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Enhancement of the heat transfer in radiator with louvered fin by using Graphene-based hybrid nanofluids

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Abstract. Newly developed hybrid nanofluids can enhance heat transfer performance of various automotive appliances. Improved thermophysical properties of this hybrid nanoparticles when used as coolants will enhance the effectiveness of the car radiators with improved engine cooling system. The present study involves the simulation-based analysis of thermal enhancement of Graphene based Hybrid Nanofluids in a Car radiator. System analysis is performed considering single tube component in the radiator for pattern development. CFD analysis is conducted using ANSYS FLUENT module. Graphene/Crystal Nanocellulose hybrid (Graphene + CNC) nanoparticles are suspended in water & ethylene glycol base fluids (40:60) at 0.01%, 0.05%, 0.1% & 0.2 % volume concentration considering at 3-7 LPM inlet mass flow rate. The effect of various volume concentration, inlet temperature and flow rate on Pressure, Enthalpy, Entropy, Heat transfer coefficient, and Heat transfer rate has been examined by simulation. The results indicate that when using a Louvered fin in a radiator, Maximum enhancement of 60% in heat transfer rate, 53% increase of heat transfer coefficient, 65% increase in pressure are achieved for Graphene with CNC hybrid nanofluids when compared with Graphene based nanofluids. Using this type of hybrid coolants along with louvered fin in radiator can significantly improve the heat transfer performance of radiators.

Keyword: Graphene, Crystal Nano Cellulose (CNC), Hybrid nanofluids, CFD analysis, Heat transfer, Radiator tube

1. Introduction

In current times, vast study has been concentrated on nanofluids having a huge ability for application of heat transfer in a vehicle radiator engine coolant. The particles (metals or metal oxides) suspended in the base fluid with less than 100nm size having higher thermal properties, low concentration with high surface area, corrosion resistant improve the thermal conductivity and heat transfer performance of the radiator. The considerable rise in nanofluids thermal properties has invited scientific consideration in recent years. Nanofluids with smaller size and thermal properties are applied in the radiator to improve the vehicles fuel consumption and better design. Radiator can be designed in a much smaller size and have high heat transfer performance. Conventionally used heat transfer fluids are water, water and ethylene glycol mixture. The laminar & turbulent flow of convective heat transfer nanofluids are



experimentally investigated by various authors to predict the thermo-physical properties of the nanofluids. Several investigations are carried out at different mass/volume concentrations to predict the heat transfer coefficients and dynamics of the fluids flowing.

Significant increase in the convective heat transfer of the copper oxide and alumina nanofluid was studied by Vajjha, Das [1] in flat tube of the radiator system. Another set of experiments Leong, Saidur [2] are carried out with copper nanoparticles and concluded that for effective heat transfer application there is a need for higher concentration of the nanoparticles in base fluids. Experiments were carried by pure water with silicon oxide nanoparticles at different temperatures in a horizontal tube by Ferrouillat, Bontemps [3]. Graphene based nanofluids are used by Sarkar, Ghosh [4] to improve the heat transfer performance and pressure drop of the system. High thermal conductivity and thermal stability is the risen attraction in recent research. The thermal conductivity of the graphene nanosheets has been increased at low level temperatures in the study of Sen Gupta, Manoj Siva [5] which is essential to transfer the heat easily. Ahammed, Asirvatham [6] conducted experimental investigations of graphene nanofluid and stated the thermal conductivity enhanced with 37.2% at 50°C. Aravind and Ramaprabhu [7] conducted experiments on thermal conductivity and heat transfer coefficient of graphene and MWCNT and observed there is an increase in 10.5% and 193% improvement. using CFD model developed expected laminar flow heat flux inside cylindrical cross segment tubes. Moraveji, Darabi [8] Used 1%,2%,3% concentrations used nanoparticles size of 45nm and 150nm in single phase simulation. The outcome is 10% higher than experiment value and found that with increase of nanoparticles concentration heat transfer increased.

CFD model developed by Akbarinia and Behzadmehr [9] for Single and Two phase. Obtained results are much nearer to experimental data for two phases rather single-phase approach. Thermal field values are different but similar flow is observed for single- and two-phase approach. Effect of CuO nanofluids is studied by Sharma, Kumar [10] using flat tube. Heat transfer coefficient obtained is 5.1 and increased by 14% compared with water as base fluid while adding 0.1 - 0.5 % vol of CuO nanoparticles. CuO nanofluid performance is also studied by Kumar, Sokhal [11] in 90 flat tube by using 0.1 to 0.4 % vol concentration and found 7-19% increase of heat transfer coefficient than the traditional flat straight tube. Bharadwaja, Ka [12] modeled automobile radiator using siemens NX and CFD analysis has been performed considering only small part of the radiator and defined that there is an increase in effectiveness while using nanofluid coolants and using this carboxyl hybrid nanofluids radiator size can be significantly downsized. Bharadwaj, Mogeraya [13] also studied the hybrid nanofluids behavior in a radiator using CFD analysis for determining the effect of heat transfer performance. Graphene oxide and Carboxyl graphene are used as hybrid nanofluids and results proved that using hybrid nanofluid in radiator the heat transfer performance significantly increased but also more pumping power was required due to friction factor. Using proper concentration, this combination provides better yield effectiveness in an automotive radiator. Pendyala, Ilyas [14] performed CFD analysis using Carbon Nano Tubes and Graphite in a distributor transformer and confirmed that using these nanoparticles the thermal heat transfer performance has improved significantly. Hybrid nanofluids containing platinum and graphene nanoplatelets are used in twisted microchannel by Bahiraei and Mazaheri [15] in their research and studied that higher heat transfer, 1.5x energy efficiency and better flow is observed in twisted microchannel when using hybrid nanofluids.

Hybrid nanofluid containing silver and graphene (Ag/HEG) is used by Zainal, Tan [16] and performed CFD simulation using Ansys fluent in a turbulent circular pipe at 0.1 to 0.9% various volumetric concentrations and results showed that with increase of volume concentrations the heat transfer coefficient and Nusselt number values of Hybrid nanofluid decreased. Along with these studies and few reviews available there is a scope of future work in hybrid nanofluids for better heat transfer capabilities. So, the main objective of the paper is to study the heat transfer performance of the mono and hybrid nanofluid. The heat transfer characteristics of the nanofluids in a turbulent flow conditions are discussed with the CFD simulation. The novelty of the study is to compare the mono and hybrid nanofluid characteristics in the single tube of a car radiator to find the percentage enhancements and heat transfer coefficient estimations along with enthalpy, entropy, total heat transfer rate and Reynolds

number. The CFD simulation is carried out using the Graphene and Graphene +CNC (Crystal Nano Cellulose) nanoparticles at different volume concentrations and flow rates. Comparative study has been made with mono and hybrid nanofluid properties and concluded with better nanoparticles at particular concentration & flow rate using ANSYS FLUENT®. The radiator with lowered strip inserted in the tube is represented in Figure 1

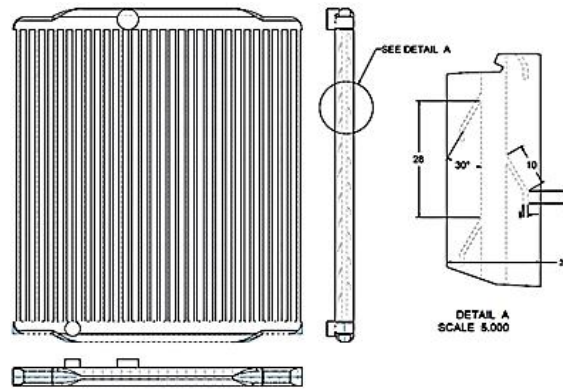


Figure 1. The Lowered strip and radiator details.

2. Mathematical modelling & Governing equations

Nanofluids density is measured based on the following equations (1). 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 [17].

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

The specific heat of the nanofluid is measured using equation (2) below. It's a purpose of concentration and base fluid specific heat [18].

$$C_{p,nf} = \frac{\phi(\rho C_p)_s + (1 - \phi)(\rho C_p)_f}{\rho_{nf}} \quad (2)$$

Thermal conductivity has an important role in heat transfer applications. Many researchers focused to improve the thermal conductivity of the fluid experimentally and numerically by many case studies. Maxwell equation [19] as shown in equation (3) is utilized by many researchers to find the thermal conductivity with different volume ratio.

$$k_{eff} = \frac{k_{np} + 2k_{bf} + 2(k_p - k_b)\phi}{k_{np} + 2k_{bf} - (k_{np} - k_{bf})\phi} K_{bf} \quad (3)$$

The dynamic viscosity is calculated by the Einstein [20] proposed in equation (4). Using the flow across one particle, the viscosity of diluted suspension of small particles is calculated. Volume fraction 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 [21].

$$\mu_{nf} = \mu(1 + 2.5\phi) \quad (4)$$

The Nusselt number of the nanofluids is given by the equation (5) where h is the convection heat transfer coefficient and T represents the temperature, m stands for the mass flow rate of the nanofluid.

$$Nu = h * d / k = m * Cp * (T_{wall} - T_{inlet}) / a * (T_{bulk} - T_{wall}) \quad (5)$$

The effectiveness of the nanofluids is given by the equation (6).

$$\varepsilon = (T_1 - T_2) / (T_1 - T_3) \quad (6)$$

2.1. Boundary conditions

The Radiator model is developed in CREO, a 3D modelling software by using various tools like Sketch, extrude, pattern and assembly. Dimensions of the Radiator & Louvered strip [22] details are mentioned in Table 1. Once the radiator tube design is completed as shown in Figure 1, the louvered strip is inserted into the radiator. The thermophysical properties of considered base fluid and nanoparticles are listed in Table 2. Using the equations (1) to (4) Thermo physical properties of nanofluids at different concentrations are evaluated and values are listed below in Table 3.

Table 1. The lowered strip and radiator details.

Louvered Strip Details	Radiator
Angle of the strip = 30°	Length of Radiator tube = 350mm
Thickness = 2mm	Thickness of Radiator = 4mm
Length = 10mm	Width of the Radiator tube = 22mm
Pitch = 30mm	
Number of Tubes = 01	

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 = 348K
- Volume concentrations of nanofluids = 0.01, 0.05, 0.1 and 0.2%

Table 2. Thermo-physical properties of Base fluids and Nanoparticles.

	Density (kg/m ³)	Specific heat (J/kg-k)	Thermal conductivity (W/m-k)	Viscosity (kg/ms)
Water	1000	4182	0.6	0.001002
Ethylene Glycol	1100	2430	0.2577	0.0161
Graphene	2267	75	4000	Nil
CNC	1050	2450.324	0.31	0.00495

Table 3. Thermo-physical properties of Nanofluids at different concentrations.

Volume concentration	Nano particles	Density (kg/m ³)	Specific Heat (J/kg-k)	Thermal conductivity(W/m-k)	Viscosity (kg/ms)
0.01	G+H2O+EG	1052.27	1040.267	0.4757	0.02426
	G+CNC+EG	1105.585	2412.4886	1.03	0.06482
0.05	G+H2O+EG	1101.35	1041.39	0.5346	0.0272
	G+CNC+EG	1127.925	2344.17736	1.15787	0.07499
0.1	G+H2O+EG	1162.7	1042.9312	0.6156	0.03132
	G+CNC+EG	1155.85	2262.502	1.3333	0.089466
0.2	G+H2O+EG	1285.4	1046.5756	0.8079	0.04096
	G+CNC+EG	1211.7	2110.444	1.74985	0.125876

3. CFD Governing equations

Computational fluid dynamics (CFD) is the assessment of techniques including liquid flow, heat transfer and related phenomena such as natural reactions by means of computer-based simulation. This technique is influential and has a wide range of engineering and non-industrial application zones such as aerodynamics, turbomachinery, power plant, hydrodynamics, electrical and electronic engineering, chemical procedure engineering, the civil construction areas, marine and environmental engineering, hydrology and oceanology, weather prediction and biomedical engineering. The foundation of CFD is the essential governing equations of fluid dynamics (i)The Continuity, (ii) Momentum, and (iii) Energy equations. These are the mathematical statements of the fundamental physical principles upon which all of fluid dynamics is based on Mass, Force and Energy conservation [23, 24].

CFD approach usages the numerical calculation by solving mass, momentum and energy conservation governing equations (7) to (11) as shown below [25-30].

Continuity equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho U) = 0 \quad (7)$$

Momentum equation:

$$\frac{\partial}{\partial t}(\rho U) + \nabla \cdot (\rho U U) = -\nabla p + \nabla \cdot \tau + \rho g \quad (8)$$

Energy equation:

$$\frac{\partial}{\partial t}(\rho h) + \nabla \cdot (\rho U C_p T) = \nabla \cdot (k \nabla T) \quad (9)$$

where,

$$\nabla = i \frac{\partial}{\partial x} + j \frac{\partial}{\partial y} + k \frac{\partial}{\partial z} \quad (10)$$

The moment equation for the steady flow:

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = \left[\frac{1}{\rho} \right] \frac{\partial \tau_{xy}}{\partial y} \quad (11)$$

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. The k -epsilon model is given by equation (12) and the dissipation, ϵ is given by equation (13).

$$\frac{\partial (\rho k)}{\partial t} + \frac{\partial (\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + P_k + P_b - \sigma \epsilon - Y_M + S_k \quad (12)$$

$$\frac{\partial (\rho \epsilon)}{\partial t} + \frac{\partial (\rho \epsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon} \right) \frac{\partial \epsilon}{\partial x_j} \right] + C_1 \epsilon \frac{\epsilon}{k} (P_k + C_3 \epsilon P_b) - \frac{C_2 \epsilon \rho \epsilon^2}{k + S_\epsilon} \quad (13)$$

4. Modelling and Procedure

4.1. Modelling

The radiator tube was developed in 3D modelling Creo Parametric software. Extrude tool is used to develop the tube by giving the thickness, width, and length of the radiator along with the louvered fin. Pattern tool was used to fix the number of louvered fins. The direction of the fluid flow is considered as top to bottom during the simulation. The final model is completed in this 3D modelling software and converted into STEP Format and then imported to CFD. The detailed view of Radiator tube with louvered fin is shown in below Figure 2. The cross-sectional view of single radiator tube with louvered fin is shown in below Figure 3 and dimensions are presented in the Table 1.

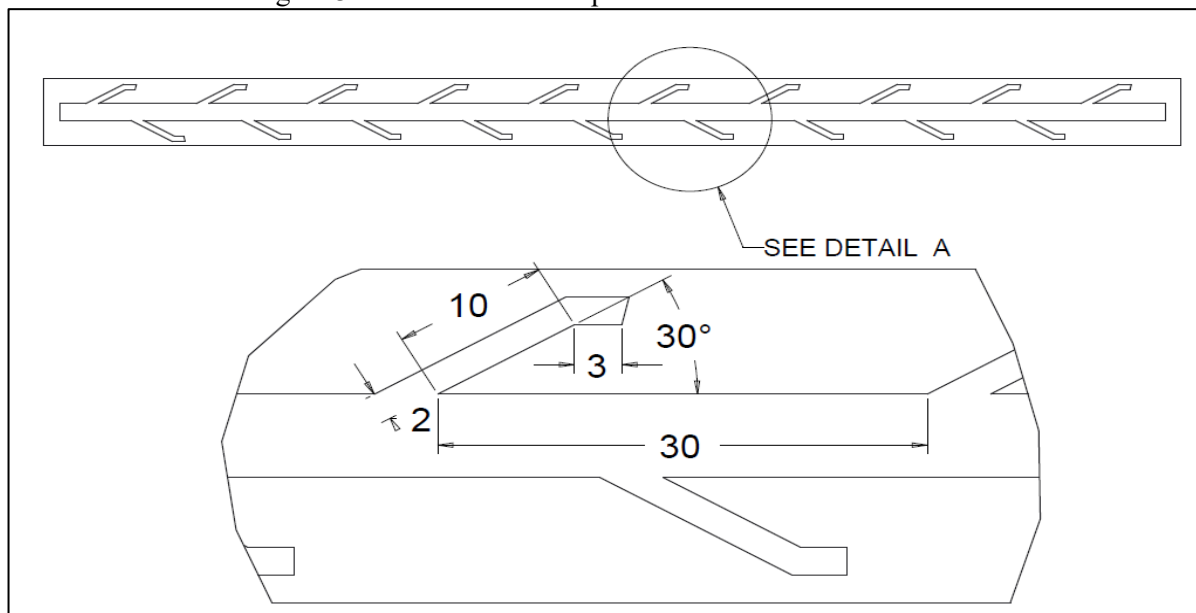


Figure 2. Detail view of radiator tube with louvered fin.

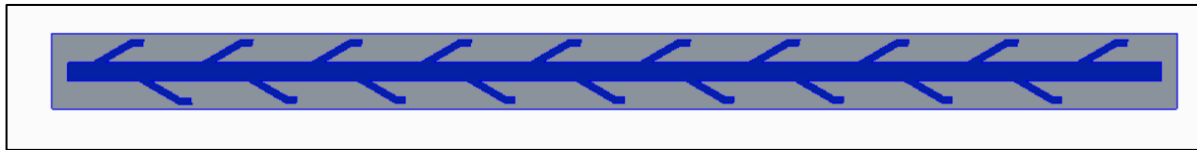


Figure 3. Cross-sectional view of the single radiator tube with louvered fin.

4.2. CFD Simulation

The radiator tube with the louvered fin is imported from the Creo parametric software with the STEP format. The model was undergone with the hexagonal fine mesh. The number of elements and nodes are divided automatically in the software. Total of 328,456 nodes and 282,365 elements were developed during the meshing process as shown in below Figure 4. Energy equation and the turbulence flow is activated. The properties of the hybrid nanofluids are added and applied according to requirement. The inlet flow range is considered as 3,4,5,6 and 7LPM with the temperature of 348K.

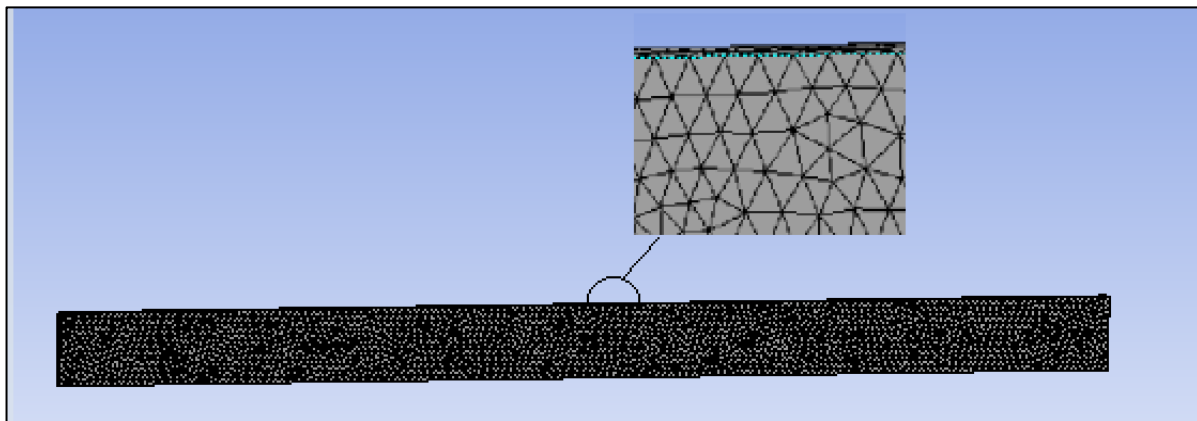


Figure 4. Meshed body.

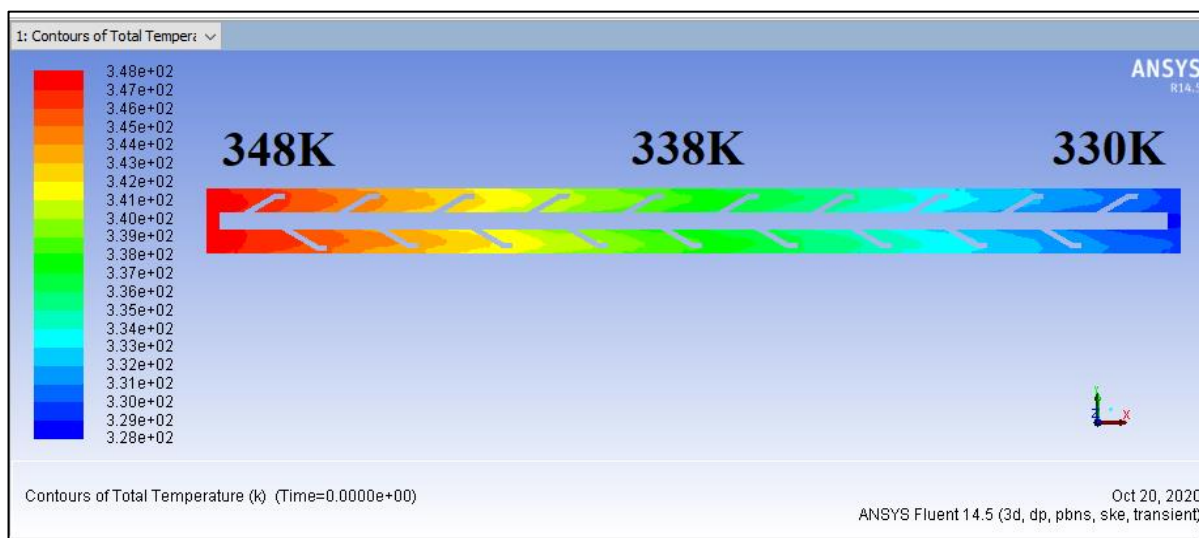


Figure 5. Total temperature of the radiator tube with Louvered Fin.

From the Figure 5 above, it can be observed that the temperature from the inlet point is very high indicated with a red color. The hot fluid is allowed to pass through the tube and blue color from the other end indicates that the hot fluid temperature is decreased. Similar observations of decreasing temperatures are identified for pressure and enthalpy and are shown in Figure 6 and Figure 7 below.

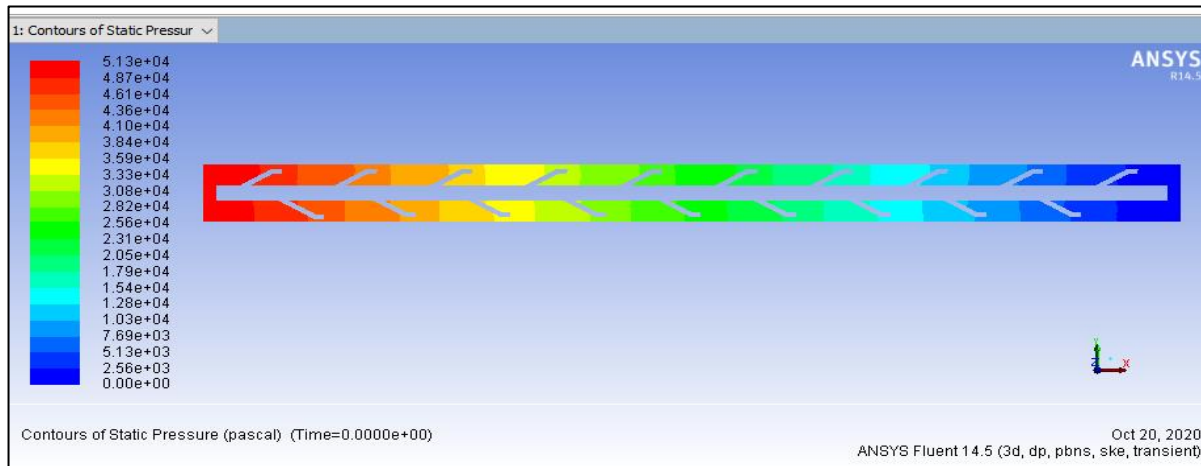


Figure 6. Pressure of the Radiator tube with louvered fin.

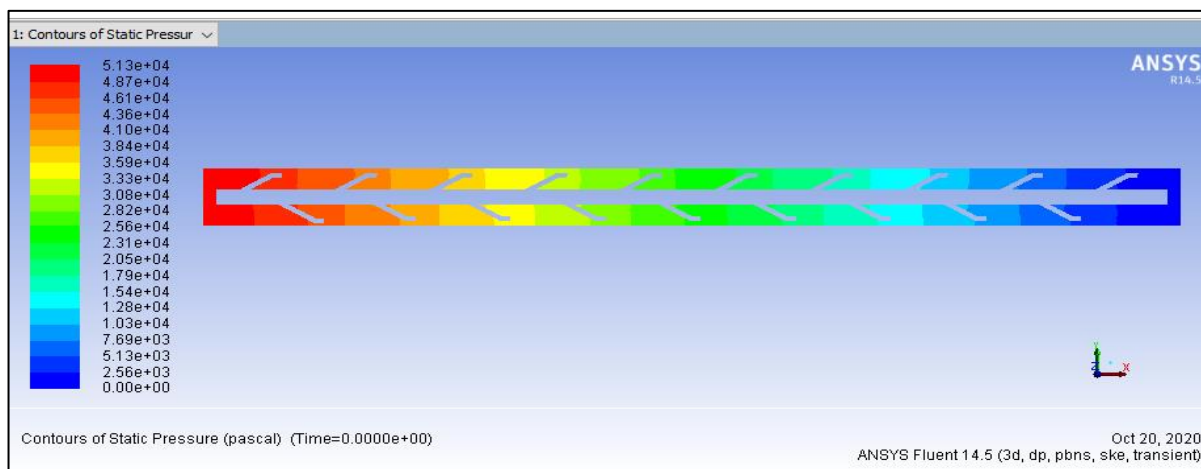


Figure 7. Enthalpy of the radiator tube with louvered fin.

5. Results and Discussion

Results are derived from CFD analysis with respect to different mass flow rates and fixed temperature. From the Figure 8., We observed that the pressure is gradually increasing from 3 LPM to 7 LPM with all volume concentrations (0.01%,0.05%,0.1% and 0.2%) of the nanofluids. The highest pressure was observed for the 0.2 volume concentration at 7 LPM. From the Figure 8(a), it was observed that 2.6 – 9.7% is enhancement from 0.01% to 0.2 % vol conc. Huge increment of pressure was absorbed in Figure 8(b). because of utilizing Graphene+ CNC hybrid nanofluid. Due to thermophysical properties of this hybrid nanofluid, the pressure increase was observed. It was observed with the minimum enhancement at 3 LPM flow rate with 0.01% volume concentration of the nanofluid and maximum at 0.2% volume concentration with 7LPM. The rate of enhancement was observed between 9.33 to 21.39% observed in Figure 8(b). It was noted that almost 55% to 65% enhancement was observed when Graphene+ CNC

based hybrid nanofluid as compared with Graphene based nanofluids. This high enhancement happened due to its thermophysical properties of the hybrid nano fluid.

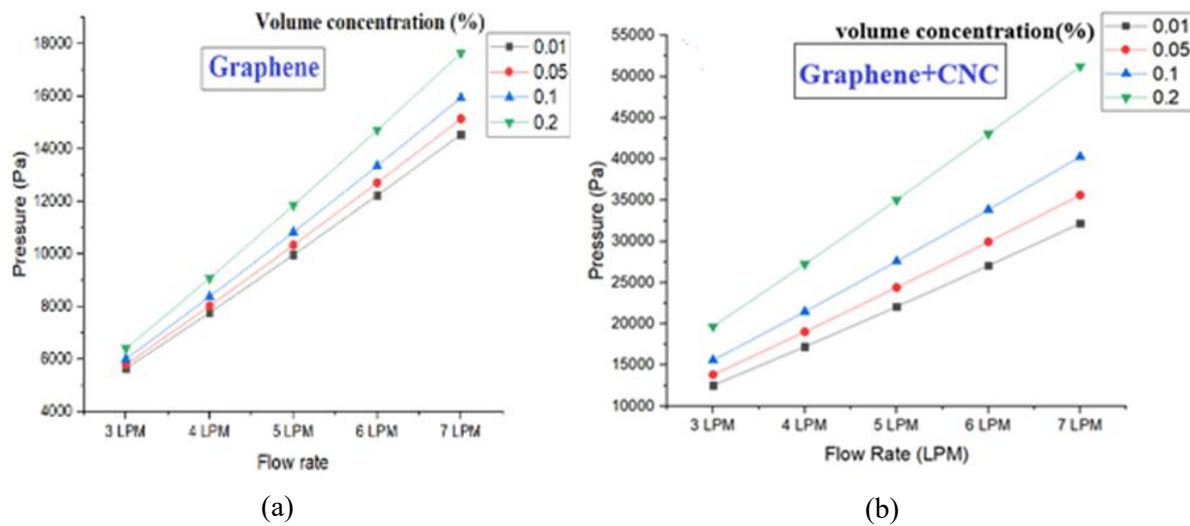


Figure 8. Pressure (Pa) for different flow rates a) Graphene b) Hybrid Graphene nanofluid.

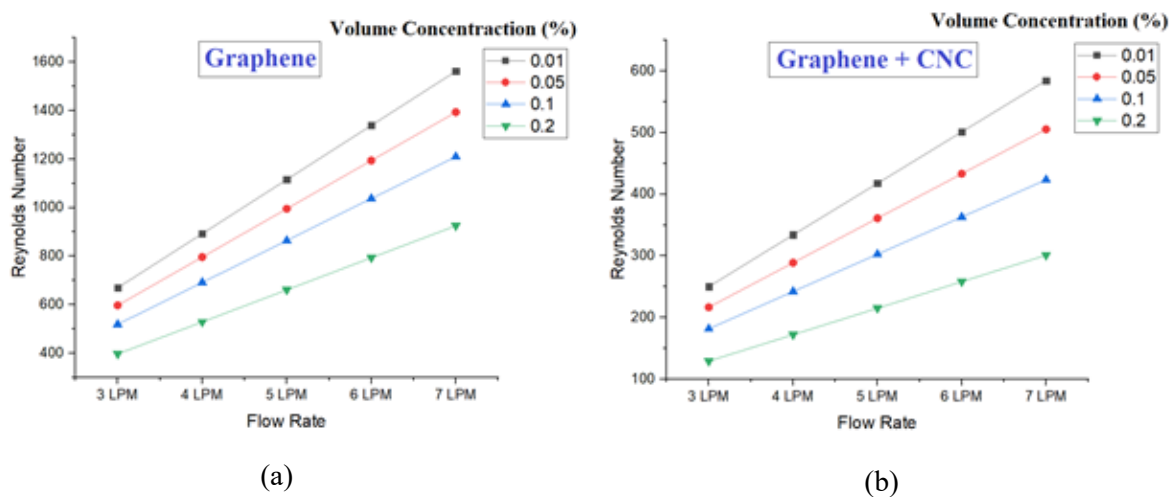


Figure 9. Reynolds number for different flow rates a) Graphene b) Graphene+ CNC hybrid nanofluid.

The flow rate of the fluid is directly proportional to the Reynolds number and also it is directly proportional to the velocity of the fluid. If the density of the nanofluid (if the volume fraction increases) is increased, then Reynolds number is decreasing. In the Figure 9 it is observed that as the flow rate is increased from 3 LPM – 7 LPM, the Reynolds number value is also increased. Highest Reynolds number observed from both Figure 9 (a) & (b) is at 0.01 % at 7LPM. As the volumetric concentration of the hybrid nanofluid increases, correspondingly the Reynolds number was decreased. This is due to the increase in viscosity of the nanofluid. When compare to 0.01% and 0.2% volume concentration in Graphene nanofluid, nearly 68.83% enhancement observed in 0.01 volume concentration due to low

viscosity of the nanofluid. In Figure 9 (b), 93% enhancement was observed for 0.01% volume concentration when compared with 0.2% volume concentration. 167 to 202% enhancement of Reynolds number is obtained for the Graphene nanofluids when compared with Graphene+ CNC based hybrid nanofluid.

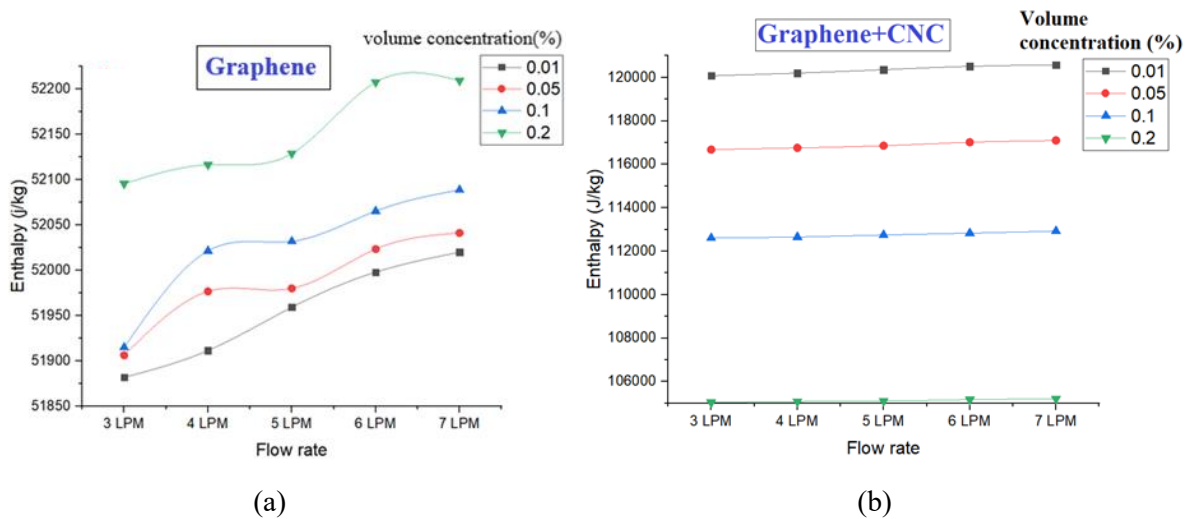


Figure 10. Enthalpy (J/kg) for different flow rates a) Graphene b) Graphene+ CNC nanofluid.

In the Figure 10(a), The enthalpy is increased immensely as the flow rate increased from 3LPM to 7LPM at volume concentration of 0.01%,0.05%,0.1% and 0.2% because the specific heat of the graphene nanofluid is increasing. The maximum of 0.4% enhanced enthalpy observed when graphene hybrid nanofluid was used when compared with 0.2% with 0.01% of volume concentration of the nanofluid. In the Figure 10(b), the specific heat of the fluid is decreasing when the concentration is increased. So, the enthalpy is very low for the 0.2% of volume concentration when compare with 0.01%. In this condition, value of the enthalpy is enhanced in Graphene hybrid nanofluid and also it raised up to 56% when compared with Graphene nanofluid.

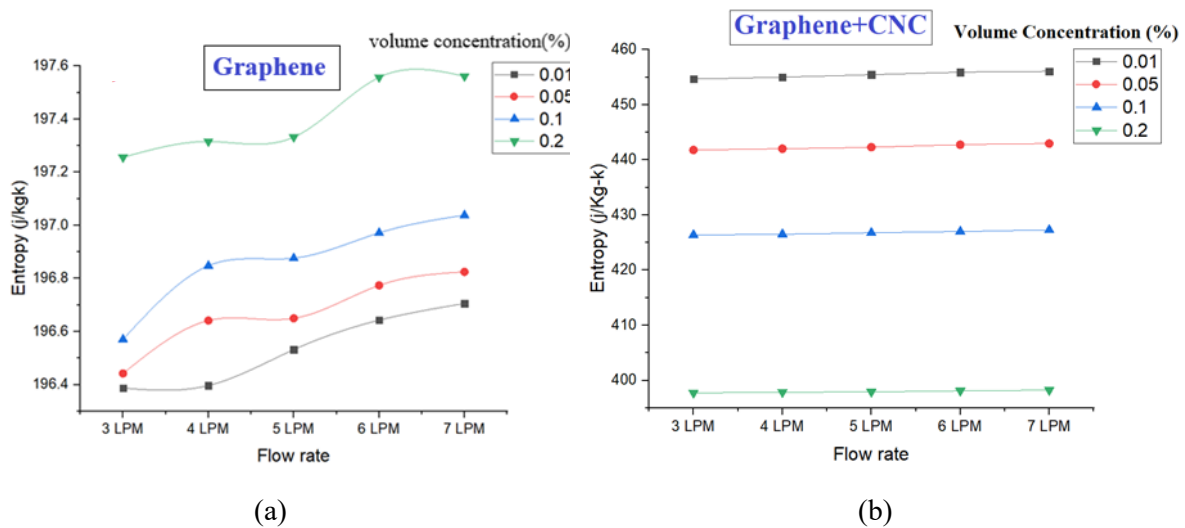


Figure 11. Entropy (J/kg-K) for different flow rates a) Graphene b) Graphene+ CNC nanofluid.

Entropy in Figure 11 is the amount of a system's thermal energy per unit temperature. In this work, higher temperature reduction is observed in the Graphene+ CNC based hybrid nanofluid than Graphene based nanofluids because of its high thermal conductivity. In the Figure 11 (b), the entropy is very low for the 0.2% of volume concentration when compare with 0.01%. In this condition, value of the entropy is enhanced when compared with Graphene nanofluid Figure 11 (a) and it is raised up to 50-56% in entropy value for Graphene hybrid nanofluid.

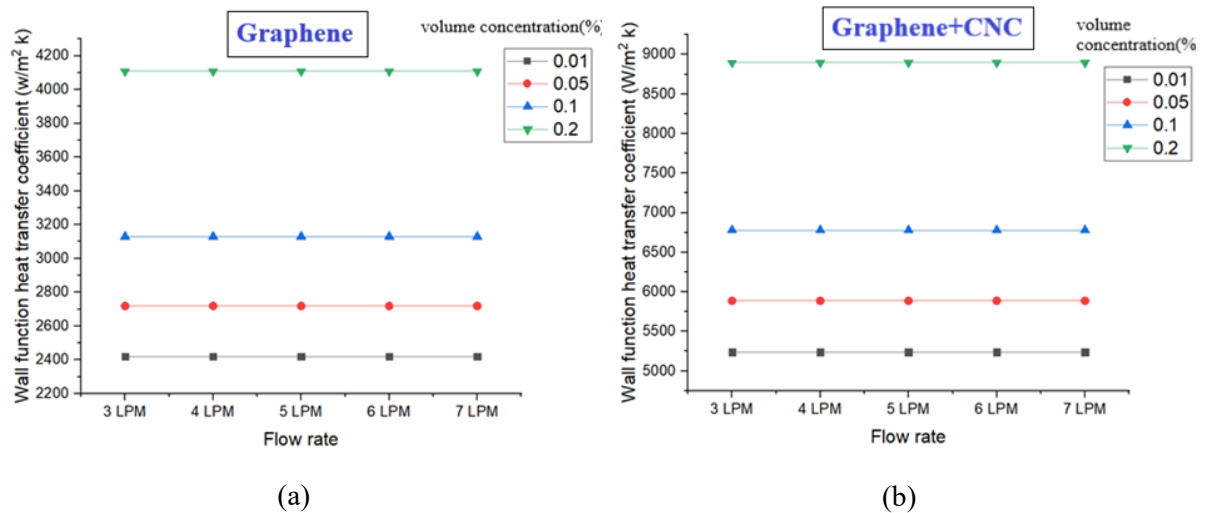


Figure 12. Wall Function Heat Transfer Rate (W/m²K) for different flow rates a) Graphene b) Graphene+ CNC nanofluid.

The thermal conductivity of the Graphene+ CNC based hybrid nanofluid have high value when compared with graphene-based nanofluid. Based on this, we can say that Graphene+ CNC based hybrid nanofluid have high heat transfer capacity. Same observation was found in the results. From the Figure 12 (a), the heat transfer coefficient is gradually increased when the concentration of the nanofluids was increased. Heat transfer coefficient is enhanced from 11 to 41.11% when graphene-based nanofluid was used. In Figure 12 (b) Same observations are identified for the Graphene+ CNC based hybrid nanofluid utilization. Heat transfer coefficient is 53.83% higher for the Graphene+ CNC based hybrid nanofluid (having high thermal conductivity (Table 3) when compared with Graphene-based nanofluid.

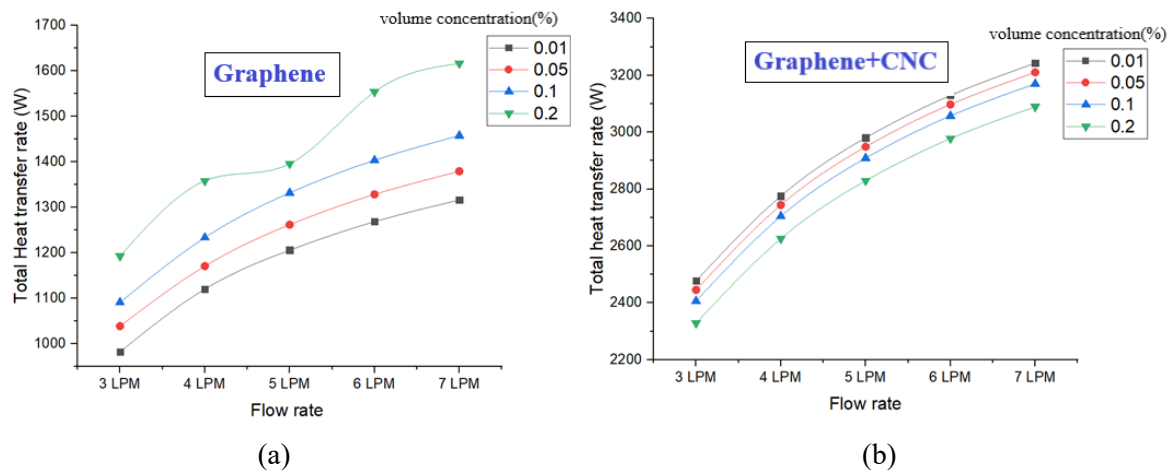


Figure 13. Total Heat Transfer Rate (W) for different flow rates a) Graphene b) Graphene+ CNC nanofluid.

The heat transfer is always dependent on the thermal conductivity of the fluid. In this work, Graphene+ CNC based hybrid nanofluid have high thermal conductivity at 0.2 % volume concentration. As the flow rate is increased concurrently it is observed that the heat transfer rate is also increased and shown in the Figure 13. In Figure 13 (a), the rate of heat transfer is enhanced from 5.43% to 18.58%. 18.58% enhanced for 0.2% when compared with 0.01 of volume concentration at 7LPM and 17.65 % at 3LPM. In Figure 13 (b), 1 to 3.34% enhancement observed for different volume concentration when Graphene+ CNC nanofluid was utilized. The comparison between Graphene+ CNC based hybrid nanofluid and Graphene based hybrid nanofluid was stated that more than 60% enhancement of heat transfer rate is observed in Graphene+ CNC based hybrid nanofluid utilization.

6. Conclusions

The present study involves the simulation-based analysis of thermal enhancement of Graphene based Hybrid Nanofluids in a Car radiator. System analysis is performed considering single tube component in the radiator for pattern development. CFD analysis is conducted using ANSYS FLUENT module. Graphene/Crystal Nanocellulose hybrid (Graphene + CNC) nanoparticles are suspended in water & ethylene glycol base fluids (40:60) at 0.01%,0.05%,0.1% & 0.2 % volume concentration considering at 3-7 LPM inlet mass flow rate. The effect of various volume concentration, inlet temperature and flow rate on pressure, heat transfer coefficient and heat transfer rate has been examined by simulation.

- More than 60% enhancement of heat transfer rate is observed in Graphene+ CNC based hybrid nanofluid when compared with Graphene based nanofluid.
- 53.83% of heat transfer coefficient enhancement is observed for Graphene+ CNC based hybrid nanofluid when compared with Graphene based nanofluid.
- Entropy is enhanced from 50.01% to 56.0% for the Graphene+ CNC hybrid nanofluid as compared with Graphene based nanofluid.
- 56% Enthalpy enhancement is observed for Graphene+ CNC hybrid nanofluids as compared with Graphene based nanofluid.
- Reynolds number has an increased value of 167-202% for 0.01 %volume concentration for Graphene nanofluid at 7 LPM flow rate.
- Pressure enhanced from 55% to 65% for Graphene+ CNC based hybrid nanofluid as compared with Graphene based nanofluids. This high enhancement happened due to its thermophysical properties of the hybrid nano fluid.

The above results indicate that Graphene+ CNC based hybrid nanofluids will enhance the performance of an automobile radiator when compared with base fluid and Graphene nanofluid.

Acknowledgments

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