J Ther Eng, Vol. 7, No. 6, pp. 1315–1328, September, 2021

Journal of Thermal Engineering
Web page info: https://jten.yildiz.edu.tr
DOI: 10.18186/thermal.989959

Journal of Thermal Engineering

Research Article

Heat transfer performance of a radiator with and without louvered strip by using Graphene-based nanofluids

M. SANDHYA[1,2,*], D. RAMASAMY[1,3], K. SUDHAKAR[1,3], K. KADIRGAMA[1], W.S.W. HARUN[1]

[1]*Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, Pekan, Pahang, Malaysia*
[2]*Department of Mechanical Engineering, KITS College, Warangal, Telangana State, India*
[3]*Automotive Engineering Centre, Universiti Malaysia Pahang, Pekan, Malaysia*

ARTICLE INFO

Article history
Received: 07 January 2020
Accepted: 17 October 2020

Key words:
Radiator; Louvered strip; Graphene (G) and Graphene oxide (GO); Heat transfer

ABSTRACT

The present work is focused on the Graphene-based nanofluids with high thermal conductivity which helps to improve the performance and enhance heat transfer. The thermal systems emphasis on the fluid coolant selection and statistical model. Graphene is a super-material, lighter than air, high thermal conductivity, and chemical stability. The purpose of the research is to work up with Graphene-based Nanofluids i.e., Graphene (G) and Graphene oxide (GO). Nanoparticles are dispersed in a base fluid with a 60:40 ratio Water & Ethylene Glycol and at different volume concentrations ranging from 0.01%–0.09%. Radiator model is designed in modelling software and louvered strip is inserted. The simulation (Finite Element Analysis) is performed to evaluate variation in temperature drop, enthalpy, entropy, heat transfer coefficient and total heat transfer rate of the considered nanofluids, results were compared by with and without louvered strip in the radiator for the temperature absorption. 58–60% enhancement of enthalpy observed when Graphene and Graphene oxide nanofluid was utilized. 1.8% enhancement of entropy is observed in 0.09% volume concentration of the Graphene and Graphene oxide nanofluid when louvered strips are inserted in the radiator tube at a flow rate of 3 LPM. With louvered strip inserted in the radiator, heat transfer coefficient enhanced by 236% for Graphene and 320% enhancement is identified for Graphene oxide nanofluid when compared to without louvered strip insert. The results stated that high performance is observed with the utilization of louvered strip in the radiator tube.

Cite this article as: Sandhya M, Ramasamy D, Sudhakar K, Kadirgama K, Harun WSW. Heat Transfer Performance of a Radiator with and without Louvered Strip by using Graphene-based Nanofluids. J Ther Eng 2021;7(6):1315–1328.

***Corresponding author.**
*E-mail address: madderla.sandhya@gmail.com

This paper was recommended for publication in revised form by Regional Editor Mustafa Kilic

J Ther Eng, Vol. 7, No. 6, pp. 1315–1328, September, 2021

INTRODUCTION

The Heat exchangers are the set of things working together as parts of a mechanism used to transfer heat from two or more fluids. One such kind of a heat exchanger is a radiator which can transfer the sensible heat termed as thermal energy to cool or heat from one medium to other [1–3]. To improve the performance of the engine, it is very much essential to deploy an efficient cooling system [4]. Cooling systems are designed with an expanded ability to throw away a considerable quantity of waste heat, thereby improving engine efficiency [5]. Conventional cooling approach made use of fins in radiators to increase the cooling capacity. Irrespective of the improved cooling capacity, the fundamental approach of using fins has become extinct due to an increase in the size of the radiator. The radiator is an essential element in any engine system as it is the fundamental component of the cooling system [1, 6]. The efficiency of an automobile engine is measured on high fuel economy , low emissions along with the performance of the engine [7]. The heat transfer fluid could not meet the design criteria to increase the thermal efficiency of the heat exchanger. Hence there is huge scope and opportunity for new heat transfer fluids which can help to improve heat transfer rate [8]. Nanofluids act as an efficient coolant, when nanoparticles are mixed with base fluids such as ethylene glycol to improve the capacity of heat transfer in the radiator by an approximate value between 15–40% [9].

The purpose of the research is to work up with Graphene based Nanofluids i.e., Graphene (G) and Graphene Oxide (GO). Radiator model is designed in modelling software (CREO) and louvered strip is inserted. The simulation (Finite Element Analysis) is carried out using Ansys Workbench tool to estimate the variation in temperature drop, enthalpy, entropy, heat transfer coefficient and the heat transfer rate of the considered nanofluids, the results were compared with and without louvered strip in the radiator for the temperature absorption. The objective of the research is to design the radiator in a modeling software and perform finite element analysis and evaluate the performance of heat transfer of a Radiator with and without Louvered Strip by using Graphene-based Nanofluids and to present the difference in radiator performance with the insertion of louvered strip. This insertion of a louvered strip in radiator tube is a new design and has never been used before.

THEORY

Generally, water, ethylene glycol (antifreeze), oil is used as traditional fluids [10, 11]. In the past decade's number of researchers have carried various investigations to increase the thermal properties of the conventional fluids [12, 13]. Colloidal dispersions of various nanoparticles with the conventional base fluid result in the formation of Nanofluids [14–16]. Heris, Shokrgozar [17] identified that the nanometer size particles, when dissolved in any traditional conventional fluids, will increase the heat transfer. Different works of literature pronounced that the thermal execution of various heat systems can be improvised by adopting various Nano-fluids with nanoparticles like Al_2O_3, CuO, and Graphene as an active working fluid [18–21]. Graphene, as a Nano-fluid, is used intensively as a cooling element [22]. Graphene nanoparticles have gained massive attention because of its high thermal conductivity value than carbon nanotubes, oxide ceramics (Al_2O_3, CuO, Sio_2, Tio_2 etc.) in thermal applications such as in photovoltaic system and heat transfer applications [16, 23, 24]. Graphene has a hexagonal structure which is like a honeycomb with largely dense carbon atoms [25]. The research papers which are published in various journals by Scopus is retrieved by keyword Graphene nanofluids from 2010–2020 is listed in the below graph of Figure 1.

This pattern is identical to the structure of various nanostructured materials, such as fullerene and carbon nanotubes [26]. Thermal conductivity of Graphene Nanoparticles is approximately 4000 to 5000 w/m-k, this can be synthesized by various techniques. Graphene formed by graphite, and it is also synthesized using epitaxial and CVD growth methods [27]. Graphene has high surface area of 2630 sq.mt/gm [28] and high electrical conductivity 13x times better than copper [29] and acts as a best heat conductor than Diamond [30].

THERMOPHYSICAL PROPERTIES OF THE NANOFLUIDS

The nanofluid thermophysical properties comprises of different volume concentration, density, viscosity, and thermal conductivity. The Thermophysical properties show the key finding that the nanofluid is efficient and enables the researcher to find better measurement to compare the nanofluids to conventional fluids.

The Volume Concentration of The Fluid

In the current study, nanofluid preparation is based on two-step technique. Nanoparticles were weighed based on the volume concentration by using weighing balance machine. Based on the volume concentration of fluid, the quantity of nanoparticles is dispersed in the base fluid. Following equation helps in finding required quantity of the nanoparticles [31].

$$\phi = \left[\frac{\frac{w}{\rho_p}}{\frac{w}{\rho_p} + \frac{w_{bf}}{\rho_{bf}}} \right] \times 100 \quad (1)$$

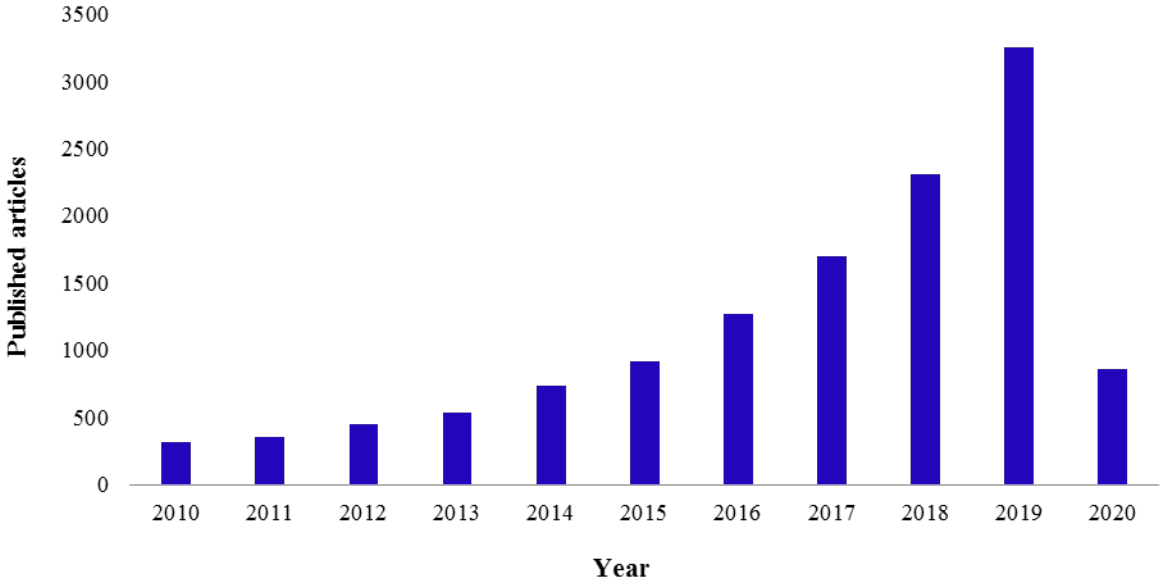

Figure 1. Published Articles each year by Scopus on Graphene nanofluids used in heat transfer applications.

Density and Specific Heat of The Fluid

Nanofluids density (Eq.2) is measured based on the following equations. The values of density and specific heat of the nanoparticles are considered from vendor. The parameter of concentration of nanofluid is considered the effective density [10]

$$\rho_{nf} = \phi\rho_s + (1 - \phi)\rho_f \tag{2}$$

The specific heat of the nanofluid is measured using below (Eq.3). It's a purpose of concentration and base fluid specific heat [32].

$$C_{p,nf} = \frac{\phi(\rho C_p)_s + (1-\phi)(\rho C_p)_f}{\rho_{nf}} \tag{3}$$

Thermal Conductivity

Thermal conductivity has an important role in heat transfer applications [33]. Many researchers focused to improve the thermal conductivity of the fluid in experimentally, numerically also by many case studies. Maxwell [34] equation is utilized by many researchers to find the thermal conductivity with different volume ratio and some of the thermal conductivity formulas are mentioned in the following Table 1.

Thermal conductivity value increased by 27% for 0.2% volume concentration of Graphene nanofluids. A linear rise in electrical conductivity was observed with increase in particle volume concentration [39]. It showed a peak value of 56.45% and 41.47% thermal conductivity enhancement in efficiency at 40°C and 50°C [40]. GO nanofluid was considered as active fluid for pulsating heat pipes. GO was mixed with base fluid, water (0.25, 0.5, 1, and 1.5 g/lit). Results indicated that addition of GO improved base fluid thermal conductivity. The thermal resistance of pulsating heat pipe was reduced up to 42% [41]. The max. enhancement of thermal conductivity at max. relative concentration is obtained at value of 0.02 vol% reduced Graphene Oxide (rGO) with 1 vol% SDBS surfactant (sodium dodecylbenzene sulfonate). The rGO exhibited optimum stability and thermal conductivity, whereas viscosity value is reduced when equated to 0.02 and 0.05 vol% rGO without using any surfactants. While using 1 vol% of SDS (Sodium dodecyl sulfate) surfactant, the value of zeta potential increased 30.7 mV to 52.2 mV. Enhancement from 2.6% to 3.9% is exhibited for thermal conductivity, reduction in viscosity progressed from 8.8% to 12.2% [42]. The Graphene Oxide (GO) and Graphene Nano Ribbons (GNR) nano-fluids were obtained by using pure water as base fluid. Enhancement of Heat transfer is calculated by using experimental data of pure water and nanofluids heat transfer coefficients (U). 5.41% and 26.08% are the mean enhancement values (U) obtained at 0.01% and 0.02% vol. concentrations of GO/water nano-fluid at all temperature. GNR and water nanofluids obtained 15.62% and 20.64% enhancement values for 0.01% and 0.02% vol. concentrations respectively [43]. The studied results of Hamze, Berrada [44] stated that the concentration of FLG (Few layer Graphene) nanosheets varies between 0.05 and 0.5% in mass. Figure 8 shows that nanofluids thermal conductivity increased with FLG content. FLG concentration of 0.05, 0.10, 0.25, and 0.50 wt.%, thermal conductivity of nanofluid increases by 4.2, 5.5, 12.2, and 23.9%, respectively, as compared to the corresponding base

Table 1. Thermal conductivity equations given by different authors

Author	Formula	Equation
Maxwell [34]	$k_{e_{ff}}=\frac{k_{np}+2k_{bf}+2\left(k_P-k_b\right)\phi}{k_{np}+2k_{bf}-\left(k_{np}-k_{bf}\right)\phi}K_{bf}$	(4)
Hamilton and Crosser [35]	$k_{eff}=\frac{k_{nP}+(n-1)k_{bf}-(n-1)(k_{bf}-k_{np})\phi}{k_{np}+(n-1)k_{bf}+(k_{bf}-k_{np})\phi}k_{bf}$ Where, $n=\frac{3}{\psi}$ $\psi=\frac{(6V_p)^{\frac{2}{3}}\pi^{\frac{1}{3}}}{A_p}$ = particle sphericity	(5)
Charunyakorn, Sengupta [36]	$\frac{k_{eff}}{k_{bf}}=\frac{k_{np}+2k_{bf}-2\phi(k_{bf}-k_{np})}{k_{np}+2k_{bf}+\phi(k_{bf}-k_{np})}(1+b\phi Pe_p^m)$	(6)
Xue [37]	$9\left(1-\frac{\phi}{\lambda}\right)\frac{k_{eff}-k_{bf}}{2k_{eff}+k_{bf}}+$ $\frac{\phi}{\lambda}\left(\frac{k_{eff}-k_{c,x}}{k_{eff}+B_{2,x}(k_{c,x}-k_{eff})}+4\frac{k_{eff}-k_{c,y}}{2k_{eff}+(1-B_{2,x})(k_{c,y}-k_{eff})}\right)=0$ $\lambda=\frac{abc}{(a+t)(b+t)(c+t)}$ $K_{c,j}$ is the effective dielectric constant and $B_{2,x}$ is the depolarization factor	(7)
Yu and Choi [38]	$K_{eff}=\frac{k_{np}+2k_{bf}+2(k_{np}-k_{bf})(1-\beta)^3\phi}{k_{np}+2k_{bf}-(k_{np}-k_{bf})(1+\beta)^3\phi}k_{bf}$	(8)

fluids when using Triton X-100 as a surfactant. The thermal conductivity enhancements are 1.3, 3.0, 9.9, and 18.3% for P-123, Pluronic. Finally, using Gum Arabic, thermal conductivity values increased by 2.1%, 4.0%, 10.5%, and 21.5%.

Viscosity

Einstein [45] proposed the viscosity model in 1881, (Eq.10). Using the flow around one particle, the viscosity of dilute suspension of small particles are calculated [46]. Volume concentration can also be applied to use the Einstein viscosity model. Later, many researchers have improved the viscosity model to find the nature of the viscosity based on its shape and size, most of research studies are focused on finding nanofluids and hybrid nanofluids thermal conductivity as well as viscosity. The viscosity of a fluid is the measure of its resistance to gradual deformation by shear stress or tensile stress. A few viscosity models are given in below Table 2.

The viscosity values observed the increment for Graphene & DW nanofluid with higher value (>1.2 times at 15μm compared with 5μm size) at a volume concentration of 0.001–0.01% [49]. The viscosity of functionalized graphene (f-HEG) was studied by [50]. f-HEG along with Ethylene Glycol & water 70/30 ratio combined at 0.041 – 0.395% concentration was recorded with 100 % increment as compared with non-Newtonian behavior base fluid. Graphene Oxide – Ethylene Glycol nanofluid obtained maximum viscosity value of 81.29 cP (pascal-second) at temperature value 20 °C, GO nanosheets mass concentration 0.005, at shear rate of 25 s^{-1}. Nanofluids viscosity diminished non-linearly for an increasing shear rate, displaying solid "shear-diminishing" conduct at lower shear rates. Nanofluids viscosity diminished fundamentally when temperature value increases, Viscosity enhances when mass concentration increases [51]. 13.4%, 14.4% and 15.8% are the maximum viscosity values at 25°C, 50°C and 70°C correspondingly. After 4 days testing, Viscosity of nanofluid recorded less values as compared with base fluid [42].

Heat Transfer Characteristics

Thermal conductivity of the material or fluid is high, the value of heat transfer coefficient similarly increases along

Table 2. Viscosity equations given by different authors.

Author	Formula for viscosity	Equation
Wang, Xu [47]	$\frac{\mu_{eff}}{\mu_f}=1+7.3\phi+123\phi^2$	(9)
Einstein [45]	$\mu_{nf}=\mu(1+2.5\phi)$	(10)
Sreedhar, Rao [48]	$\mu_{nf}=\frac{c_p(b)\mu b}{k_{(b)}}\times\frac{k_{nf}}{c_{p(nf)}}$	(11)

with the volume concentration of the nanofluids [52]. The effectiveness of the radiator in terms of thermal conductivity was increased by 10.5% and about 193% enhancement is obtained for heat transfer coefficient [53]. GNP nanofluid significantly improves characteristics of heat transfer. About 200% enhancement of heat transfer coefficient is attained after adding GNP compared to distilled water [54]. Peyghambarzadeh et al., performed investigation on forced heat transfer by using Al_2O_3 nanofluid of water-based, he observed that the nanofluids of 1 vol% concentration increased heat transfer by 45% as compared with normal water [55].

Methodology for The Simulation

CFD approach usages the numerical calculation by solving mass, momentum and energy conservation governing equations [56]

i) Continuity equation.

$$\frac{\partial\rho}{\partial t}+\nabla\cdot(\rho U)=0 \tag{12}$$

ii) Momentum equation

$$\frac{\partial}{\partial_t}(\rho U)+\nabla\cdot(\rho UU)=-\nabla p+\nabla\cdot\tau+\rho g \tag{13}$$

iii) Energy equation

$$\frac{\partial}{\partial t}(\rho h)+\nabla\cdot(\rho UC_pT)=\nabla\cdot(k\nabla T) \tag{14}$$

where,

$$\nabla=i\frac{\partial}{\partial x}+j\frac{\partial}{\partial y}+k\frac{\partial}{\partial z} \tag{15}$$

iv) The moment equation for the steady flow.

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\left[\frac{1}{\rho}\right]\frac{\partial\tau_{xy}}{\partial y} \tag{16}$$

Here u and v are the x and y velocity components respectively, τ_{xy} is shear stress & ρ is the density of non-Newtonian fluid.

v) k-epsilon model

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho kui)}{\partial xi}=\frac{\partial}{\partial xj}\left[\left(\mu+\frac{\mu t}{\sigma k}\right)\frac{\partial k}{\partial xj}\right]+P_k+P_b-\sigma\epsilon-Y_M+S_k \tag{17}$$

For dissipation €

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial(\rho\varepsilon ui)}{\partial xi}=\frac{\partial}{\partial xj}\left[\left(\mu+\frac{\mu t}{\sigma\epsilon}\right)\frac{\partial\varepsilon}{\partial xj}\right]+C_{1\epsilon}\frac{\varepsilon}{k}(P_k+C_{3\epsilon}P_b)-\frac{C_{2\epsilon}\rho\varepsilon^2}{k}+S\varepsilon \tag{18}$$

Boundary Conditions

The Radiator model is developed in CREO, a 3D modelling software by using various tools like Sketch, extrude, draft and assembly. Dimensions of the Radiator & Louvered strip [57] are presented in the Table 3. Once the radiator design is completed as shown in Figure 2 (a), the louvered strip is inserted into the radiator as shown in below Figure 2(b).

The main boundary conditions of the simulations applied for the radiator are below:

- Input flow rate = 3,4,5,6 and 7 LPM
- Maximum Inlet temperature = 353K
- Volume concentrations of nanofluids = 0.01, 0.03, 0.05 and 0.09%

The radiator will be undergone with finite element analysis (FEA) with hexagonal fine meshing as shown in Figure 3 (a) & (b) and it is solving the turbulence of k--epsilon model. The results show that it obtained 380253 nodes and 298520 elements without louvered strip and 462015 nodes and 331523 elements are obtained with the louvered strip. The elemental and orthogonal quality of the mesh along with skewness is detailed in Table 4, Mesh sensitivity is presented in Table 5.

Table 3. Details of the radiator dimensions & louvered strip

Louvered strip details	Radiator
Angle of the strip = 30°	Length of Radiator = 340mm
Thickness = 1mm	Height of Radiator = 350mm
Length = 10mm	Diameter of Inlet = 25mm
Pitch = 30mm	Diameter of Outlet = 18mm
Number of Tubes = 31	Thickness of Radiator = 22mm

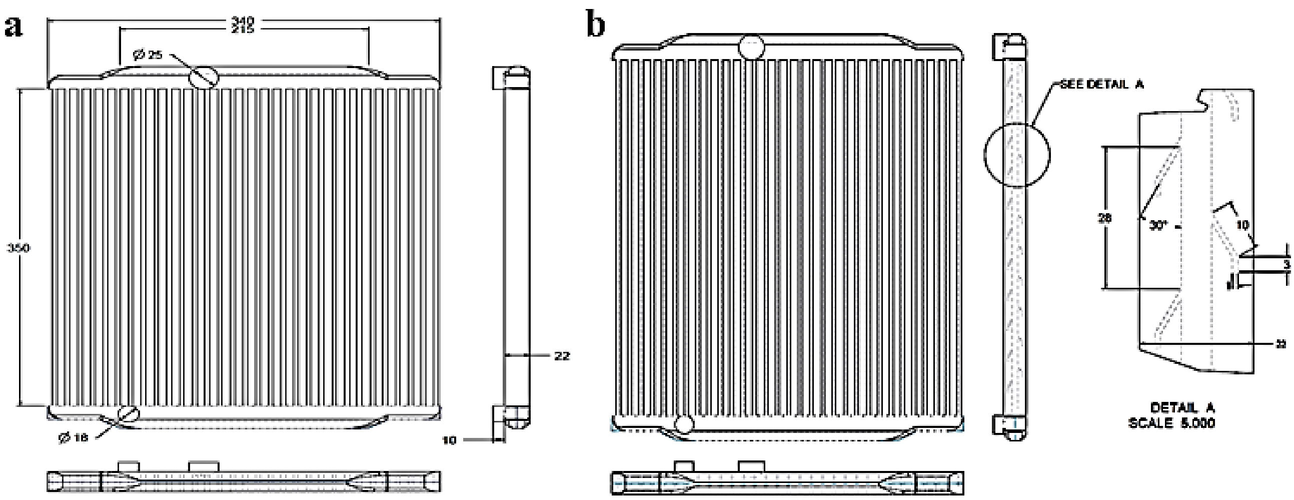

Figure 2. (a) Drafting of the Radiator without strip (b) Drafting of the Radiator with the strip.

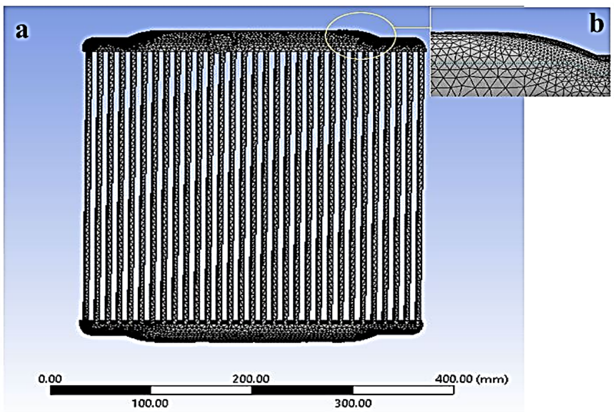

Figure 3. (a) Radiator with hexagonal fine mesh (b) Hexagonal fine mesh

Table 4. Quality of the mesh

	Element quality	Aspect ratio	Skewness	Orthogonal quality
Minimum	$6.75e^{-5}$	1.1618	$3.799e^{-5}$	1.687
Maximum	0.99	202.26	0.99	0.99
Average	0.637	3.5391	0.4633	0.68
Standard deviation	0.2676	3.741	0.306	0.241

Table 5. Mesh sensitivity

Minimum size (mm)	$7.678e^{-2}$
Maximum face size (mm)	1.0250
Maximum size (mm)	2.568
Maximum edge length (mm)	0.18994

Using the k–ε turbulence model with improved wall treatment, a steady-state simulation was performed. Recent studies revealed that the k-ε turbulence model has yielded positive results in terms of measurement. This method was allowed to run 500 iterations and converged to converge 10-5. The plot of residuals with a number of iterations is shown in Figure 4.

The thermophysical properties are calculated for the Graphene and Graphene Oxide nanofluids with the base fluid as Water: Ethylene glycol (60:40). The volume concentration is 0.01, 0.03, 0.05 and 0.09. The density, specific heat, thermal conductivity, and viscosity were calculated based on equations (2),(3),(4) and (11). The pressure drops, temperature drop, enthalpy, entropy, heat transfer coefficients etc., are estimated by using CFD. In the following images, the maximum value is indicated by red and minimum value is indicated by blue colour. From the Temperature distribution of radiator image, with and without louvered strip of Figure 5 and 6 explains that, the fluid temperature about 353K will be applied into the radiator at the inlet and pass through the tubes, with given forced convection the temperature reduction will take place. At the outlet point of the radiator it is observed that temperature gradually decreases from inlet to the outlet.

RESULTS AND DISCUSSIONS

For the original radiator and louvered strip inserted radiator, the pressure drop is very huge due to inserted strips. In the original model, the fluid is passed through the radiator tubes without any disturbance, but then with an obstacle there creates the turbulence which caused drop-in pressure, velocity, temperature.

There is 80–86% (50kpa to 74kpa) drop observed in louvered strip radiator compared with the original radiator

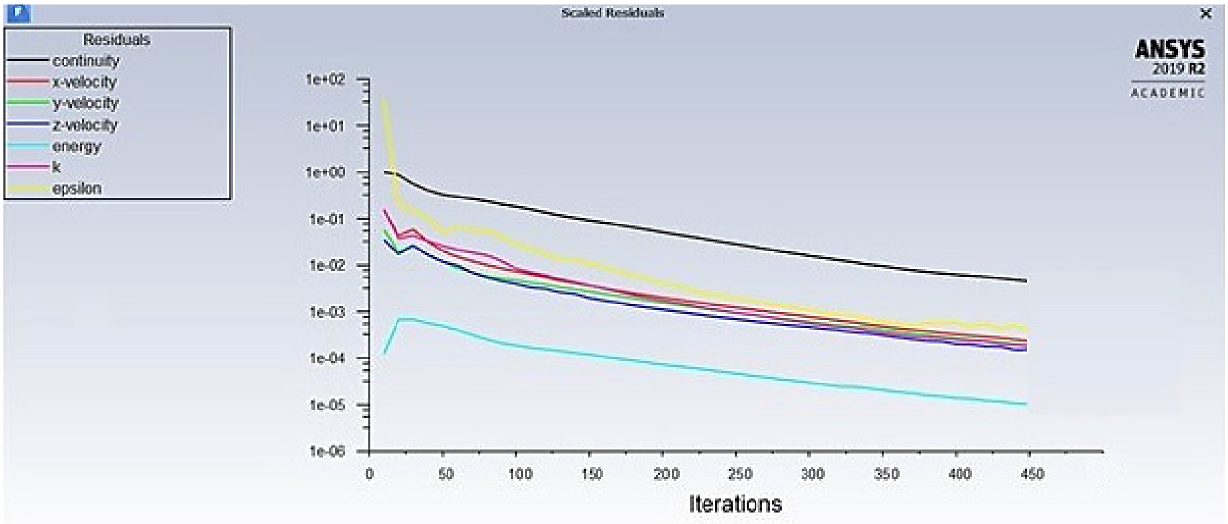

Figure 4. Residual vs. number of iterations plot.

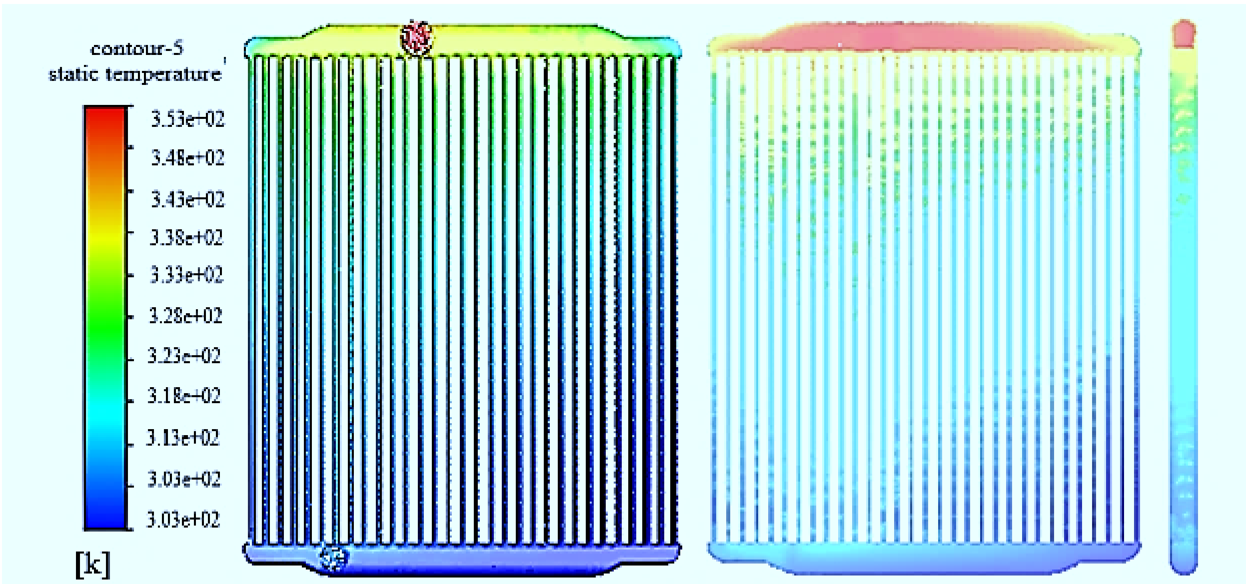

Figure 5. Temperature distribution of radiator without louvered strip.

(10kpa to 10.6 kpa), which seems that pressure is reduced in working fluid. This result is observed for both fluids. The author Karthik, Kumaresan [58] by changing of louvered strip angle from 26˚C to 30˚C then pressure drop is 42.3%. The pitch is maintained 0.8mm with same angles, it is noticed that 90.1% pressure drop is enhanced when the water is utilized.

where M refers to modified radiator model with insert in the tube. In Figure 7, G (0.01) is Graphene nano particles at 0.01 % concentration and G (0.01) M is the concentration of the Graphene with louvered strip inserted in the radiator tube, similarly GO indicates Graphene Oxide at their respective concentrations with and without louvered strip inserted. Thermal conductivity plays a prominent role in heat transfer. The fluid which has high thermal conductivity will be having high heat transfer rate. Water with ethylene glycol has a high transfer rate so this fluid is mostly used in the radiators. But, to achieve a high heat transfer coefficient value, thermal conductivity of the fluid needs to be increased. In this research, the Graphene nanoparticles are added at various concentrations to the base fluid for obtaining high thermal conductivity. 23–31% of pressure drop is identified when the combination of water with ethylene glycol (60:40) used and when compared with water. i.e., 4.4 to

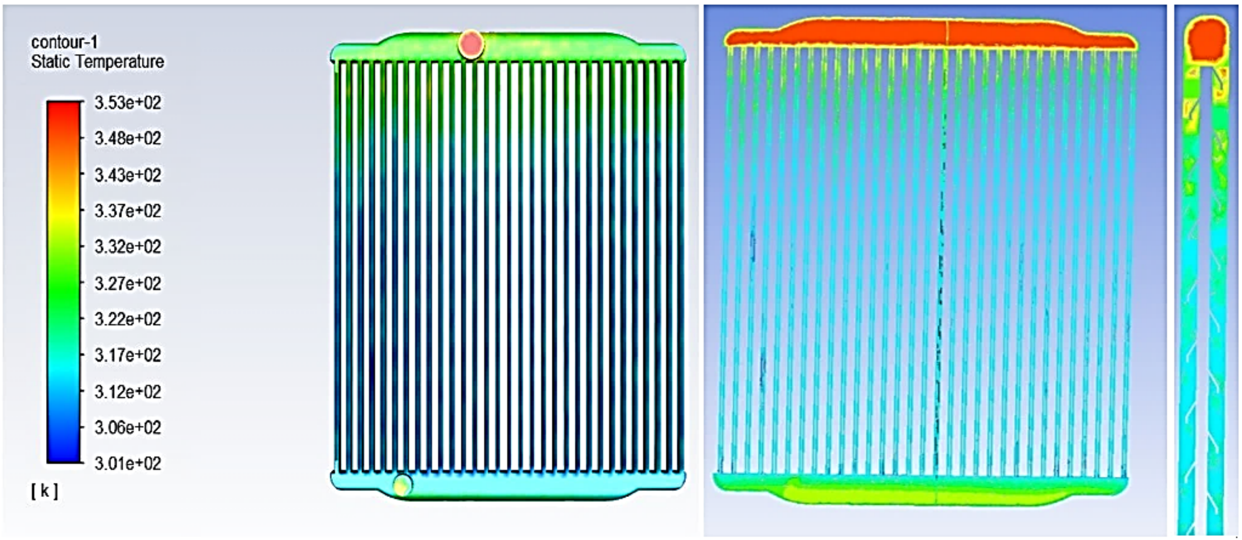

Figure 6. Temperature distribution of radiator with louvered strip.

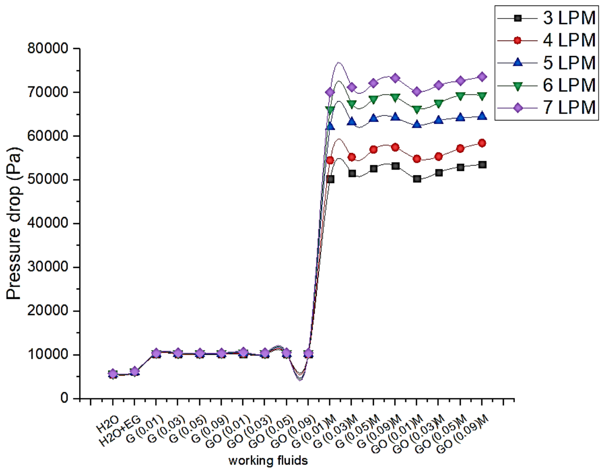

Figure 7. Comparison of the Pressure drop with different working fluids at different volume concentrations.

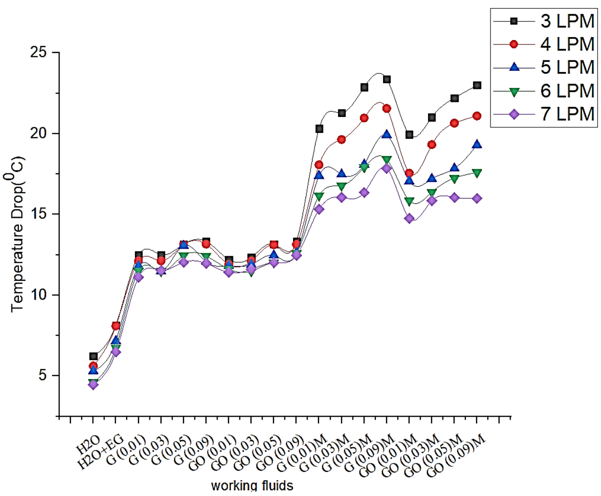

Figure 8. Comparison of the Temperature drop with different fluids at different volume concentrations.

6.2°C drop was observed in water whereas for the water + ethylene glycol 6.4 to 8.2°C drop is observed.

When the Graphene based nanofluid is used in this radiator, the temperature drop is very huge. It was observed that 34 to 45% (11 to 14°C) of the temperature drop when Graphene and Graphene oxide nanofluid is used with different concentration and mass flow rate. The highest temperature drop is observed at 3LPM because the mass flow rate is inversely proportional to temperature. 0.2 to 1°C variation is observed in between Graphene with different volume concentration along with different mass flow rate and same results showed up for the Graphene oxide. In between Graphene and Graphene oxide, the temperature drop is 0.5 to 2% is varied based on the different flow rate.

The louvered strip is inserted in the radiator and simulated to identify the temperature drop. 4.5 to 8.3°C variation is observed in between the Graphene with different volume concentration along with different mass flow rate and similarly for the Graphene oxide. In between Graphene and Graphene oxide, the temperature drop is 1 to 4% is varied based on the different flow rate. When compared to with and without louvered strip radiator, it was found that 27 to 42 % improvement in temperature drop for louvered strip radiator.

Temperature is directly proportional to enthalpy and entropy. Temperature of fluid depends on the engine condition, here about 353k temperature of fluid is entered into the radiator, different fluids are investigated to identify the maximum temperature drop. From the Figure 8, the results stated that the temperature drop is high for the less mass flow rate similarly, enthalpy is also high at a low mass flow rate.

Enthalpy is a thermodynamic property of a system. The sum of the internal energy added to the product of the pressure and volume of the system. It shows non-mechanical work and also capacity to release heat. As obtained below from Figure 9, 14.5 – 15.5% improvement of enthalpy for the water+ ethylene glycol is obtained compared with only water. 58–60% enhancement of enthalpy observed when Graphene and Graphene oxide nanofluid was utilized. Nanofluid thermophysical properties have improved the enthalpy. Less than 0.1% improvement is observed in-between Graphene and Graphene oxide with different mass flow rate along with volume concentration of the nanofluid for the original radiator. With louvered strip inserted radiator, the enthalpy improvement of Graphene is observed at 1.5% and Graphene oxide nanofluid achieved 2.5% increment of enthalpy.

Entropy is directly proportional to temperature and enthalpy. The results from Figure 10, indicate that when the mass flow rate increases, the entropy is slightly decreased. 8.5 to 13.2% entropy increased when the water with ethylene glycol is used as a fluid used in radiator. The entropy is increased to 19% when the Graphene and Graphene oxide nanofluid is utilized. Internally utilization of different volume concentration of the nanofluid, it was stated that 0.6% enhancement for the Graphene nanofluid and 1.3% enhancement for the Graphene oxide nanofluid. It seems that Graphene oxide plays a major role to achieve high entropy. 1.8% enhancement of entropy is observed in 0.09 volume concentration of the Graphene and Graphene oxide nanofluid at 3LPM when strips are inserted in the radiator i.e., high entropy is obtained at strips are inserted in the radiator.

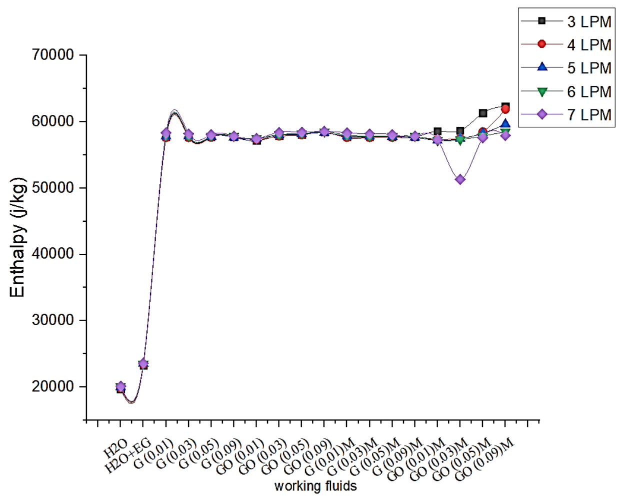

Figure 9. Comparison of the Enthalpy with different fluids at different volume concentrations.

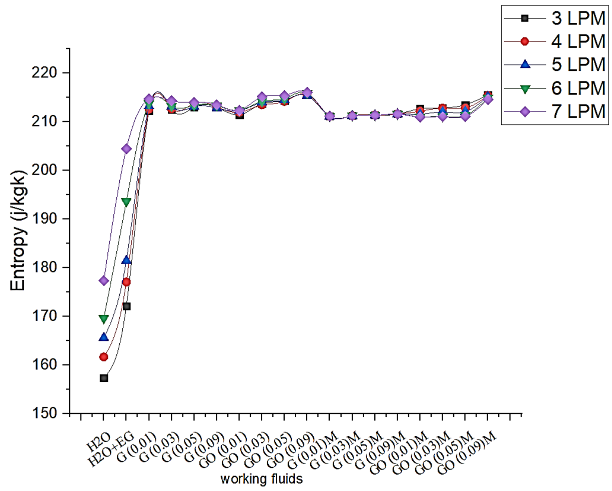

Figure 10. Comparison of the Entropy with different fluids at different volume concentrations.

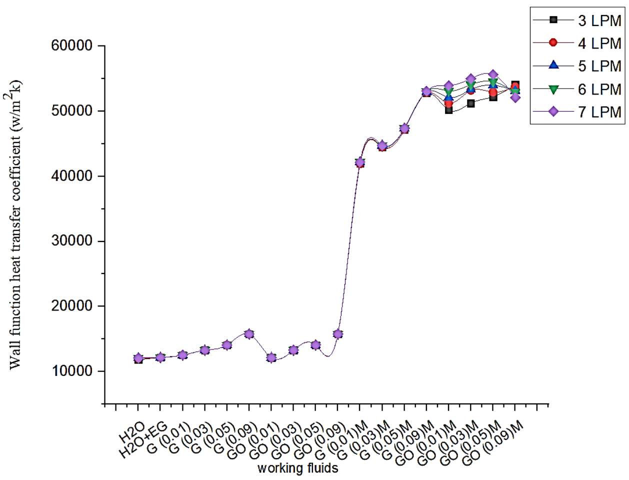

Figure 11. Comparison of the Wall function heat transfer coefficient with different fluids at different volume concentrations.

Heat transfer coefficient is directly proportional to mass flow rate. In result, from the Figure 11 it is observed that high heat transfer is observed for 7LPM. The heat transfer coefficient difference between water & ethylene glycol/ water is 0.54 to 3%. 5.7 to 10.7% enhancement was observed when using 0.01 – 0.09 volume concentration of Graphene nanofluid. From 0.01 to 0.09 volume concentration of Graphene oxide nanofluid utilization, 8.7 to 10.7% enhancement was observed. It increased up to 22% when Graphene and Graphene oxide nanofluid is utilized in radiator. Similar observation is found when strip is inserted in radiator tubes.

Graphene nanofluid circulating in the radiator tube with strip inserted, the Heat transfer coefficient is enhanced by 236% similarly Graphene oxide nanofluid observed 320%

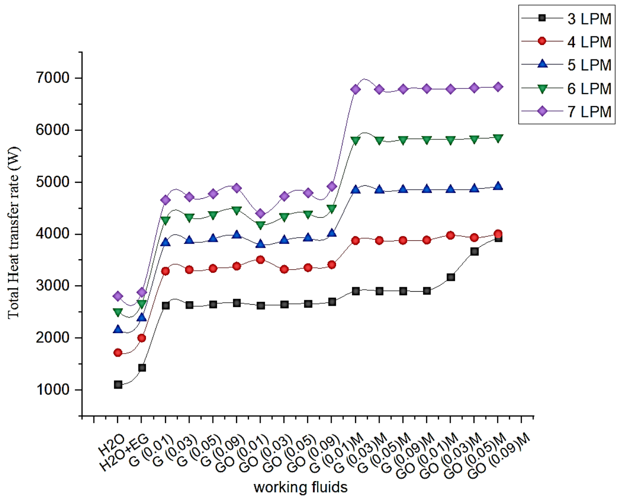

Figure 12. Comparison of the Total heat transfer coefficient with different fluids at different volume concentrations.

improvement. From the observation, it was found that a huge heat transfer is obtained when the strip is inserted in radiator tubes.

Heat transfer rate is directly proportionate to mass flow rate. In result from Figure 12, it is observed that high heat transfers for 7LPM for all fluids. The total heat transfer rate difference between water and water with ethylene glycol is 10 to 22%. For volume concentration from 0.01 to 0.09 of Graphene nanofluid utilization, 40 to 45% enhancements were observed. 40 to 47% enhancement was observed between 0.01 to 0.09% volume concentration of the Graphene oxide nanofluid. Up to 25% enhancement was observed when louvered strip inserted in radiator tubes. When the comparison of Graphene nanofluid used in the radiator and without strip inserted in the radiator, Heat transfer coefficient increased by 45% and improved by 54% for Graphene oxide nanofluid at 7LPM. The heat transfer rate is improved up to 50% by Hussein, Bakar [59] when SiO_2 based nanofluid was employed and in comparison with pure water in the automotive cooling system. In the experimental study conducted by Ali, El-Leathy [60] it is noticed that for the Toyota Yaris 2007 model car for cooling system (radiator), by using Al_2O_3 nanoparticles mixed with water as a nanofluid, and by varying the volume concentrations: 0.1%, 0.5%, 1%, 1.5%, and 2%. The heat transfer rate and heat transfer coefficient were improved 14.79 & 14.72, which occurred at maximum load 1. Another researcher Wen and Ding [61] experimentally studied & observed up to 47% heat transmit improvement when 1.6% volume portion of Al_2O_3 nanoparticles was distributed in water. From the present study, it was found that a huge heat transfer rate is obtained at 7LPM when the strip inserted in radiator tubes.

CONCLUSION

Suspended Nanofluid is a mixture of colloidal suspension of nanoparticles in base fluids. The nanofluids have excellent thermal property enhancement than conventional fluids. These fluids containing nanometer-sized particles. Graphene and Graphene Oxide nanofluids are utilized into the radiator to boost cooling performance and heat transfer. The simulation results are stated in the following statements.

1. 80–86% (50kpa to 74kpa) pressure drop was observed in louvered strip radiator compared with the original radiator model (10 kpa to 10.6 kpa).
2. 4.4 to 6.2°C drop in temperature is observed with water whereas for the water + ethylene glycol 6.4 to 8.2°C drop is observed. It was observed that 34 to 45% (11 to 14°C) of the temperature drop when Graphene and Graphene oxide nanofluid is used with different concentration and mass flow rate. When compared to with and without louvered strip radiator, it was found that 27 to 42 % improvement in temperature drop for louvered strip radiator.
3. 58–60% enhancement of enthalpy observed when Graphene and Graphene oxide nanofluid was utilized.
4. 1.8% of enhancement for entropy is observed in 0.09 volume concentration of the Graphene and Graphene oxide nanofluid at 3LPM when louvered strips are inserted in the radiator
5. With the louvered strip inserted in the radiator, 236% enhancement of heat transfer coefficient is observed for Graphene and Graphene oxide nanofluid is 320% identified.
6. The comparison of Graphene nanofluid used in the radiator and with strip inserted in the radiator, 45% enhancement of heat transfer coefficient is observed and for Graphene oxide nanofluid, 54% improvement identified at 7LPM.

By considering all the above factors, it can be concluded that the performance of Radiator is enhanced with insertion of louvered strip using Graphene based nanofluids with optimum concentration.

ACKNOWLEDGMENTS

The authors would like to thank University Malaysia Pahang (UMP) for Grant RDU 190194, FRGS/1/2018/TK03/UMP/02/26 and UMP Flagship RDU192204 for financial assistance and facilities provided.

NOMENCLATURE

A Constant
D diameter of tube, mm
d diameter of particle
h heat transfer coefficient, W/m^2-K

k	thermal conductivity, W/m-K
Kc, j	Effective dielectric constant
m	Constant
n	Empirical shape factor, n= 3/ψ
G	Graphene
GO	Graphene oxide
t	Temperature, k
w	Water
EG	Ethylene glycol
LPM	Liters per minute, l/m
CVD	Chemical vapor deposition
B 2, x	Depolarization factor along the x-symmetrical axis

Greek symbols

α	aspect ratio of nanoparticles
β	ratio of the nanolayer thickness to the original particle radius, B = h/r
γ	ratio of nanolayer thermal conductivity to particle thermal conductivity, γ = k layer/k p
ν	dynamic viscosity
φ	volume concentration of nanoparticles in suspension
ψ	particle sphericity
ρ	density
m	Mass of particle
Cp	Specific heat
μ	Viscosity

Subscripts

bf	Base fluid
nf	Nano fluid
p	particle
eff	effective

AUTHORSHIP CONTRIBUTIONS

M. Sandhya: Conceptualization, Visualization, Investigation, Data curation, Writing - original draft, Writing - review & editing. D. Ramasamy: Supervision, Writing - review & editing. K. Sudhakar: Writing – review & editing. K. Kadirgama: Writing – review & editing. W.S.W. Harun: Writing - review & editing.

DATA AVAILABILITY STATEMENT

No new data were created in this study. The published publication includes all graphics collected or developed during the study.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] Yadav JP, Singh BR. Study on performance evaluation of automotive radiator. S-JPSET, 2011;2:47-56. [CrossRef]

[2] Sandhya M, Devarajan R, Sudhakar K, Kadirgama K, Mahendran S, Harun WS et al. A systematic review on graphene-based nanofluids application in renewable energy systems: Preparation, characterization, and thermophysical properties. Sustain Energy Technol Assess 2021;44:101058. [CrossRef]

[3] Kilic M, Muhammad AH. Numerical investigation of combined effect of nanofluids and multiple impinging jets on heat transfer. Thermal Science 2019;23:3165-73. [CrossRef]

[4] Kilic M, Yavuz M, Yılmaz I. Effects of nanofluids on heat transfer and fluid flow with impinging jet. Elazığ: International Conference On Advances And Innovations in Engineering ICAIE, 2017 May 10 to 12; Conference Proceedings. p. 466-72.

[5] Khot AR, Thombare DG, Gaikwad SP, Adadande AS. An overview of radiator performance evaluation and testing. IOSR-JMCE 2012;2:7-10.

[6] Kilic M, Abdulvahitoglu A. Numerical investigation of heat transfer at a rectangular channel with combined effect of nanofluids and swirling jets in a vehicle radiator. Thermal Science 2019;23:3627-37. [CrossRef]

[7] Sandhya M, Devarajan R, Kadirgama K, Harun WS, Mahendran S, Ameer A. Enhancement of tribological behaviour and thermophysical properties of engine oil lubricant by Graphene/Co-Cr nanoparticle additives for preparation of stable nanolubricant. IOP Conf Ser: Mater Sci Eng 2021;1078:012016. [CrossRef]

[8] Sandhya M, Ramasamy D, Sudhakar K, Kadirgama K, Harun WS. Enhancement of the heat transfer in radiator with louvered fin by using Graphene-based hybrid nanofluids. IOP Conf Ser: Mater Sci Eng 2021;1062:012014. [CrossRef]

[9] Sahoo RR, Sarkar J. Heat transfer performance characteristics of hybrid nanofluids as coolant in louvered fin automotive radiator. Heat and Mass Transfer 2017;53:1923-31. [CrossRef]

[10] Peyghambarzadeh S, 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;38:1283-90. [CrossRef]

[11] Kilic M, Numerical investigation of heat transfer from a porous plate with transpiration cooling J Ther Eng 2018;4:1632-47. [CrossRef]
[12] Oliet C, Castro J, Perez-Segarra CD. Parametric studies on automotive radiators. Appl Therm Eng 2007;27:2033-43. [CrossRef]
[13] Mohebbi R, Izadi M, Chamkha AJ, Heat source location and natural convection in a C-shaped enclosure saturated by a nanofluid. Phys Fluids 2017;29:122009. [CrossRef]
[14] Eastman JA, Choi SU, Li S, Yu W, Thompson LJ. Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles. Appl Phys Lett 2001;78:718-20. [CrossRef]
[15] Umavathi J, Chamkha AJ, Mateen A, Al-Mudhaf A. Unsteady oscillatory flow and heat transfer in a horizontal composite porous medium channel. Nonlinear Anal-Model 2009;14:397-415. [CrossRef]
[16] Ghalambaz M, Doostanidezfuli A, Izadpanahi E, Chamhka AJ. Conjugate natural convection flow of Ag–MgO/water hybrid nanofluid in a square cavity. J Therm Anal Calorim 2020;139:2321-36. [CrossRef]
[17] Heris SZ, Shokrgozar M, Poorpharhang S, Shanbedi M, Noie SH. Experimental study of heat transfer of a car radiator with CuO/ethylene glycol-water as a coolant. J Dispers Sci Technol 2014;35:677-84. [CrossRef]
[18] Jiao Y, Zhang J, Liu S, Liang Y, Li S, Zhou H, et al. The graphene oxide ionic solvent-free nanofluids and their battery performances. Sci Adv Mater 2018;10:1706-13. [CrossRef]
[19] Kilic M. A numerical analysis of transpiration cooling as an air cooling mechanism. Heat Mass Trans 2018;54:3647-62. [CrossRef]
[20] Rashad A, Armaghani T, Chamkha AJ, Mansour MA. Entropy generation and MHD natural convection of a nanofluid in an inclined square porous cavity: effects of a heat sink and source size and location. Chin J Phys 2018;56:193-211. [CrossRef]
[21] Chamkha A, Rashad AM, Mansour MA, Armaghani T, Ghalambaz M. Effects of heat sink and source and entropy generation on MHD mixed convection of a Cu-water nanofluid in a lid-driven square porous enclosure with partial slip. Phys Fluids 2017;29:052001. [CrossRef]
[22] Wang Z, Wu Z, Han F, Wadsö L, Sundén B. Experimental comparative evaluation of a graphene nanofluid coolant in miniature plate heat exchanger. Int J Therm Sci 2018;130:148-56. [CrossRef]
[23] Sumanth S, Rao PB, Krishna V, Seetharam TR, Seetharamu KN. Effect of carboxyl graphene nanofluid on automobile radiator performance. Heat Transf - Asian Res 2018;47:669-83. [CrossRef]
[24] Chamkha AJ, Miroshnichenko IV, Sheremet MA. Numerical analysis of unsteady conjugate natural convection of hybrid water-based nanofluid in a semicircular cavity. J Thermal Sci Eng Appl 2017;9:041004. [CrossRef]
[25] Liu X, Wang X, Huang J, Cheng G, He Y. Volumetric solar steam generation enhanced by reduced graphene oxide nanofluid. Appl Energy 2018;220:302-12. [CrossRef]
[26] Sandhya M, Ramasamy D, Sudhakar K, Kadirgama K, Harun WS. Ultrasonication an intensifying tool for preparation of stable nanofluids and study the time influence on distinct properties of graphene nanofluids – A systematic overview. Ultrason Sonochem 2021;73. [CrossRef]
[27] Abbas F, Ali HM, Shah TR, Babar H, Janjua MM, Sajjad U, et al. Nanofluid: Potential evaluation in automotive radiator. J Mol Liq 2019;207:112014. [CrossRef]
[28] Taghioskoui M. Trends in graphene research. Mater Today 2009;12:34-7. [CrossRef]
[29] Cervenka J, Harder than diamond, stronger than steel, super conductor… graphene's unreal. Available at: https://theconversation.com/harder-than-diamond-stronger-than-steel-super-conductor-graphenes-unreal-5123. Accessed Sep 2, 2021.
[30] Bolotin KI, Sikes KJ, Klima M, Fudenberg G, Hone J, Kim P, et al. Ultrahigh electron mobility in suspended graphene. Solid State Commun 2008;146:351-5. [CrossRef]
[31] Ponangi BR, Sumanth S, Krishna V, Seetharam TR, Seetharamu KN. Heat transfer analysis of radiator using graphene oxide nanofluids. Dubai, UAE: IOP Conf Series: Materials Science and Engineering 346 2018;012032. [CrossRef]
[32] Ponangi BR, Sumanth S, Krishna V, Seetharam TR, Seetharamu KN. Performance analysis of automobile radiator using carboxyl graphene nanofluids. Dubai, UAE: IOP Conf. Series: Materials Science and Engineering 346 2018;012031. [CrossRef]
[33] Parvin S, Alim MA, Hossain NF, Chamkha AJ. Thermal conductivity variation on natural convection flow of water–alumina nanofluid in an annulus. Int J Heat Mass Transf 2012;55:5268-74. [CrossRef]
[34] Maxwell JC. A treatise on electricity and magnetism. Vol. 1. Clarendon press; 1881.
[35] Hamilton RL, Crosser O. Thermal conductivity of heterogeneous two-component systems. Ind Eng Chem Fundam 1962;1:187-91. [CrossRef]

[36] Charunyakorn P, Sengupta S, Roy S. Forced convection heat transfer in microencapsulated phase change material slurries: flow in circular ducts. Int J Heat Mass Transf 1991;34:819-33. [CrossRef]
[37] Xue QZ. Model for effective thermal conductivity of nanofluids. Phys Lett A 2003;307:313-7. [CrossRef]
[38] Yu W, Choi S. The role of interfacial layers in the enhanced thermal conductivity of nanofluids: a renovated Maxwell model. J Nanoparticle Res 2003;5:167-71. [CrossRef]
[39] Gandhi K, Velayutham M, Das SK, Thirumalachari S. Measurement of thermal and electrical conductivities of graphene nanofluids. Thessaloniki, Greece: 3rd Micro and Nano Flows Conference; 22-24 August 2011. [CrossRef]
[40] Bahaya B, Johnson D, Yavuzturk C. On the effect of graphene nanoplatelets on water–graphene nanofluid thermal conductivity, viscosity, and heat transfer under laminar external flow conditions. J Heat Transfer 2018;140. [CrossRef]
[41] Bahiraei M, Mazaheri N, Rizehvandi A. Application of a hybrid nanofluid containing graphene nanoplatelet–platinum composite powder in a triple-tube heat exchanger equipped with inserted ribs. Appl Therm Eng 2019;149:588-601. [CrossRef]
[42] Shah SNA, Syed S, Mohd Faizul Mohd S, Faiz A, Mohamad Azlin H, Nasir S, et al. Experimental investigation on stability, thermal conductivity and rheological properties of rGO/ethylene glycol based nanofluids. Int J Heat Mass Transf 2020;150:118981. [CrossRef]
[43] Kılınç F, Buyruk E, Karabulut K. Experimental investigation of cooling performance with graphene based nano-fluids in a vehicle radiator. Heat Mass Transf 2020;56:521-30. [CrossRef]
[44] Hamze S, Berrada N, Cabaleiro D, Desforges A, Ghanbaja J, Gleize J, et al. Few-layer graphene-based nanofluids with enhanced thermal conductivity. Nanomaterials 2020;10:1258. [CrossRef]
[45] Einstein A. On the theory of the Brownian movement. Ann Phys 1906;19:371-81.
[46] Nasrin R, Alim MA, Chamkha AJ. Combined convection flow in triangular wavy chamber filled with water–CuO nanofluid: effect of viscosity models. Int Commun Heat Mass Transf 2012;39:1226-36. [CrossRef]
[47] Wang X, Xu X, Choi SU. Thermal conductivity of nanoparticle-fluid mixture. J Thermophys Heat Trans J 1999;13:474-80. [CrossRef]
[48] Sreedhar T, Rao BN, Kumar DV. Heat Transfer Enhancement with Different Nanofluids in Heat Exchanger by CFD. Emerging Trends in Mechanical Engineering 2020:387-97.
[49] Park SS, Kim NJ. Influence of the oxidation treatment and the average particle diameter of graphene for thermal conductivity enhancement. J Ind Eng Chem J 2014;20:1911-5. [CrossRef]
[50] Kole M, Dey T. Investigation of thermal conductivity, viscosity, and electrical conductivity of graphene based nanofluids. J Appl Phys 2013;113:084307. [CrossRef]
[51] Hadadian M, Goharshadi EK, Youssefi A. Electrical conductivity, thermal conductivity, and rheological properties of graphene oxide-based nanofluids. J Nanopart Res 2014;16:2788. [CrossRef]
[52] Sreedhar T, B.N.a.D.V., heat transfer enhancement with different fluids in double pipe heat exchanger by Ansys fluent. International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), Feb 2019. , ISSN (P): 2249-6890(special issue): p. 59-65.
[53] Bharadwaj BR, Mogeraya KS, Manjunath DM, Ponangi BR, Rajendra Prasad KS, Krishna V. CFD analysis of heat transfer performance of graphene based hybrid nanofluid in radiators. Dubai, UAE: IOP Conf. Series: Materials Science and Engineering 346 2018;012084. [CrossRef]
[54] Mehrali M, Sadeghinezhad E, Rosen MA, Latibari ST, Mehrali M, Metselaar HSC, et al. Effect of specific surface area on convective heat transfer of graphene nanoplatelet aqueous nanofluids. Exp Therm Fluid Sci 2015;68:100-8. [CrossRef]
[55] Peyghambarzadeh S, Hashemabadi H, Jamnani MS, Hoseini T. Improving the cooling performance of automobile radiator with Al2O3/water nanofluid. Appl Therm Eng 2011;31:1833-8. [CrossRef]
[56] Anderson JD. Computational fluid dynamics - The basics with applications. New York: McGraw-Hill; 1995.
[57] Mohammed H, Hasan HA, Wahid MA. Heat transfer enhancement of nanofluids in a double pipe heat exchanger with louvered strip inserts. Int. Commun Heat Mass Transf 2013;40:36-46. [CrossRef]
[58] Karthik P, Kumaresan V, Velraj R. Experimental and parametric studies of a louvered fin and flat tube compact heat exchanger using computational fluid dynamics. Alex Eng J 2015;54:905-15. [CrossRef]
[59] Hussein AM, Bakar RA, Kadirgama K. Study of forced convection nanofluid heat transfer in the automotive cooling system. Case Stud Therm Eng 2014;2:50-61. [CrossRef]
[60] Ali M, El-Leathy A, Al-Sofyany Z. The effect of nanofluid concentration on the cooling system of vehicles radiator. Adv Mech Eng 2014;6:962510. [CrossRef]

[61] Wen D, Ding Y. Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions. Int J Heat Mass Transf 2004;47:5181-8. [CrossRef]

.