a) EG/W (b) Al2O3 (c) CuO and (d) SiO2

This study investigates the heat transfer characteristics of a car radiator using a mixture of 60% ethylene glycol and 40% water by mass (60:40 EG/W), incorporating various types of nanoparticles including Al2O3, CuO, and SiO2 as coolants with varying volume concentrations (1 vol %, 3 vol %, and 5 vol %). These coolants undergo numerical investigation. Conventional coolants' thermal and hydraulic performance in automobile radiators is utilised for comparative analysis. The anticipated outcomes, including temperature contour, fluctuations in the heat transfer coefficient, and Nusselt number resulting from utilising different types and volume concentrations of nanofluids, are depicted as functions of Reynolds number and heat transfer coefficient along the tube. These results can be utilised to develop an effective and efficient car radiator. It is clear from the following table that laminar and turbulent flow have different temperature contours. The temperature decreases range from 1 K to 10 K, dependent on coolant flow conditions.

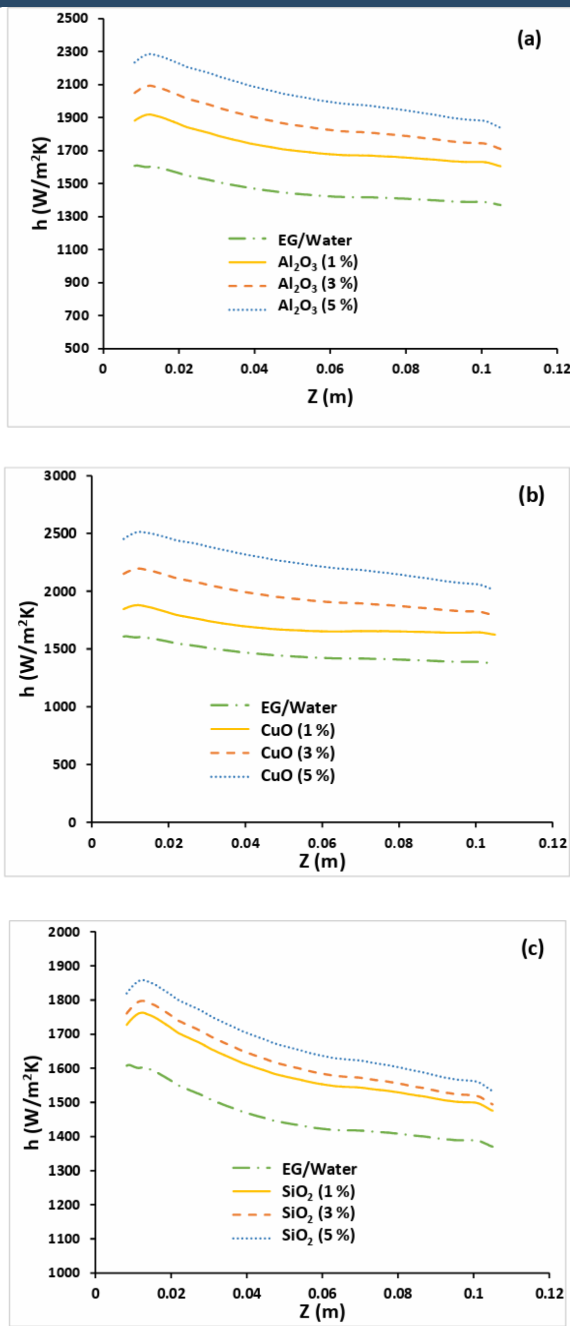



Figure 3. Variation of Heat Transfer Coefficient along the Tube Length for Various

Nanofluids, i.e. (a) Al2O3, (b) CuO and (c) SiO2 in Laminar Flow (Re = 100).

## 4. CONCLUSIONS

In conclusion, using nanofluids as coolant additives in car radiators presents a promising approach to enhance heat transfer performance. By incorporating nanoparticles with high thermal conductivity into the coolant, the effective thermal conductivity of the fluid is increased, leading to improved cooling system efficiency. Our study, which employed alumina, silica, and copper oxide nanoparticles in ethylene glycol-water mixtures for three-dimensional car radiator simulations, revealed notable enhancements in fluid flow patterns and heat transfer performance. Varying nanoparticle concentrations and coolant velocities resulted in significant improvements in heat transfer coefficients, indicating the efficacy of nanofluids in enhancing overall heat transfer performance. In particular, nanofluids with higher particle loadings exhibited superior heat transfer performance, highlighting the potential benefits of nanofluids in automotive cooling systems. These findings underscore the importance of further research and development efforts to optimise nanofluid formulations for enhanced thermal management in automotive applications.

## REFERENCES

[1]. Leong KY, Saidur R, Kazi SN, Mamun AH. Performance investigation of an automotive car radiator operated with nanofluid-based coolants (nanofluid as a coolant in a radiator). Applied Thermal Engineering. 2010;30(17):2685-92.

[2]. Che Sidik NA, Witri Mohd Yazid MNA, Mamat R. Recent advancement of nanofluids in engine cooling system. Renewable and Sustainable Energy Reviews. 2017;75:137-44. [3] Hemmat Esfe M, Abbasian Arani AA, Esfandeh S, Afrand M. Proposing new hybrid nano-engine oil for lubrication of internal combustion engines: Preventing cold start

engine damages and saving energy. Energy. 2019;170:228-38.

[3]. Żyła G, Fal J, Estellé P. Thermophysical and dielectric profiles of ethylene glycol based titanium nitride (TiN–EG) nanofluids with various size of particles. International Journal of Heat and Mass Transfer. 2017;113:1189-99.

[4]. S.U.S.Choi. Developments and Applications of Non-Newtonian Flows. ASME, New York. 1995;231:99–102.

[5]. Nieh HM, Teng TP, Yu CC. Enhanced heat dissipation of a radiator using oxide nano-coolant. International Journal of Thermal Sciences. 2014;77:252-61.

[6]. Qiu L, Zhu N, Feng Y, Michaelides EE, Żyła G, Jing D, et al. A review of recent advances in thermophysical properties at the nanoscale: From solid state to colloids. Physics Reports. 2020;843:1-81.

[7]. Kole M, Dey TK. Thermal conductivity and viscosity of Al2O3 nanofluid based on car engine coolant. Journal of Physics D: Applied Physics. 2010;43(31):315501.

[8]. Kole M, Dey TK, the viscosity of alumina nanoparticles dispersed in car engine coolant. Experimental Thermal & Fluid Science. 2010;34(6):677-83.

[9]. Tijani AS, Sudirman ASb. Thermos-physical properties and heat transfer characteristics of water/anti-freezing and Al2O3/CuO based nanofluid as a coolant for car radiator. International Journal of Heat and Mass Transfer. 2018;118:48-57.

[10]. Oliveira GA, Cardenas Contreras EM, Bandarra Filho EP. Experimental study on the heat transfer of MWCNT/water nanofluid flowing in a car radiator. Applied Thermal Engineering. 2017;111:1450-6.

[11]. Ali HM, Ali H, Liaquat H, Bin Maqsood HT, Nadir MA. Experimental investigation of convective heat transfer augmentation for car radiator using ZnO–water nanofluids. Energy. 2015;84:317-24.

[12]. Zou, Changjun, Qi, Aihua, Li, Xiaoke. Experimental study on the thermo-physical properties of car engine coolant (water/ethylene glycol mixture type) based SiC nanofluids. International Communications in Heat & Mass Transfer A Rapid Communications Journal. 2016.

[13]. Teng TP, Yu CC. Heat dissipation performance of MWCNTs nano-coolant for the vehicle. Experimental Thermal & Fluid Science. 2013;49(9):22-30.

[14]. Jana S, Salehi-Khojin A, Zhong W-H. Enhancement of fluid thermal conductivity by the addition of single and hybrid nano-additives. Thermochimica Acta. 2007;462(1):45-55.

[15]. Akilu S, Baheta AT, M.Said MA, Minea AA, Sharma KV. Properties of glycerol and ethylene glycol mixture based SiO2 - CuO/C hybrid nanofluid for enhanced solar energy transport. Solar Energy Materials and Solar Cells. 2018;179:118-28.

[16]. Wei B, Zou C, Yuan X, Li X. Thermo-physical property evaluation of diathermic oil-based hybrid nanofluids for heat transfer applications. International Journal of Heat and Mass Transfer. 2017;107:281- 7.

[17]. Esfe MH, Esfandeh S, Amiri MK, Afrand M. A novel applicable experimental study on the thermal behaviour of SWCNTs(60%)-MgO(40%)/EG hybrid nanofluid by focusing on the thermal conductivity. Powder Technology. 2019;342:998-1007.

[18]. Giwa SO, Sharifpur M, Meyer JP. Experimental study of the thermo-convection performance of hybrid nanofluids of Al2O3-MWCNT/water in a differentially heated square cavity. International Journal of Heat and Mass Transfer. 2020;148:119072. Journal Pre-proof

[19]. Toghraie D, Chaharsoghi VA, Afrand M. Measurement of thermal conductivity of ZnO–TiO2/EG hybrid nanofluid. Journal of Thermal Analysis and Calorimetry. 2016;125(1):527-35.