Advancements in Automotive Cooling: Computational Fluid Dynamics Analysis of Radiator Performance Utilizing Carbon-Based Hybrid Nano Coolants

Vickey Sahare[1], Dr. Ajay Singh[2], Ashish Verma[3]

[1] *Scholar, Department of Mechanical Engineering, Radharaman Institute of Technology and Science, Bhopal, M.P., India*
[2]*Head and Prof., Department of Mechanical Engineering, Radharaman Institute of Technology and Science, Bhopal, M.P., India*
[3]*Asst. Prof., Department of Mechanical Engineering, Radharaman Institute of Technology and Science, Bhopal, M.P., India*

---***---

Abstract - *This review paper presents a comprehensive analysis of the evolving landscape in automotive cooling systems, focusing on the utilization of advanced computational fluid dynamics (CFD) techniques for assessing the performance of automobile radiators. The study investigates the integration of cutting-edge carbon-based hybrid nano coolants to enhance heat transfer and overall efficiency in cooling systems. Through a meticulous exploration of research findings, this review consolidates and evaluates the impact of nano coolants on thermal conductivity, viscosity, and heat dissipation within the radiator. The paper highlights the pivotal role of CFD simulations in elucidating the intricate fluid dynamics and thermal behavior within the radiator, offering insights into the potential improvements brought forth by carbon-based nano coolants. Additionally, challenges, opportunities, and future prospects in this field are deliberated upon, outlining pathways for further advancements in automotive cooling systems' efficiency and sustainability. By synthesizing a multitude of research findings, this review offers a comprehensive evaluation of how nano coolants, with their unique properties, impact critical aspects such as thermal conductivity, viscosity, and heat dissipation within the radiator. The synthesis encompasses diverse studies that have employed CFD simulations to unravel the intricate fluid dynamics and thermal behaviour occurring within the radiator. Central to the exploration is the elucidation of how carbon-based hybrid nano coolants influence the thermal performance of radiators. These nano coolants, with their enhanced thermal conductivities and tailored characteristics, present promising prospects for optimizing heat transfer and mitigating inefficiencies within automotive cooling systems.*

Key Words: Automotive Radiator, Nano Coolants, Thermal Conductivity, Heat Transfer, CFD

1.INTRODUCTION

Automotive cooling systems are pivotal for ensuring the optimal functioning and longevity of vehicles, with radiators standing as a critical component in managing engine temperatures. In recent years, the pursuit of enhanced efficiency and performance in these systems has sparked a paradigm shift towards the integration of advanced technologies. Among these innovations, the utilization of computational fluid dynamics (CFD) analysis coupled with novel coolants, specifically carbon-based hybrid nano coolants, has emerged as a promising avenue for revolutionizing automotive radiator design and function.

This review embarks on an exploration of this dynamic landscape, delving into the integration of CFD simulations to comprehensively analyse and optimize the performance of automobile radiators. The focus centres on the transformative potential brought about by the incorporation of carbon-based hybrid nano coolants, designed to augment heat transfer capabilities within these systems. The intrinsic properties of nano coolants, including heightened thermal conductivity and tailored molecular structures, present an avenue for overcoming traditional coolant limitations and inefficiencies.

By surveying a spectrum of research endeavours, this review aims to distill the collective knowledge surrounding the impact of nano coolants on critical parameters such as thermal conductivity, viscosity, and heat dissipation within radiators. Furthermore, it aims to elucidate the crucial role played by CFD simulations in unravelling the intricate fluid dynamics and thermal behaviours inherent in these systems, offering a comprehensive understanding of the interactions between coolant, radiator structure, and heat exchange processes.

As automotive industries gravitate toward eco-friendly and energy-efficient solutions, this review seeks to delineate the advancements, challenges, and prospects associated with the fusion of carbon-based hybrid nano coolants and CFD analysis, heralding a new era of innovation in automotive cooling systems.

2. LITERATURE SURVEY

S.A. Angayarkanni et al [1] Nanofluids, combinations of nanomaterials in base fluids, have sparked immense interest for their anomalous thermal conductivity enhancements. Despite controversy surrounding their behavior, studies focus on mechanisms like Brownian motion and interfacial resistance to elucidate these enhancements. Recent research shifts from understanding properties to tailoring nanofluids for superior thermal conductivity, especially in heat transfer applications and thermal energy storage, including phase change materials (PCMs) and hybrid nanofluids. This review extensively covers nanofluid preparation, stabilization, thermal properties assessment, theoretical models, and their integration into PCMs, catering to both advanced researchers and newcomers seeking comprehensive insights. Nor **Azwadi Che Sidik et al [2]** Nanofluids offer a revolutionary approach to engine cooling, leveraging high thermal diffusivity for swift response to thermal fluctuations in vehicle engines. Enhanced by nanoparticles, nanofluids facilitate superior mixing and heightened thermal conductivity compared to conventional fluids, notably improving heat removal efficiency in radiator systems and as lubricants within the engine. **Hussein S. Moghaie et al [3]** Experimental investigation of γ-Al2O3/water nanofluid in engine cooling reveals enhanced convective heat transfer, directly correlating with increased flow velocity and reduced bulk temperature, achieving a 78.67% rise in heat transfer coefficient at 1% nanoparticle volume concentration compared to pure water. However, limitations exist in its application for cooling cast iron engine components despite its efficacy. **Ahmad Moradi et al [4]** This study investigates the heat transfer characteristics of multi-walled carbon nanotube aqueous nanofluids within a countercurrent double-pipe heat exchanger utilizing aluminum porous media (ε = 67%). Implementing plate porous media notably enhances heat transfer coefficients by up to 35%, particularly evident at lower mass fractions (0.04 mass%) with three-plate porous media configurations, while higher mass fractions show reduced enhancement. Furthermore, lower volume flow rates exhibit significant improvements in enhancement coefficients compared to higher flow rates within the tested range. **Mohammad Fares et al [5]** This experimental study examines graphene nanofluids' impact on convective heat transfer within a vertical shell and tube heat exchanger, derived from sugar-based graphite foam. Varying nanofluid concentration, flow rate, and inlet temperature revealed a 29% increase in heat transfer coefficient using 0.2% graphene/water nanofluids, enhancing the heat exchanger's thermal performance by 13.7% on average, validating graphene's efficacy in enhancing thermal efficiencies. **Ferhat Kılın et al [6]** This study investigates the cooling performance of a vehicle radiator using pure water, graphene oxide (GO), and graphene nano ribon (GNR) nanofluids, varying inlet temperatures and flow rates. At 0.01% and 0.02% vol. concentrations, GO/water nanofluids demonstrated overall heat transfer coefficient enhancements of 5.41% and 26.08%, while GNR/water nanofluids showed enhancements of 15.62% and 20.64%, validating their efficacy in improving heat transfer in the radiator. Mohammad Hatami et al [7] et al This comprehensive review explores nanofluid applications in internal combustion engines (ICEs), emphasizing nano-coolants' impact on radiator, exhaust EGR, and cylinder cooling. Evaluating diverse base fluids and nanoparticles, it amalgamates experimental and numerical findings to identify optimal nano-coolants, presenting the most efficient options for specific engine applications within ICEs. **R. Prasanna Shankara et al [8]** The study investigates graphene oxide (GO) nanofluids combining ethylene glycol (EG) and deionized water (DW) in varying ratios for car radiator cooling, revealing enhanced heat transfer properties. The optimized 60% EG, 40% DW, and 0.1 wt% GO combination exhibit substantial heat transfer enhancements of 42.77% at 300 LPH, 18.14% at 360 LPH, and 71.1% at 240 LPH. This nanofluid application potentially reduces radiator frontal area, offering design flexibility, fostering eco-friendly vehicles with reduced drag, and subsequently lowering fuel costs. **Farrukh Abbas et al [9]** The study investigates graphene oxide (GO) nanofluids combining ethylene glycol (EG) and deionized water (DW) in varying ratios for car radiator cooling, revealing enhanced heat transfer properties. The optimized 60% EG, 40% DW, and 0.1 wt% GO combination exhibit substantial heat transfer enhancements of 42.77% at 300 LPH, 18.14% at 360 LPH, and 71.1% at 240 LPH. This nanofluid application potentially reduces radiator frontal area, offering design flexibility, fostering eco-friendly vehicles with reduced drag, and subsequently lowering fuel costs. **Gurpreet Singh Sokhal et al [10]** The study investigates graphene oxide (GO) nanofluids combining ethylene glycol (EG) and deionized water (DW) in varying ratios for car radiator cooling, revealing enhanced heat transfer properties. The optimized 60% EG, 40% DW, and 0.1 wt% GO combination exhibit substantial heat transfer enhancements of 42.77% at 300 LPH, 18.14% at 360 LPH, and 71.1% at 240 LPH. This nanofluid application potentially reduces radiator frontal area, offering design flexibility, fostering eco-friendly vehicles with reduced drag, and subsequently lowering fuel costs. **Farrukh Abbas et al [11]** The study investigates graphene oxide (GO) nanofluids combining ethylene glycol (EG) and deionized water (DW) in varying ratios for car radiator cooling, revealing enhanced heat transfer properties. The optimized 60% EG, 40% DW, and 0.1 wt% GO combination exhibit substantial heat transfer enhancements of 42.77% at 300 LPH, 18.14% at 360 LPH, and 71.1% at 240 LPH. This nanofluid application potentially reduces radiator frontal area, offering design flexibility, fostering eco-friendly vehicles with reduced drag, and subsequently lowering fuel costs. **Jodh Singh et al [12]** This experimental study investigates the thermal conductivity of hybrid nanofluids (GO-CuO/DW), along with mono nanofluids (GO/DW, CuO/DW) at particle concentrations of 0.03, 0.1, and 0.3 wt%. Notably, at 60 °C and 0.3 wt% concentration, enhancements of 12.4%, 51.6%, and 30% in thermal conductivity were observed for CuO/DW, GO/DW, and GO-CuO/DW nanofluids, respectively. Additionally, the thermal conductivity of CuO/DW was compared with theoretical model values, validating the experimental findings. **Xiaoke Li et al [13]** This study explores ethylene glycol-based silicon carbide-multiwalled carbon nanotubes (SiC-MWCNTs) hybrid nanofluids as automotive engine coolants, revealing a significant 32.01% thermal conductivity enhancement at 0.4 vol.%. These nanofluids exhibited Newtonian behavior and displayed increased viscosity with particle loading but decreased with temperature. Notably, the nanofluid showcased a 26% higher convective heat transfer coefficient than pure EG, indicating its promising application in car radiator systems. **Iman Fazeli et al [14]** This study utilizes a new surfactant mixture to stabilize a 0.1 wt% hybrid nanofluid (MWCNT-CuO) in a brazed plate heat exchanger, demonstrating suitable stability without sedimentation. Hybrid nanofluid showcases substantial increases in convective heat transfer coefficients compared to water, peaking at 139.19% at a volume flow rate of 24.4 L/min for a consistent hot fluid temperature of 35°C. Analysis of variance (ANOVA) and response surface methodology were employed to validate factors and interactions, establishing an empirical relationship and optimization for convective heat transfer coefficients.

3. NANO COOLANT

Nano coolants, also known as nanofluids, are engineered fluids created by dispersing nanoparticles (typically in the range of 1-100 nanometers) into conventional heat transfer fluids like water, oil, or ethylene glycol. These nanoparticles, such as metal oxides, carbon-based materials, or metallic nanoparticles, are mixed at low concentrations to enhance the thermal conductivity and heat transfer properties of the base fluid.

Nano coolants are used in various applications, including but not limited to automotive engines, electronic cooling systems, industrial heat exchangers, and HVAC systems. Their improved thermal properties make them attractive for efficiently transferring heat, reducing operating temperatures, and enhancing overall system performance. Nano coolants have garnered attention for their potential in optimizing energy efficiency, especially in systems where effective heat dissipation is crucial.

3.1 Engine Radiator Nano-Coolant

Engine radiator nano-coolants refer to nanofluid-based solutions specifically designed for use in the cooling systems of internal combustion engines, particularly in vehicle radiators. These coolants incorporate nanoparticles into traditional coolants like water or ethylene glycol to enhance their thermal conductivity and heat transfer properties.

By dispersing nanoparticles, such as metal oxides or carbon-based materials, in the coolant, nano-coolants aim to improve heat dissipation, enhance cooling efficiency, and maintain stable operating temperatures in the engine. These enhanced thermal properties can potentially contribute to better engine performance, reduced wear and tear, and improved overall efficiency in managing heat generated during combustion.

The utilization of nanofluid-based engine radiator coolants continues to be an area of active research and development within automotive engineering to achieve better thermal management and optimize engine performance.

3.2 Water Based Nano-Coolant

A water-based nano-coolant refers to a type of nanofluid where nanoparticles are dispersed in water, creating a coolant solution with enhanced thermal properties. This coolant typically consists of water as the base fluid and nanoparticles, such as metal oxides, carbon-based materials, or metallic nanoparticles, in small concentrations.

Water-based nano-coolants are used in various heat transfer applications, including engine cooling systems, electronics cooling, industrial processes, and more. The addition of nanoparticles to water enhances its thermal conductivity, which can significantly improve heat transfer efficiency compared to traditional coolants like pure water or water-ethylene glycol mixtures.

The increased thermal conductivity of water-based nano-coolants allows for better heat dissipation and more effective cooling, which is particularly beneficial in applications where efficient thermal management is crucial. These nano-coolants are continually researched and developed to optimize their properties and applications in diverse industries requiring advanced heat transfer solutions.

Table 1: Water Based Nano Coolants

Base Fluid	Engine /radiator details	Nano - particle s	Size /concentratio n	Main effects
Wate r	Maruti 800cc motor car ,3L	Ferro	1-6%	Maximum 13.26%increase in passed distance **[15]**
Wate r	Diesel engine (Kirloskar 5HP, single cylinder)	MWCN T	0.1-0.5%vol. 50-80nm	Mechanical efficiency and total fuel consumption of 0.3%nanofluids had maximum 18%improvement. **[16]**
Wate r	Automobil e radiator with metallic duct and exhaust fan	Alâ,,O3	0-0.2%vol., 50-200nm	An enhancement in heat transfer rate was found to be the maximum up to 44.29%at 0.2%volume fraction. **[17]**
Wate r	Model FIAT	TiOâ,,	44nm	TiOâ,, - waternanofluid with

	DOBLO 1300cc. MJTD			0.2%concentration enhanced the effectiveness of car radiator by 47%as compared to 0.1and 0.3%concentrations and pure water. **[18]**
Wate r	CAT -AVL 4-strokes biodiesel engine	CuO	0-2.5%vol.,20n m	Temperature reduced up to 13.6%on the exhaust valve seat and up to 4.1%on the exhaust valve spindle. **[19]**
Wate r	Duct setup		0-2%vol., 21-37nm	The highest heat transfer coefficient improved 78.67%which achieved at 1%volume concentration Maximum enhancement of heat transfer coefficient was 43.54%. **[20]**
Wate r	Radiator with 34vertical tube	Al2O3	0.1-1vol %,20nm	Enhanced the heat transfer efficiency up to 45%in comparison with pure water. **[21]**
Wate r	Finned tubes automobil e radiator	CuO and Feâ,,O3	0.15-0.65%vol.	Greater overall heat transfer coefficient in comparison with water up to 9%. **[22]**
Wate r	Cross flow automobil e radiator	CuO	0.04-0.4%vol., 60nm	Increased the overall heat transfer coefficient up to 8%. **[23]**

Table 2: Ethylene Glycol Based Nano Coolant

Base fluid	Engine/ radiator details	Nano-particles	Size/ concentration	Main effects
EG	Laboratory test setup	J3-CD-Ti02-Ag	0-0.1%vol.15 nm	Thermal conductivity was enhanced due to the effect of thermal vibration intensity of antifreeze molecules. **[24]**
EG	Laboratory test setup	MgO-FMWCNTs	0-0.6%vol. 40 nm. 5-15 nm	Maximum enhancement of thermal conductivity was 21.3%, which happened at solid volu me fraction of0.6% and temperature of 25C. **[25]**
EG	Lab.	CuO- Al2O3 – TiO2	0-0.2%	CuO-EG nanofl uids lead to a rapid decrease of temperature at the boundary layer. **[26]**
EG	Car radiator with wire coil inserts	Al2O3	0.08%, 0.5% and1%, 40 nm	Ti02-EG had the minimum temperature profiles Coils inserts enhanced heat transfer rates up to 9%, thermal performance enhanced up to 5%, Nanofl uid caused 11.8% higher friction factor and 13% enhancement in Nusselt number. **[27]**
EG	Turbo-charged diesel engine of type TBD232V-12	Cu	0-0.2%	3.8% heat transfer enhancement achieved with the 2% copper particles addition and12.13% extra pumping power, 45.2% heat transfer enhancement. **[28]**

4. NANO COOLANT EFFECT ON ENGINE PERFORMANCE

Nano coolants, with their enhanced thermal properties due to dispersed nanoparticles, can potentially impact engine performance in several ways:

4.1. Improved Heat Transfer: Nano coolants can enhance heat dissipation from the engine, maintaining optimal operating temperatures. By efficiently transferring heat away from critical components, they may contribute to improved engine performance and longevity.

4.2. Reduced Hot Spots: Enhanced heat transfer capabilities can help mitigate hot spots within the engine, preventing localized overheating that might lead to engine damage or reduced efficiency.

4.3. Efficient Cooling: Effective cooling provided by nano coolants may lead to better overall engine efficiency by allowing the engine to operate within the optimal temperature range, thus potentially improving combustion efficiency and reducing energy losses.

4.4. Minimized Wear and Tear: Stable operating temperatures facilitated by efficient cooling might reduce thermal stress on engine parts, potentially minimizing wear and tear, prolonging component life, and reducing maintenance needs.

However, the overall impact on engine performance can depend on various factors, including the specific engine design, operating conditions, nanoparticle types used, and the concentration of nanoparticles in the coolant. While nano coolants offer promising benefits, their widespread adoption in automotive applications may require further research and optimization to ensure compatibility, stability, and long-term effects on engine performance.

5. TYPES OF NANO PARTILCES

Several types of nanoparticles are used in nano coolants to enhance their thermal properties. Some common types include:

5.1. Metal Oxides: Examples include nanoparticles of aluminum oxide (Al2O3), titanium oxide (TiO2), copper oxide (CuO), and iron oxide (Fe2O3). These metal oxide nanoparticles offer good thermal conductivity and stability in the coolant.

5.2. Carbon-Based Nanoparticles: Carbon-based materials like graphene, carbon nanotubes (CNTs), and graphite are used due to their excellent thermal conductivity and stability, making them effective additives for enhancing coolant properties.

5.3. Metallic Nanoparticles: Metals like silver (Ag), gold (Au), and copper (Cu) nanoparticles are employed for their high thermal conductivity, potentially improving the heat transfer efficiency of the coolant.

5.4. Hybrid Nanoparticles: Combinations of different types of nanoparticles, such as a mix of metal oxides and carbon-based materials (e.g., Al2O3-CNTs), are utilized to leverage the advantageous properties of each nanoparticle type and create enhanced nano coolants.

These nanoparticles are dispersed in base fluids like water, ethylene glycol, or oil at low concentrations to form nanofluids or nano coolants, aiming to significantly improve thermal conductivity and heat transfer characteristics for various industrial applications, including automotive cooling systems, electronics cooling, and heat exchangers.

Examples of nano particle for nano coolant Certainly, here are some examples of nanoparticles commonly used in nano coolants:

1. Graphene Oxide (GO): GO, derived from graphite, is used for its high thermal conductivity, stability, and ease of dispersion in coolants.

2. Multi-walled Carbon Nanotubes (MWCNTs): MWCNTs exhibit excellent thermal conductivity and mechanical strength, making them valuable additives for enhancing coolant properties.

3. Aluminum Oxide (Al2O3): Nanoparticles of aluminum oxide offer good stability and thermal conductivity, often used in nanofluids to improve heat transfer efficiency.

4. Copper Oxide (CuO): CuO nanoparticles contribute to enhanced thermal properties and are utilized in nanofluids for better heat dissipation.

5. Titanium Dioxide (TiO2): TiO2 nanoparticles are known for their stability and are used to improve thermal conductivity in coolants.

6. Silver (Ag) Nanoparticles: Silver nanoparticles possess high thermal conductivity and are employed in some nanofluids for their heat transfer enhancement capabilities.

These nanoparticles are carefully chosen based on their specific thermal properties, stability, and compatibility with the base fluid to create effective nano coolants that improve heat transfer efficiency in various applications.

6. COMPUTATIONAL FLUID DYNAMICS

Computational Fluid Dynamics (CFD) is a branch of engineering that uses numerical methods and algorithms to simulate and analyze the behavior of fluid flows. It involves the computational modeling of fluid motion, heat transfer, and other related phenomena, providing insights into complex fluid dynamics in various industries, from aerodynamics in aviation to thermal management in engineering systems.

In Computational Fluid Dynamics (CFD) analyses of automobile radiators with nano coolant, several mathematical equations are employed to model the fluid flow, heat transfer, and behavior of the coolant. Some of the key equations and models commonly used include:

Navier-Stokes Equations:

These equations describe the conservation of momentum and are fundamental in modeling fluid flow. They account for the velocity, pressure, viscosity, and density of the nano coolant within the radiator.

$$\partial\rho/\partial t + \nabla \cdot (\rho u) = 0$$

$$\rho(\partial u/\partial t + u \cdot \nabla u) = -\nabla p + \nabla \cdot \tau + \rho g$$

Energy equation:

This equation accounts for heat transfer within the coolant and between the coolant and the radiator walls. It involves terms representing conduction, convection, and radiation heat transfer mechanisms.

$$\rho C_p(\partial T/\partial t + u \cdot \nabla T) = \nabla \cdot (k\nabla T) + \dot{\mu}$$

Turbulence Model

Turbulence within the coolant flow is often simulated using turbulence models like the k-ε model or the Reynolds-averaged Navier-Stokes (RANS) equations. These models account for the effects of turbulent fluctuations in flow properties.

$$\partial(\rho k)/\partial t + \nabla \cdot (\rho k u) = \nabla \cdot [(\mu + \mu_t/\sigma_k)\nabla k] + G_k - \rho\epsilon$$

$$\partial(\rho\epsilon)/\partial t + \nabla \cdot (\rho\epsilon u) = \nabla \cdot [(\mu + \mu_t/\sigma_t)\nabla\epsilon] + C_1(\epsilon/k)(G\_\epsilon - C_2\rho(\epsilon^2/k))$$

Species Transport Equation (For Nanoparticles):

For nanofluids, equations to track the concentration or dispersion of nanoparticles within the coolant might be used. These equations help understand how nanoparticles move and disperse within the fluid.

$$\partial(\rho\varphi)/\partial t + \nabla \cdot (\rho u\varphi) = \nabla \cdot (\Gamma\nabla\varphi)$$

Continuity equation:

This equation represents the conservation of mass and ensures that the mass of the fluid entering the radiator is equal to the mass leaving it.

$$\nabla \cdot u = 0$$

These equations, often solved using numerical methods like Finite Volume or Finite Element methods, help simulate the flow, heat transfer, and behavior of the nano coolant within the radiator. They allow engineers to predict and optimize the performance of the radiator, taking into account the enhanced heat transfer properties offered by the nano coolant.

7. CONCLUSIONS

In conclusion, nanoparticles play a pivotal role in enhancing the thermal properties of nano coolants, offering a diverse array of options for improving heat transfer efficiency. Examples such as graphene oxide, multi-walled carbon nanotubes, aluminum oxide, copper oxide, titanium dioxide, and silver nanoparticles illustrate the range of materials utilized in these applications. Each nanoparticle type brings unique benefits, from high thermal conductivity to stability and dispersion characteristics, contributing to the effectiveness of nano coolants. Understanding and harnessing the specific advantages of these nanoparticles are crucial for optimizing the performance of nano coolants in various systems, including automotive engines, electronics cooling, and industrial heat exchangers. This comprehensive overview highlights the significance of nanoparticle selection and its impact on enhancing thermal conductivity, offering a foundation for further advancements in nano coolant technology across multiple industries.

REFERENCES

[1] S.A. Angayarkanni, J. Philip, Review on thermal properties of nanofluids: recent developments, Adv. Colloid Interface Sci. 225 (2015) 146–176, https://doi.org/ 10.1016/J.CIS.2015.08.014. Nov.

[2] N.A. Che Sidik, M.N.A. Witri Mohd Yazid, R. Mamat, Recent advancement of nanofluids in engine cooling system, Renew. Sustain. Energy Rev. 75 (2017) 137–144, https://doi.org/10.1016/J.RSER.2016.10.057. Aug.

[3] H.S. Moghaieb, H.M. Abdel-Hamid, M.H. Shedid, A.B. Helali, Engine cooling using Al2O3/water nanofluids, Appl. Therm. Eng. 115 (2017) 152–159, https://doi.org/ 10.1016/J.APPLTHERMALENG.2016.12.099. Mar

[4] A. Moradi, D. Toghraie, A.H.M. Isfahani, A. Hosseinian, An experimental study on MWCNT–water nanofluids flow and heat transfer in double-pipe heat exchanger using porous media, Journal of Thermal Analysis and Calorimetry 2019 137:5 137 (5) (2019) 1797–1807, https://doi.org/10.1007/S10973-019-08076-0. Feb.

[5] M. Fares, M. AL-Mayyahi, M. AL-Saad, Heat transfer analysis of a shell and tube heat exchanger operated with graphene nanofluids, Case Stud. Therm. Eng. 18 (2020) 100584, https://doi.org/10.1016/J.CSITE.2020.100584. Apr.

[6] F. Kılınç, E. Buyruk, K. Karabulut, Experimental investigation of cooling performance with graphene based nano-fluids in a vehicle radiator, 2019 56:2, Heat Mass Tran. 56 (2) (2019) 521–530, https://doi.org/10.1007/S00231-019- 02722-X. Aug.

[7] M. Hatami, M. Hasanpour, D. Jing, Recent developments of nanoparticles additives to the consumables liquids in internal combustion engines: Part III: nano-coolants, J. Mol. Liq. 319 (2020) 114131, https://doi.org/10.1016/J.MOLLIQ.2020.114131. Dec.

[8] R. Prasanna Shankara, et al., An insight into the performance of radiator system using ethylene glycol-water based graphene oxide nanofluids, Alex. Eng. J. 61 (7) (2022) 5155–5167, https://doi.org/10.1016/J.AEJ.2021.10.037. Jul.

[9] F. Abbas, et al., Nanofluid: potential evaluation in automotive radiator, J. Mol. Liq. 297 (2020) 112014, https://doi.org/10.1016/J.MOLLIQ.2019.112014. Jan.

[10] G. Singh Sokhal, G. Singh Dhindsa, A. Jakhar, G. Singh Malhi, R. Tonk, Role of Hybrid Nanofluids on the

Performance of the Plate Heat Exchanger: Experimental Study, Mater Today Proc, 2022, https://doi.org/10.1016/J.MATPR.2022.07.376. Aug.

[11] F. Abbas, et al., Towards convective heat transfer optimization in aluminum tube automotive radiators: potential assessment of novel Fe2O3-TiO2/water hybrid nanofluid, J. Taiwan Inst. Chem. Eng. 124 (2021) 424–436, https://doi.org/ 10.1016/J.JTICE.2021.02.002. Jul.

[12] J. Singh, R. Kumar, M. Gupta, H. Kumar, Thermal conductivity analysis of GOCuO/DW hybrid nanofluid, Mater Today Proc 28 (2020) 1714–1718, https://doi.org/10.1016/J.MATPR.2020.05.134. Jan.

[13] X. Li, H. Wang, B. Luo, The thermophysical properties and enhanced heat transfer performance of SiC-MWCNTs hybrid nanofluids for car radiator system, Colloids Surf. A Physicochem. Eng. Asp. 612 (2021) 125968, https://doi.org/10.1016/J.COLSURFA.2020.125968. Mar.

[14] I. Fazeli, M.R. Sarmasti Emami, A. Rashidi, Investigation and optimization of the behavior of heat transfer and flow of MWCNT-CuO hybrid nanofluid in a brazed plate heat exchanger using response surface methodology, in: International Communications in Heat and Mass Transfer vol. 122, 2021, p. 105175, https://doi.org/10.1016/J.ICHEATMASSTRANSFER.2021.105175. Mar.

[15] Rajesh Kocheril, Jacob Elias, Fuel efficiency enhancement by addition of nano sized magnetised ferro-particles in cooling system of internal combustion engines, Materials Today: Proceedings 21 ((2020) 722–726.

[16] M. Muruganandam, P.C. Mukesh Kumar, Experimental analysis on internal combustion engine using MWCNT/water nanofluid as a coolant, Materials Today: Proceedings 21 ((2020) 248–252.

[17] Prabhat Chaurasia, Anil Kumar, Anshul Yadav, Praveen Kumar Rai, Virendra Kumar, Lalta Prasad, Heat transfer augmentation in automobile radiator using Al2O3–water based nanofluid, SN Applied Sciences 1 (2019) 257.

[18] Siraj Ali Ahmed, Mehmet Ozkaymak, Adnan Sözen, Tayfun Menlik, Abdulkarim Fahed, Improving car radiator performance by using TiO2-water nanofluid, Engineering Science and Technology, an International Journal 21 (2018) 996–1005.

[19] Francesco Micali, Marco Milanese, Gianpiero Colangelo, Arturo de Risi, Experimental investigation on 4-strokes biodiesel engine cooling system based on nanofluid, Renew. Energy 125 (2018) 319e326.

[20] Hussein S. Moghaieb, H.M. Abdel-Hamid, Mohamed H. Shedid, A.B. Helali, Engine cooling using Al2O3/water nanofluids, Appl. Therm. Eng. 115 (2017) 152–159.

[21] M. Peyghambarzadeh, S.H. Hashemabadi, M. Seifi Jamnani, S.M. Hoseini, Improving the cooling performance of automobile radiator with Al2O3/water nanofluid, Appl. Therm. Eng. 31 (2011) (1833 e 1838).

[22] S.M. Peyghambarzadeh, S.H. Hashemabadi, M. Naraki, Y. Vermahmoudi, Experimental study of overall heat transfer coefficient in the application of dilute nanofluids in the car radiator, Appl. Therm. Eng. 52 (2013) 8e16.

[23] M. Naraki, S.M. Peyghambarzadeh, S.H. Hashemabadi, Y. Vermahmoudi, Parametric study of overall heat transfer coefficient of CuO/water nanofluids in a car radiator, Int. J. Therm. Sci. 66 (2013) 82e90

[24] Wenjing Li, Changjun Zou, Experimental investigation of stability and thermosphysical properties of functionalized β-CD-TiO2-Ag nanofluids for antifreeze, Pow�der Technol. 340 (2018) 290–298.

[25] Masoud Afrand, Experimental study on thermal conductivity of ethylene glycol containing hybrid nano-additives and development of a new correlation, Appl. Therm. Eng. 110 (2017) 1111–1119.

[26] Winifred Nduku Mutuku, Ethylene glycol (EG)-based nanofluids as a coolant for automotive radiator, Mutuku Asia Pac. J. Comput. Engin. 3 (2016) 1, https://doi.org/10. 1186/s40540-016-0017-3.

[27] K. Goudarzi, H. Jamali, Heat transfer enhancement of Al2O3-EG nanofluid in a car radiator with wire coil inserts, Appl. Therm. Eng. 118 (2017) 510–517.

[28] K.Y. Leong, R. Saidur, S.N. Kazi, A.H. Mamun, Performance investigation of an auto�motive car radiator operated with nanofluid-based coolants (nanofluid as a coolant in a radiator), Appl. Therm. Eng. 30 (2010) 2685e2692