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Improving Thermal Efficiency of Radiators and Heat Exchangers Through Nanofluid-Based CFD Analysis

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Abstract: *The present study throws an insight into the enhancement of thermal performance of an automotive radiator using nanofluid-based coolants through a mathematical model and Computational Fluid Dynamics (CFD) analysis. In order to do this, a three-dimensional CAD model was made for the construction of the radiator (350 mm × 18 mm × 300 mm) with 40 tubes and 61 fins utilized in ANSYS Fluent for validation under steady-state conditions. Deionized water, EG: W/*Al_2O_3 *(60:40) and EG: W/ZnO (50:50) were applied in nanofluids, and a mass flow rate of 180 to 420 LPH used at an inlet temperature of 91°C. For deionized water, the heat transfer rate at 180 LPH increased from 3806.26 W to be 6729.24 W at 420 LPH. The convective heat transfer coefficient increased from 3122.60 W/m²K to 7238.75 W/m²K; and the Nusselt number rose from 42.59 to 98.72. The* Al_2O_3 *nanofluids displayed a significant enhancement, with the highest heat transfer rate of 9499.49 W and a heat transfer coefficient of 29,456.93 W/m²K, which were attained at 420 LPH, with the Reynolds number rising from 13,215.76 to 31,717.76. The best thermal performance proved by ZnO nanofluid was the peak heat transfer rate of 13,592.19 W and a convective heat transfer coefficient of 56,221.77 W/m²K at 420 LPH, with the Reynolds number reaching 56,903.27 and Nusselt number 238.25. Results reveal that ZnO nanofluids outdo deionized water by more than 100% performance at higher flow rates. The study confirms that nanofluids have a noticeable ability in augmenting convective heat transfer and compensating in heat exchanger efficiency under similar boundary conditions.*

Keywords: *Automotive radiator, Nanofluid, Computational fluid dynamics, Heat transfer enhancement,* Al_2O_3*, ZnO, Convective heat transfer coefficient*

I. Introduction

This continuous demand for highly efficient thermal management sytems for automotive and energy applications has intensified research on advanced coolants with a commendable heat transfer capability. Conventional heat transfer mediums including water and ethylene glycol have a restriction on their thermal conductivity. Thus, it becomes necessary for them to be used in places like automotive radiators which have highly compact structures and an enormous load. To overcome these limitations, nanofluids have flourished as promising alternatives; essentially, they are base fluids carrying engineered nanoparticles with superior thermophysical and rheological properties. Recent research works have come to show that some graphene oxide added through polymeric additives can greatly boost the solution's rheological stability and thermal endurance, highlighting the synergistic potential of hybrid formulations [1]. Similarly, a water-based nanofluid modified with few-layer graphene exhibits significant enhancement in thermal conductivity and heat transport properties [2].

The thermo-physical properties of the dispersed hyperthermic CuO nanoparticles in base fluids are even more preferable when compared with pure base fluids, as the liquid such as crude oil could be an example, and glycol mixture as other examples [3]. In both cases, an improved stability controller is incorporated between the base fluid and the dispersed fluid. In the area of application, the nano-bio ceramic ice, added to the class, showed a better structural morphology and heat transfer efficiency profile; the future prospects of these nanofluids as practical industrial options are bright [4]. Staggeringly fascinating with its unique qualities is an advanced class of hybrid nanofluids, hybrid systems comprising graphene oxide and carbon nanotubes finely dispersed in liquid CO_2, displaying admirable overall performance and superior thermal, rheological efficiency suitable for the next cooling generation technology [5]. In vivo, machine learning optimization methods were used to tune the viscosity/thermal conductivity of the base fluid for fuel cell or automotive cooling applications [6].

The enhancement in the synergistic effect graphene oxide towards a particular set of other nanoparticles such as MoS_2 through either direct experimental evidence or consequently, molecular dynamics simulation, confirmed an improvement in dispersion stability and thermophysical properties [7]. In automotive radiators, methane glycol-dispersed graphene oxide-based nanofluids exhibited better cooling performance when compared to what is generally observed for standard coolants [8]. Experimental and numerical investigations over graphene amine-based nano coolants showed an excellent increment in heat transfer coefficients and overall radiator efficiency [9]. The low-concentration hybrid nanofluids might intensify heat transfer rates by much, yet they do not tag along with severe penalties of pressure drop, indicating that they are safe for practical applications in radiators [10]. Modifications on radiator tube configurations in combination with different enriched nanofluids have contributed to the increment of heating performance [11], whereas alyssum oxide-based nanofluids showed increased thermal conductivities and, therefore, were considered useful for efficient heat removal from car radiators [12].

II. Related Work

Experimentally investigates the heat transfer performance of graphene oxide at 0.1 wt%-based nanofluids dispersed in different ratios of ethylene glycol and deionized water at 60:40, 30:70, and 20:80 for car radiator applications. Coolant flow rates were varied between 180 to 420 LPH at a constant temperature of 90 °C. The stability of said nanofluids was assessed by visual inspection and zeta potential while the density was measured using an oscillating U-tube meter. A 60:40 EG/DW nanofluid gave the best performance, showing a maximum of 71.1% heat transfer enhancement and Nusselt numbers up to 192, bringing potential reductions in radiator size and enhanced fuel efficiency [1].

Recently, many studies have provided significant evidence to patronize the idea that nanofluids bring much enhancement in thermal transportation behavior as well as the rheologicalapeutics for advanced heat transfer. Present work reported that graphene oxide has good syndication in improvement in the resistance to thermal treatment, rheological stability, and thermal endurance under severe operating conditions in advanced heat transfer technologies [5]. Nanofluids based on a few layers of graphene improved thermophysical properties, especially the competitive thermal conductivity with respect to the other types of nanofluids. Investigations on CuO/crude oil nanofluids revealed notable remediation to thermophysical and rheological behavior due to effective nanoparticle dispersion. Again, silica-based bio-ceramic nanofluids have shown superior structural morphology and heat transfer improvement. Hybrid graphene oxide/carbon nanotube nanoparticles dispersed in liquid CO_2 show promise for exceptional thermal properties and rheology for advanced cooling applications.

Graphene oxide was proven to give a synergetic effect in the lubrication action with MOS2 nanoparticles [7]. The creation of automobile cooling was further shown by nano coolants made up of graphene oxide with ethylene glycol–water mixtures in the radiator system, [8]. Also given our knowledge of how amine-functionalized graphene nanoparticles in the hardening of the rubber bolstering the theory of performance improvement of heat transfer characteristics in the radiator [9]. Nanofluids had shown a significant increase in heat transfer rates in automobile radiators without a significant pressure drop penalty [10]. Modified radiator tubes with these materials have shown improved thermal performance as well [11]. The nano-alumina base enhances the thermal conductivity when added to nanofluids for efficient heat dissipation in car radiators [12].

Comprehensive review and bibliometric analysis indicated enhanced development in nanoparticle radiator cooling technologies [13]. The supported study illustrates the greatness of the effectivity of the heat transfer coefficient of the GO with an opinion, the share below its pressure drop compared to TiO2, and Al2O3 nanoparticles [14]. An increase in enhance the cooling system was reported, where inclusions of graphene nanoplatelets in the presence of cellulose nanocrystals may possess for this segment [15]. Activated carbon-based nanofluids have feasibly improvised thermal performance [16]. Graphene oxide nanofluids have reported improved heat transfer performance via convective transfer in heat exchangers in numerical and ANN-based studies proposed [17]. The effect of thermal radiation in molds and magnetic fields to GO-Fe3O4/EG also helped to significantly increase heat transfer enhancement [18]. Research optimization for car radiators and nanofluids-based with an improvement in thermal efficiency was concretely proven [19]. Experimental and irreversibility theories regarding graphene and water nanofluids further documented their improved enhancement of convectively [20]. Hybridizations involving graphene nanoplatelet nanofluids accentuated solar thermal systems stability economically with good convective performance [21]. CuO and MgO nanofluids, in comparison with glycol, were confirmed to be superior coolants useful for radiator optimization [22].

III. Research Objectives

- To study the theoretical concept and heat transfer mechanism from the engine radiator.
- To create the three-dimensional CAD model of the engine radiator.
- To perform the Mathematical and computational fluid dynamics analysis on created CAD model of radiator in order to investigate the temperature distribution, heat transfer rate, heat transfer coefficient, nusselt number by using different types of nanofluids as a coolant.
- To compare the results from the mathematical & computational fluid dynamics analysis and validate with base paper.

IV. Research Methodology

Radiators are heat exchangers, which are built to either cool the working fluid or heat it. All radiators emit heat toward their environment, be it for the purpose of heating that same environment or for cooling the fluid or coolant running the radiator, as in automobile engine cooling. Most radiators transfer heat by convection rather than by thermal radiation. Heat transfer from a radiator occurs through thermal radiation, convection into flowing air or liquid, and conduction into the air or liquid. Multiple fins in a radiator are meant to increase available surface area for heat exchange with the surroundings.

These fins are in contact with the tube holding the liquid pumped through the radiator. The air that comes in contact with these fins takes the heat away. Figure 1 represents algorithm used for Computational fluid dynamics analysis

4.1 Algorithm used for Computational Fluid Dynamics Analysis

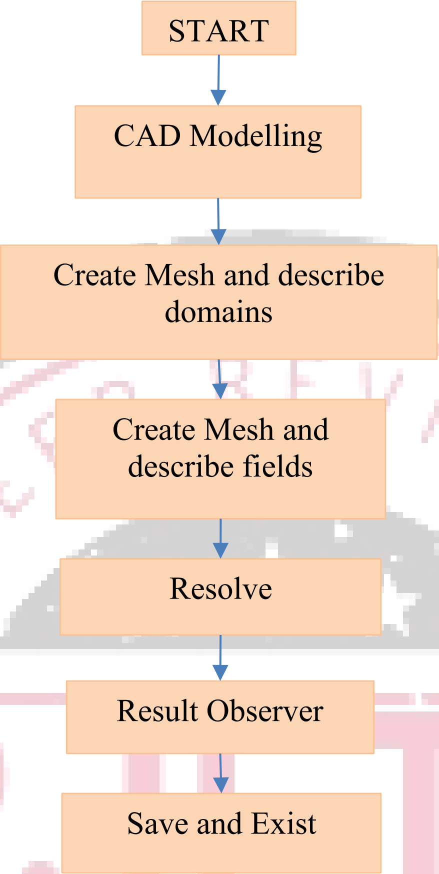

Figure 1 Algorithm used for Computational fluid dynamics analysis

Table 1 Thermo-physical properties of heat transfer fluid for the CFD analysis

Properties	**Deionized water [2]**	**EG:W/Al_2O_3 (60:40) [34]**	**EG:W/ZnO(50:50) [17]**	**EG:W/GO (60:40)[2,40]**
Density (Kg/m^3)	1001	1057.19	1001.86	1158.5
Specific Heat (J/Kg K)	4185	3526.70	4016.63	3527.73
Thermal conductivity (W/mK)	0.23	0.443	0.70804	0.57
Dynamic Viscosity (Ns/m^2)	0.00319	0.00170	0.0008929	0.0029
Prandtl Number	08	13.54	5.05629	19

4.2 Validation of Work

4.2.1 Calculation of Heat Transfer Rate for EG/W (60:40) & Deionized Water

$$\dot{Q} = \dot{m}C_p(T_{in} - T_{out}) \tag{1}$$

Calculation of Heat transfer rate for EG/W (60:40)

$$\dot{Q} = 0.05 \times 3529.71(90 - 60.23) = 5253.97\ W \tag{2}$$

Calculation of Heat transfer rate for Deionized water

$$\dot{Q} = 0.05 \times 4184(90 - 74.28) = 3288.62\ W \tag{3}$$

Similarly, Heat transfer rate for EG/W (60:40) & Deionized water can be calculated as mentioned in below table.

Table 2 Rate of heat transfer for EG/W (60:40) & Deionized water

Mass flow rate [LPH]	Rate of heat transfer for Deionized water [W] (Base Paper)	Rate of heat transfer for EG:W/GO (60:40) [W] (Base Paper)	Rate of heat transfer for Deionized water [W] (Present Work)	Rate of heat transfer for EG:W/GO (60:40) [W] (Present Work)
180	3176.63	5153.94	3288.63	5253.99
240	3553.94	6615.63	3663.94	6715.67
300	4156.36	7532.64	4187.36	7632.63
360	4789.89	8596.04	4999.89	8796.06
420	5412.10	9453.06	5814.10	9653.06

It has been observed that as the flow rates of the nanofluid were increased the outlet temperature increases and the heat transfer rate increasing as shown in figure.

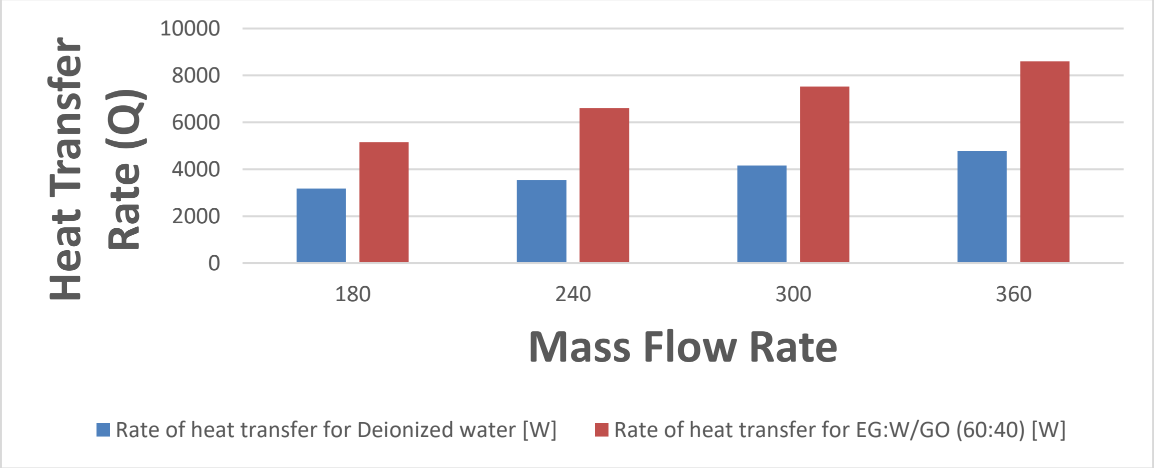

Figure 2: Heat transfer rate Vs Flow rate

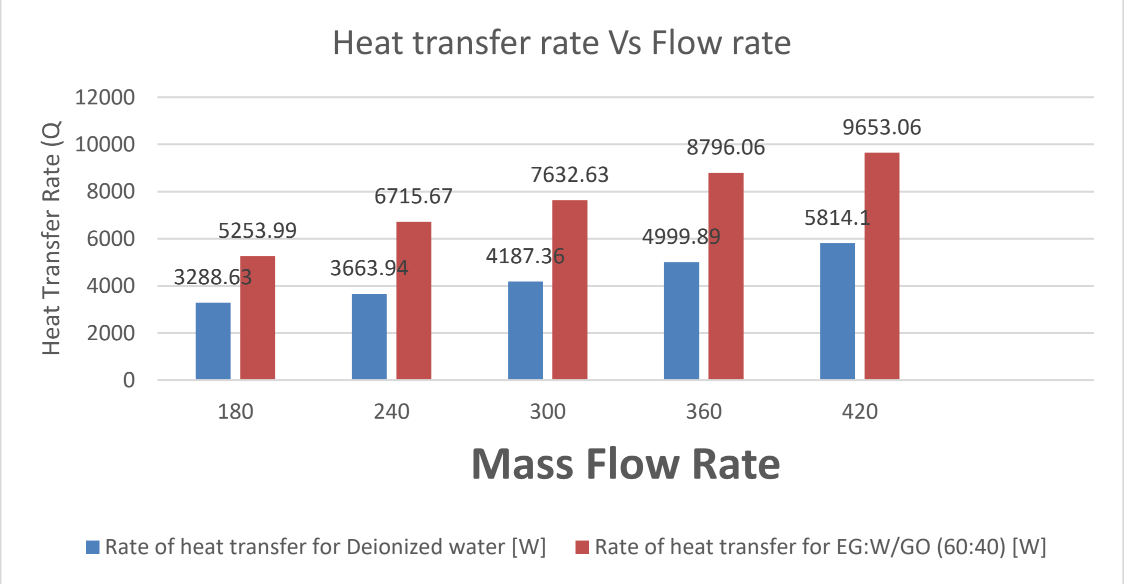

Figure 3: Heat transfer rate Vs Flow rate *[Present work]*

In the above figure 2 and 3, the performance of the heat transfer device in radiator configurations has been compared using graphene oxide/ethylene glycol: water (60:40) and Deionized water as a coolant, which increases with the flow rate of the heat transfer fluid of 180-420 LPH. It was observed that maximum enlargement in heat transfer rate by varied coolant at 78.3%, ·8% error in the case of graphene oxide/ethylene glycerol:water (60:40) coolant when compared with Deionized water. About all the compared results show very good agreement between the base paper and the present work so further analysis of the heat transfer could be done using different coolants with nanofluid additives under the same boundary conditions.

V. RESULT AND DISCUSSION

5.1 Computational Fluid Dynamics Analysis for Radiator using Deionized Water Ranging from 180-420 LPH

Table 4: Comparative results of temperature difference & heat transfer rate for Deionized water

Mass flow rate [LPH]	Inlet Temperature [°C]	Outlet temp [°C]	Temperature Difference Δ*T*	Heat transfer rate [W]
180	91	74.29	15.75	3806.26
240	91	77.50	12.53	4240.65
300	91	77.65	12.39	4792.22
360	91	78.07	11.97	5786.89
420	91	78.45	11.59	6729.24

Table 5.1 shows some points taken on utilizing data presented in Figures 5.1a and b to show the effect of mass flow rates effect on the temperature differences and heat transfer rate of deionised water. With the increase in flow rates from 180 LPH to 420 LPH, the exit temperature of the water has increased slightly and, therefore, the ΔT decreases. The decrease in ΔT as the flow rate increased could also somehow be interpreted as, because of the higher mass flow rates, the water spends comparatively less time in the heating section. However, the heat transfer rate kept increasing continuously as the flow rate was increased in the heat exchanger, all owing to its greater mass of water being passed to carry energy. Altogether, higher flow rates are likely to improve the heat transfer performance at lower (ΔT).

Table 3: Comparative results of Reynolds number, Nusselt number & heat transfer coefficient for Deionized water

Mass flow rate [LPH]	Reynolds number [Re]	Nusselt number [Nu]	Convective heat transfer coefficient [W/m^{2}K]
180	5245.170	42.59	3122.60
240	8614.19	60.98	4470.99
300	12275.61	76.47	5606.47
360	15752.12	86.15	6316.15
420	18089.19	98.72	7238.75

Table 3 illustrates the variation of Reynolds number, Nusselt number, and convective heat transfer coefficient with mass flow rate for deionized water. As mass flow rate varies from 180 to 420 LPH, Reynolds number is heavily amplified signifying high turbulence in the flow. With this increased chaos, Nusselt numbers were correspondingly elevated, which means better convective heat transfer from the form of turbulence. Therefore, all the more so do the heat transfer coefficients show a clear increase in value as the flow rate increases. An increase in flow at a high mass flow rate would confirm that the efficiency of heat transfer gets improved because of stronger mixing and convection of the fluid.

5.2 Computational Fluid Dynamics Analysis for Radiator using Al_2O_3 Nanofluid Mixture of Ethylene Glycol and Water Ranging from 180-420 LPH

Table 4: Comparative results of temperature difference & heat transfer rate for Al_2O_3 nanofluid mixture of ethylene glycol and water (60:40)

Mass flow rate [LPH]	Inlet Temperature [°C]	Outlet temp [°C]	Temperature Difference Δ*T*	Heat transfer rate [W]
180	91	61.62	28.42	5007.90
240	91	63.89	26.15	6450.67
300	91	63.90	26.14	7366.56
360	91	67.56	22.47	8713.03
420	91	69.30	20.75	9499.49

Table 4 shows that increase in mass flow rate results in lower temperature difference over the plate and higher heat transfer rate for ethylene glycol and water (60:40) nanofluid mixed with Al_2O_3. For 180 LPH, outlet temperature or t_1 is 61.62 °C, corresponding to a temperature difference of 28.42 °C and a rate of heat transfer of 5007.90 W. As we increase the twist into 240 and 300 LPH, the temperature difference results in decreasing to about 26.15 and 26.14 °C, while the heat transfer rate increases to 6450.67 and 7366.56 W. On further increase of the flow rate to 360 and 420 LPH, the temperature difference was decreased to 22.47 and 20.75 °C. However, the heat transfer rate increased to 8713.03 W and 9499.49 W. This clearly indicates that at a higher mass flow rate, the enhancement of the heat transfer increases even though; in such a case, the temperature difference is relatively reduced, emphasizing very much the higher thermal effects of the Al_2O_3 nanofluid.

Table 5 significantly portrays the change in Reynolds number, Nusselt number, and heat transfer coefficient for Al_2O_3 nanofluid in a mixture of ethylene glycol and water (60:40) at different flow rates. Moving from a mass flow rate of 180 being increased to 420 LPH, the dwarfs of Reynolds number climb to a substantial number of 13,215.76 to 31,717.76, spawn very strong turbulent flow. Meanwhile, the Nusselt number augments from 99.49 to 200.40, and heat transfer by convection ensures vast improvements. Correspondingly, the heat transfer coefficient increased from a low of 14,622.40 W/m²K to 29,456.93 W/m²K. These results only elucidate the prolific heat- transfer performance of the Al_2O_3 nanofluid over a base fluid, brought about by enhanced thermal properties and flow dynamics.

Table 5: Comparative results of Reynolds number, Nusselt number & heat transfer coefficient for Al_2O_3 nanofluid mixture of ethylene glycol and water (60:40)

Mass flow rate [LPH]	Reynolds number [Re]	Nusselt number [Nu]	Convective heat transfer coefficient [W/m²K]
180	13215.76	99.49	14622.40
240	18502.05	130.19	19139.09
300	21145.19	144.90	21296.81
360	26431.49	173.20	25459.07
420	31717.76	200.40	29456.93

5.3 Computational Fluid Dynamics Analysis for Radiator using ZnO Nanofluid Mixture of Ethylene Glycol and Water Ranging from 180-420 LPH

Table 6: Comparative results of temperature difference & heat transfer rate for EG:W/ ZnO (50:50)

Mass flow rate [LPH]	Inlet Temperature [°C]	Outlet temp [°C]	Temperature Difference ΔT	Heat transfer rate [W]
180	91	53.15	36.88	7402.60
240	91	56.55	33.47	9407.70
300	91	56.87	33.15	10648.83
360	91	59.03	30.99	12443.45
420	91	61.9	28.3	13592.19

The changes in temperature difference and heat transfer rate of EG-W/ZnO 50:50 nanofluids concerning a variation in mass flow rate are displayed in Table 6. At 180 LPH, which is high in terms of mass flow rate, the temperature difference is found as 36.88°C, with a heat transfer rate of 7402.60 W. As the mass flow rate is increased to 240 and 300 LPH, the temperature difference decreases to 33.47°C and 33.15°C with heat transfer rates of 9407.70 W and 10648.83 W. When the mass flow rate is 360 LPH and 420 LPH, the temperature differences are down to 30.99°C and 28.3°C and the heat transfer rates jump to 12443.45 W and 13,592.19W respectively. The increased heat transfer rate, whereas the fall in temperature difference, suggests that the higher mass flow rates do help in providing for better heat transfer.

The effect of mass flow rate on the Reynolds number,7. The Reynolds number increases from 23,709.70 at 180 LPH to 56,903.27 at 420 LPH, indicating highly turbulent flow conditions. Accordingly, the Nusselt number also increases from 118.29 to 238.25, demonstrating that the convective heat transfer is effectively enhanced. In addition, convective heat transfer coefficient also substantially improves from 27,908.45 W/m²K to 56,221.77 W/m²K. This implies that the novel ZnO-based nanofluids will give higher improvements in their thermal performance due to turbulence enhancement and the betterment of thermophysical properties.

Table 7: Comparative results of Reynolds number, Nusselt number & heat transfer coefficient for EG:W/ ZnO (50:50)

Mass flow rate [LPH]	Reynolds number [Re]	Nusselt number [Nu]	Convective heat transfer coefficient [W/m²K]
180	23709.70	118.29	27908.45

240	33193.59	154.82	36529.02
300	37935.51	172.25	40647.29
360	47419.39	205.91	48591.43
420	56903.27	238.25	56221.77

Table 8: Comparative results of temperature difference & heat transfer rate for graphene oxide/ethylene glycol: water (60:40)

Mass flow rate [LPH]	Inlet Temperature [^oC]	Outlet temp [^oC]	Temperature Difference ΔT	Heat transfer rate [W]
180	91	60.25	29.79	5253.99
240	91	62.85	27.19	6715.65
300	91	62.99	27.06	7632.66
360	91	65.07	24.94	8796.07
420	91	67.25	22.81	9653.08

Table 9: Comparative results of Reynolds number, Nusselt number & heat transfer coefficient for graphene oxide/ethylene glycol: water (60:40)

Mass flow rate [LPH]	Reynolds number [Re]	Nusselt number [Nu]	Convective heat transfer coefficient [W/m^2K]
180	9404.69	82.62	15143.49
240	13166.54	108.14	19821.15
300	15047.47	120.32	22055.75
360	18809.35	143.84	26366.35
420	22571.19	166.42	30506.67

Table 8 presents comparative results for temperature difference and heat transfer rate under different mass flow rates for the graphene oxide-ethylene glycol:water (60:40) nanofluid. It is observed that the outlet temperature increases and so does the temperature difference (ΔT) as the mass flow rate goes up. The maximum temperature difference was 29.79°C at 180 LPH, and the least was 22.81°C at 420 LPH despite a decrease in ΔT. Through this, we may conclude that heat transfer enhancement with the mass flow rate is dominant; we find that the marriage should then have reality within the current context. Heat transfer rate increased with mass flow rates from 5253.99 W with 180 LPH to 9653.08 W with 420 LPH. Further, this trend indicates that higher flow rates in the tube improve thermal energy removal even with a lower temperature difference.

In Table 9, we observe the variation in terms of Reynolds number, Nusselt number, and convective heat transfer coefficient for a specific nanofluid. With the increase in mass flow rate, the Reynolds number steadily increases with respect to the transition from weak to relatively stronger turbulent flow conditions. The highest Nusselt number is obtained as a textbook standard curve from 82.62 to 166.42 at 180 and 420 LPH, respectively, with fringes of influential paralleled heat transfer. Such enhancements of convective heat transfer vigorously enhance high convective heat transfer coefficient from 15,143.49 W/m2K up to 30,506.67 W/m2K. This explains how the mass flow rate impacts so significantly on fluid dynamics and heat transfer performance in a graphene oxide nanofluid.

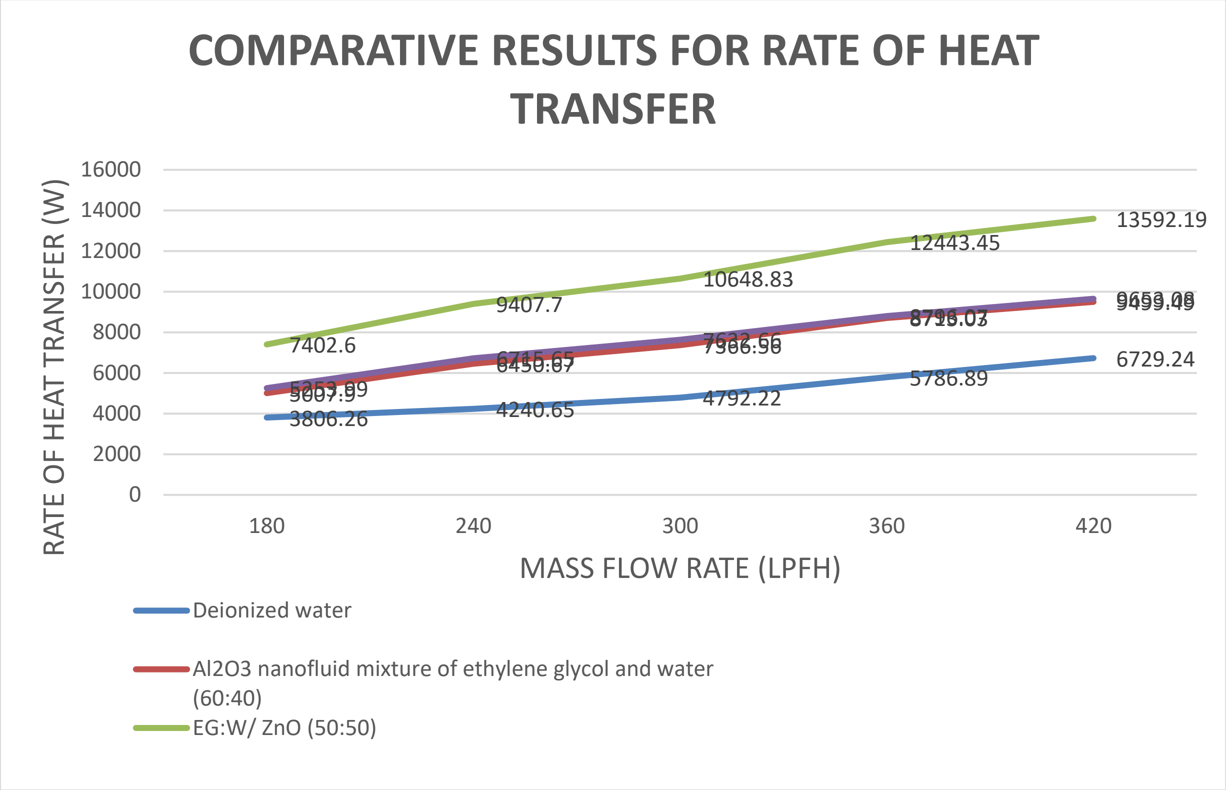

Figure 4: Comparative results for rate of heat transfer at different flow rate

In Figure 4 of the heat transfer coefficient comparison by different flow rates (180–420 LPH) for various working fluids, the coefficient increase is proportional at higher mass flow rate. As increased mass flow eases more turbulence and better fluid mixing, convincing enough to claim that enhanced heat transfer is mainly because of increased convection. Among tested fluids, EG: W/ZnO (50:50) nanofluid shows the highest heat transfer coefficient at all flow rates and, hence, the better thermal performance. The mixtures of graphene oxide/ethylene glycol-water (60:40) nanofluid and water-based Al_2O_3 nanofluids also significantly enhance the heat transfer coefficients compared to the DI water. DI water has uniform less values in the entire flow rate range.

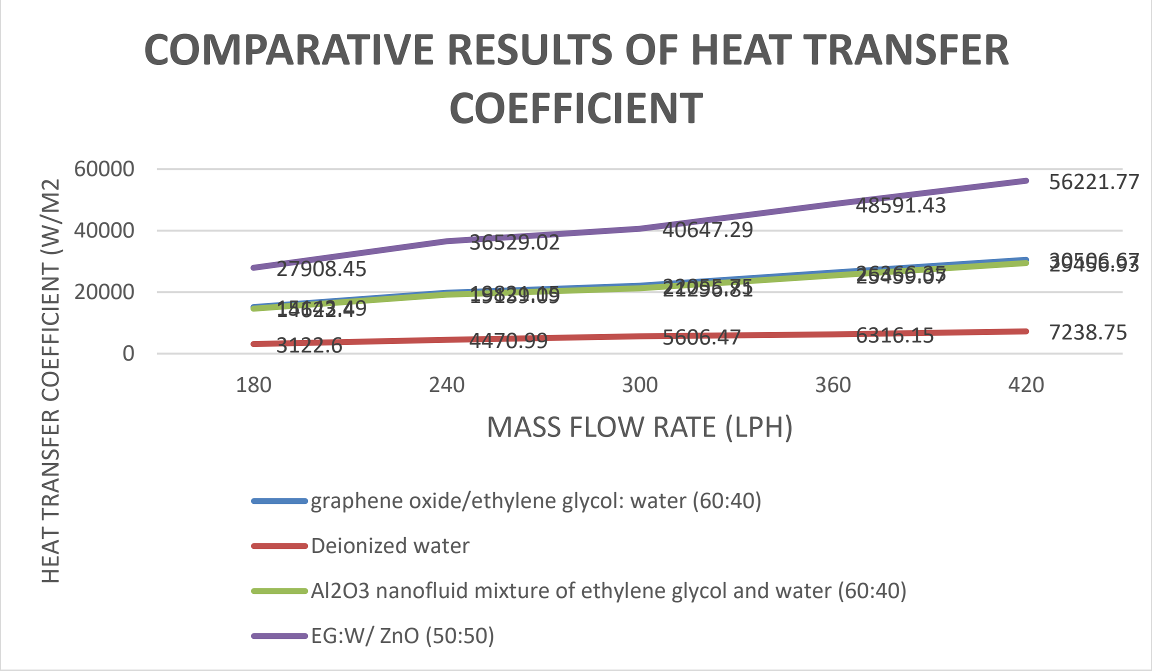

Figure 5: Comparative results of heat transfer coefficient at different flow rate

Figure 5 shows a comparison of the heat transfer coefficient (h) for various working fluids, depending on the rate of water flow. As is clear from this figure, the heat transfer coefficient for all fluid substances increases from up to down with the ascending mass flow rate. This process may be further explained in terms of higher flow turbulence and better fluid mixing, which improves the convective heat transfer. In comparison to the tested fluids, the EG:W/ZnO (50:50) nanofluid gave the highest heat transfer coefficients at all flow rates and was the best performer. The graphene oxide/ethylene glycol-water (60:40) and Al_2O_3 nanofluid mixtures also showed high heat transfer coefficients when compared to deionized water. Deionized water exhibited low performance irrespective of the flow rates.

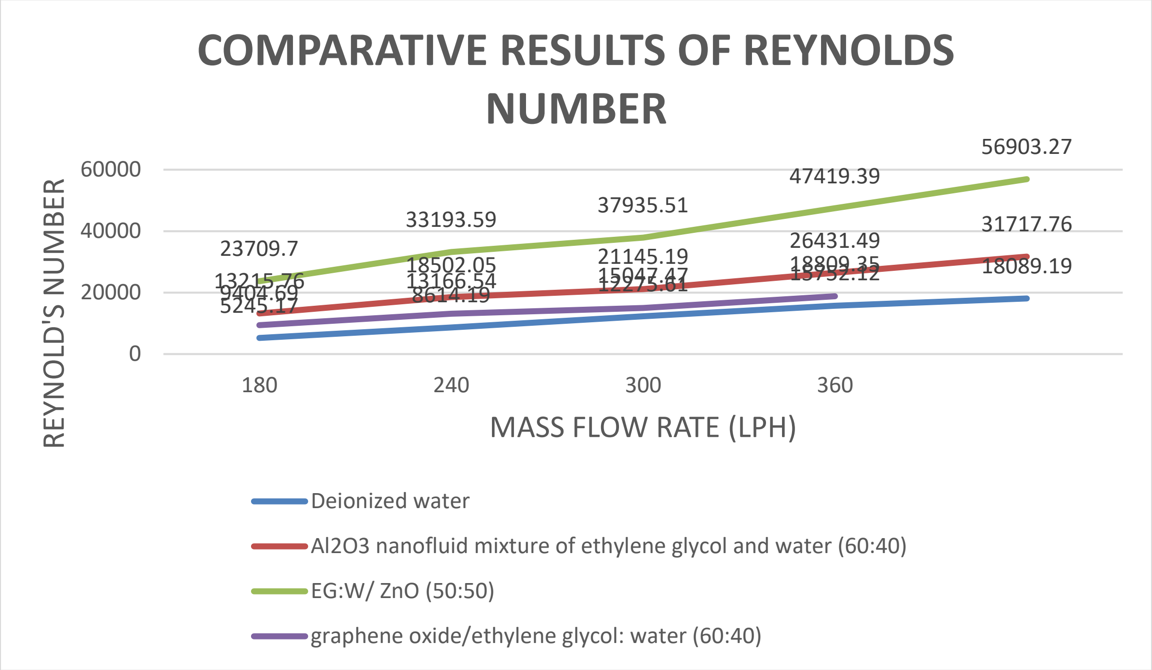

Figure 6: Comparative results of Reynolds number at different flow rate

Figure 6 substantiates Reynolds number comparative results for different fluids viz. Increased mass flow from 180 to 480 lph. Revenue shows a steady increase on a mass flow basis, indicating that rapidity downstream causes transitory to turbulent flow-situations. The EG:W/ZnO nanofluid had the highest Reynolds number for all flow rates, indicating improvement in the flow behavior from the significant alterations in the thermophysical properties. Graphene oxide/ethylene glycol-water (60:40) mixtures of alumina and nanofluid also exhibit the higher Reynolds number as opposed to deionized water. At flow rates, deionized water (DI) still manages to register the smallest value of Reynolds number. The growing relationship is further explained by the increasing flow rate, which results to an increase of inertial forces over the viscous forces, thus aiding in the promotion of turbulent flow. To sum up, the highlights in the outcome emphasize the importance of conducting the study of improved flow characteristics in nanofluids compared to common base fluids.

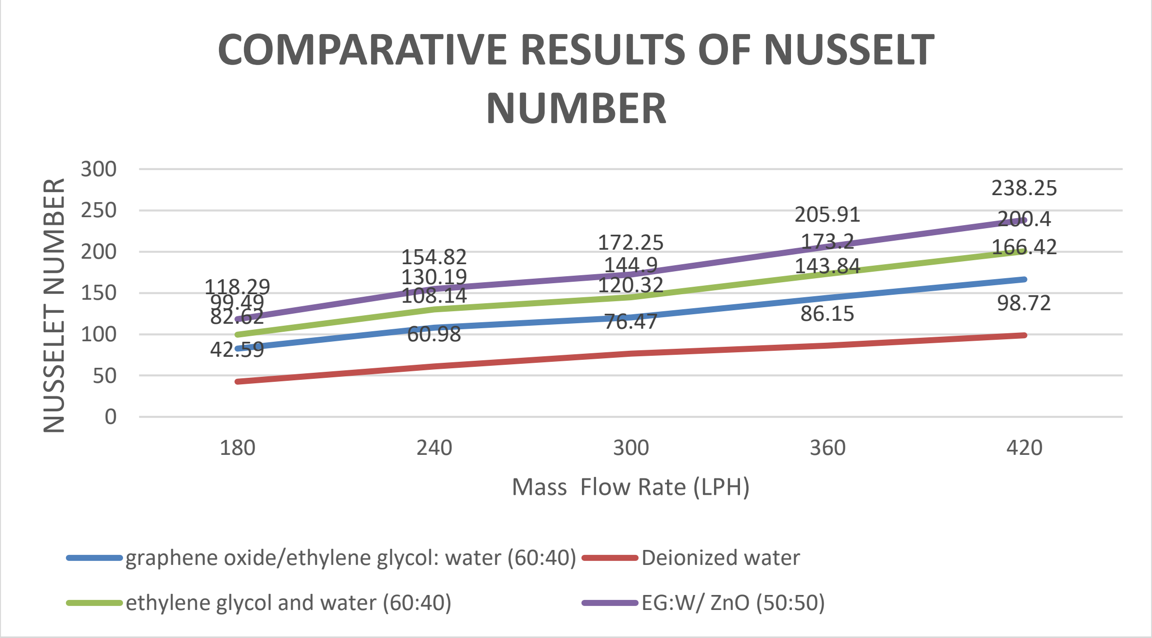

Figure 7: Comparative results of Nusselt number at different flow rate

The experimental results of the Nusselt number in a different range of flow rates from 180-420 LPH for various working fluids have been presented in Figure 5.60. It can easily be seen that the increase in the Nusselt number with elevated mass flow rates is true for all types of fluids. This gives a direct idea that heat transfer flows continue to be enhanced with the increase in convective flow. Among the examined working fluids, EG:W/ZnO (50:50) nanofluid shows a higher Nusselt number at all flow rates compared to others, with the best thermal conductivity and heat transfer enhancements. Again, the graphene oxide/ethylene glycol-water (60:40) mixture ensured a considerable improvement over the base fluid. Ethylene glycol and water (60:40) shows a moderate performance, and deionized water presents the worst Nusselt number values consistently.

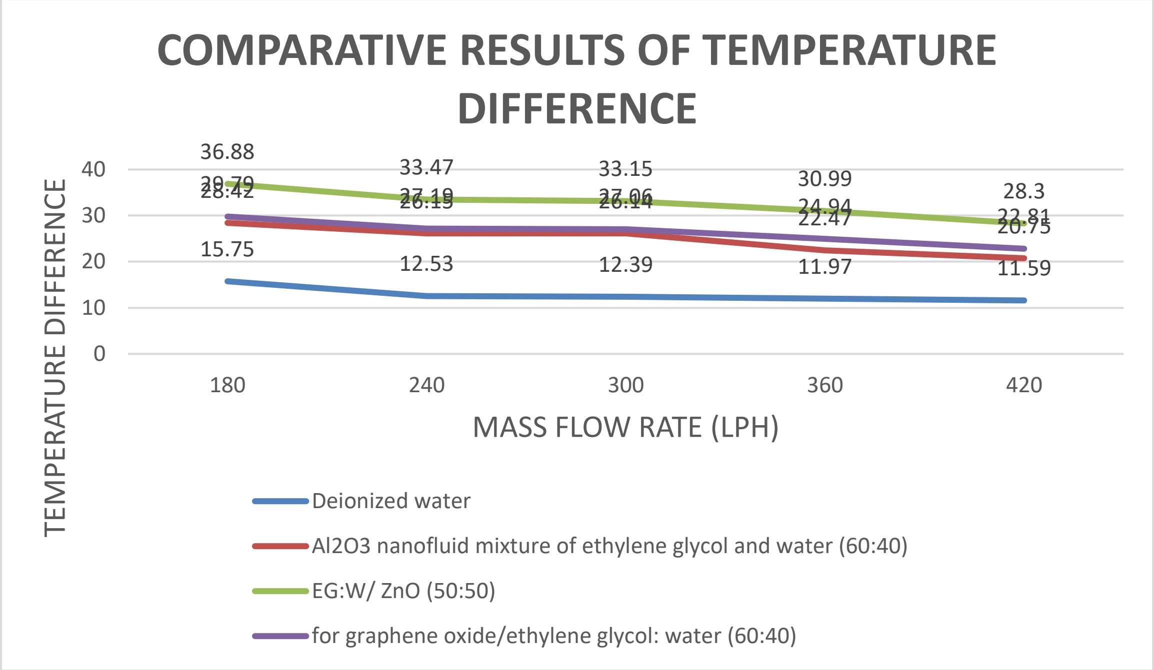

Figure 8: Comparative results of Temperature difference at different flow rate

Temperature difference between various flow ranges is shown in Figure 8 for different nanofluids. It can be observed that when flow is increased, the temperature difference reduced steadily, irrespective of the fluid used. Clean water was the fluid with the smallest temperature difference although it extends over combination flow rates, and this loss of heat transfer is from poorly performing heat transfer enhancement. However, in comparison to the other fluids, the best enhancements are exhibited with EG:W/ZnO (50: 50) nanofluids. Other nanofluids, such as Al_2O_3 and graphene oxide-water/ethylene glycol mixtures, show heat transfer performances that are superior to deionized water but slightly lesser than ZnO-based nanofluids.

VI. Conclusion

This study involved a comprehensive mathematical and Computational Fluid Dynamics (CFD) analyses in predicting the thermal response of an automotive radiator dealing with different coolants available at mass flow rates ranging from 180 LPH to 420 LPH. The three-dimensional CAD model of the radiator was built on ANSYS Workbench and analyzed under steady-state, pressure-based conditions using the RNG k–ε turbulence model with standard wall functions. The analysis included the Energy equation to study the temperature distribution, the heat transfer rate, heat transfer coefficient, Reynolds number, and Nusselt number for deionized water, EG:W/Al_2O_3 (60:40), EG:W/ZnO (50:50), and EG:W/graphene oxide (60:40) nanofluids. To reach a maximum enhancement in heat transfer rate, increasing the heat transfer nature of 76.79% over deionized water while contributing to a proper solution of 9499.47 W heat transferation and 29,456.91 W/m²·K heat transfer coefficient at 420 LPH, the overall improvement is nearly doubled. The nanofluid of graphene oxide has a much better subsequent result from 9653.05 W heat transfer rate to 30,506.64 W/m²·K heat transfer coefficient at 420 LPH. The 50:50 ZnO nanofluid imbibed the highest thermal performance among all coolants, attaining the peak heat transfer value of 13,592.17 W, 56,221.75 W/m²K heat transfer coefficient, and 238.22 Nusselt number at 420 LPH flow rate. Nanofluids in general contributed appreciably to convective heat transfer and radiator efficiency, with ZnO nanofluid in specific for being hailed as the most effective coolant for enhanced automotive radiator performance.

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