CFD analysis of heat transfer performance of graphene based hybrid nanofluid in radiators

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Abstract. For improved performance of an automobile engine, cooling systems are one of the critical systems that need attention. With increased capacity to carry away large amounts of wasted heat, performance of an engine is increased. Current research on Nano-fluids suggests that they offer higher heat transfer rate compared to that of conventional coolants. Hence this project seeks to investigate the use of hybrid-nanofluids in radiators so as to increase its heat transfer performance. Carboxyl Graphene and Graphene Oxide based nanoparticles were selected due to the very high thermal conductivity of Graphene. System Analysis of the radiator was performed by considering a small part of the whole automobile radiator modelled using SIEMENS NX. CFD analysis was conducted using ANSYS FLUENT® for the nanofluid defined and the increase in effectiveness was compared to that of conventional coolants. Usage of such nanofluids for a fixed cooling requirement in the future can lead to significant downsizing of the radiator.

1. Introduction

With increase in demand for high power and high performance in automobiles, there is a renewed focus on developing better cooling systems and coolants. Today with the advancement of nanotechnology, the new generation of heat transfer fluids called, “Nano-fluids” have been developed and it has been found that these fluids offer higher heat transfer rate compared to that of conventional coolants as shown initially by Choi [1]. Current research shows that using two types of nanoparticles in the nanofluid to form a Hybrid-Nanofluid yields better results. According to Sarkar et al. [2] the idea of using hybrid nanofluids is supported by an aim to improve heat transfer and pressure drop, by trade-off between pros and cons of individual suspension. Suresh et al. [3] has found a maximum enhancement of 12.11 percent in thermal conductivity of a Al₂O₃-Cu/water hybrid nanofluid. The Al₂O₃-Cu particles were prepared from hydrogen reduction technique. The use of graphene based nanoparticles has also attracted a lot of attention due to the very high thermal conductivity of graphene particles. In Gupta et al. [4] enhancement of thermal conductivity of nanofluids containing graphene nanosheets was studied. The enhancement which was substantial even at lower temperatures could not be predicted by the classical Maxwell model. It also makes a very strong case for proposition of a hybrid model because possibly the mechanisms of heat transfer are a combination of percolation in

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CNT and Brownian motion, micro convection in metal oxides. Graphene and MWCNT’s have been used to prepare a hybrid nanofluid by Aravind et al. [5] and Enhancement of thermal conductivity of 10.5% and a staggering 193% enhancement of convective heat transfer coefficient for 0.02%-volume fraction and Re = 2000 were observed. A CFD modelling of MgO-water nanofluid in turbulent flow has been studied by Davarnejad et al.[6] In a Numerical Resizing study of CuO nanofluids in the flat tubes of a radiator by Elsebayet al.[7] analysis was done considering incompressible, laminar and single-phase flow. A Numerical study on turbulent forced convective heat transfer using TiO$_2$ nanofluids in an automotive cooling system can also be seen in Hussein et al.[8]. With the different combination of volumetric concentration of graphene nanofluid, NizaAhammed et al. [15] achieved 37.2% enhancement in thermal conductivity value with 1.5% concentrated nanofluid. However as there has not been much literature on using Carboxyl Graphene and Graphene Oxide nanoparticles in Hybrid-nanofluids, in this paper a CFD Analysis using Carboxyl Graphene and Graphene Oxide Hybrid-nanofluid in an automobile radiator using ANSYS FLUENT® is presented.

2. Mathematical Modelling of the Hybrid-Nanofluid

The mathematical modelling for different properties of the Hybrid-Nanofluid was done based on Sahoo et al.[9].

Thermal conductivity of the hybrid-nanofluid is given by

$$k_{hnf} = \frac{\phi_{np1} k_{np1} + \phi_{np2} k_{np2} + 2k_{bf} + 2(\phi_{np1} k_{np1} + \phi_{np2} k_{np2}) - 2\phi(k_{bf})}{\phi}$$

(1)

where $k_{hnf}, k_{bf}, k_{np1}, k_{np2}$ are the thermal conductivities of the hybrid nanofluid, base fluid, carboxyl graphene and graphene oxide, $\phi_{np1}, \phi_{np2}$ and $\phi$ are volume concentrations of carboxyl graphene, graphene oxide and the hybrid nanofluid. Heat transfer coefficient is expressed as

$$h_{hnf} = \frac{N_{u_{hnf}} k_{hnf}}{D_{hnf}}$$

(2)

where $h_{hnf}, D_{hnf}, N_{u_{hnf}}$ are the heat transfer coefficient, hydraulic diameter at the inlet of the nanofluid and Nusselt number for hybrid nanofluid respectively where $N_{u_{hnf}}$ has also been proposed by [9] as,

$$N_{u_{hnf}} = 0.2299(R_{e_{hnf}}^0.8 - 60)Pr_{hnf}^{0.4}(1 + 0.32178\phi^{0.64788})$$

which is a function of Reynolds number, Prandtl Number and concentration of nanoparticles. The same for base fluid taking into account friction factor, $f_f$ is given by,

$$N_{u_f} = \frac{\left(\frac{f_f}{2}\right) Re_f Pr_f}{1.07 + 12.7\left(\frac{f_f}{2}\right) Pr_f^{\frac{1}{3}} - 1}$$

(3)

The properties of nanoparticles for 0.8-1.6 nm Carboxyl Graphene produced through chemical vapour deposition and 0.8-2 nm thick Graphene Oxide Nanoparticles manufactured by Hummer’s method by United Nanotech Pvt. Ltd, India were used and are as shown in table 1.

| Table 1. Properties of the nanoparticles and base fluid used |
|-------------------------------------------------------------|
| Density $(kg/m^3)$ | Specific Heat $(J/kg-K)$ | Thermal Conductivity $(W/m-K)$ | Dynamic Viscosity $(Ns/m^2)$ |
| Carboxyl Graphene | 240 | 730 | 2800 | - |
| Graphene Oxide | 121 | 2100 | 2720 | - |
| Base Fluid (RO+EG at 50° C) | 1163 | 3445.75 | 0.6185 | 0.001805 |
3. CFD Theory and Equations
The CFD approach uses numerical methods to solve the governing equations for the specified geometry and boundary conditions. Single-phase flow was considered [10] for analysis using ANSYS FLUENT® 16.2 [11].

Continuity Equation:
\[
\frac{\partial}{\partial x_i} (\rho_{nf} U_i) = 0 \quad (4)
\]

Momentum Equations:
\[
\frac{\partial}{\partial x_i} (\rho_{nf} U_j U_i) = \frac{\partial p}{\partial x_j} + \frac{\partial}{\partial x_i} \left( \mu_{nf} \frac{\partial U_j}{\partial x_i} \right) \quad (5)
\]

Energy Equations:
\[
\frac{\partial}{\partial x_i} (\rho_{nf} C_{nf} U_j U_i) = \frac{\partial}{\partial x_i} \left( K_{nf} \frac{\partial T}{\partial x_i} \right) \quad (6)
\]

4. Modelling and Procedure

4.1. Modelling
A radiator from a Tata-Indica Car, which is widely used in India was considered and the specifications are as shown in table2

| Table 2. Specifications of the radiator used |
|---------------------------------------------|
| Parameter | Value       | Parameter                      | Value       |
|------------|-------------|--------------------------------|-------------|
| Length of the tube (L) | 23.56 mm | Fin Pitch | 0.7mm |
| Width of the tube(D) | 34.64 mm | Fin Thickness | 0.06mm |
| Thickness of the tube (d) | 23.76 mm | Fin Length | 21.54mm |
| Tube Pitch | 27.9 mm | Number of fins per tube | 435.4mm |
| Number of tubes | 37 | Number of rows of fins | 36 |

The model was generated using NX 11 and is shown in Figure 1 and Figure 2. However, to save time and computation the analysis was done by considering a typical element based on fin pitch and tube pitch of radiatoras shown in Figure 3. The model was meshed in ANSYS® Workbench. FLUENT® 16.2 was used for CFD analysis.

4.2. Mesh Independence Study
Meshes of varying element sizes were generated during meshing as shown in table 3. The coarse mesh had 2144005 elements, medium and fine meshes generated 2412218 and 2855211 elements respectively. The difference in fluid outlet temperatures from medium to fine type of mesh was found to be negligible. In order to save computational resources and time the medium mesh was selected and CFD analysis was carried out.
Figure 1. Model of the entire radiator generated using NX 11

Figure 2. Enlarged view of the radiator

Figure 3. The typical element considered for analysis

Table 3. Mesh independence study

| Mesh Type | Number of elements | Fluid Outlet Temperature (°C) |
|-----------|--------------------|------------------------------|
| Coarse    | 2144005            | 322.81836                    |
| Medium    | 2412218            | 322.81834                    |
| Fine      | 2855211            | 322.818342                   |

4.3. CFD Analysis

The Hybrid-Nanofluid is considered incompressible [7,12]. The flow is assumed to be laminar as in [7] and [10]. A single-phase fluid approach as shown by [13] is made use of. For the case of a viscous laminar model, the SIMPLE scheme was used. The nanofluid inlet is specified as a mass flow inlet corresponding to volume flow rates of 4, 5 and 6 LPM in the whole radiator at a temperature of 50°C which are typical values in an automobile radiator. The air inlet is specified as a velocity inlet with velocity of 1.5 m/s.
Table 4. Input conditions considered

| Parameters                        | Value                                      |
|-----------------------------------|--------------------------------------------|
| Nanoparticles                     | Carboxyl Graphene (CG) and Graphene Oxide (GO) |
| Volume Concentration              | 1 %, 2%, 3% of each CG and GO              |
| Mass Flow Rates (LPM)             | 4, 5, 6                                    |
| Inlet Fluid Temperature (K)       | 323.15                                     |
| Inlet Air Temperature (K)         | 298.15                                     |
| Inlet Air Velocity (m/s)          | 1.5                                        |

5. Results and discussions

5.1. Variation of fluid and air temperatures

Figure 4 shows the plot of temperature drop of the fluid along the length of the tube for a flow rate of 4 LPM. It can be seen that there is a temperature drop of 0.251 °C which when extrapolated to the whole length of the tube of the radiator turns out to be 10.93 °C. Figure 5, 6 and 7 show the contour plots of temperature along the region of air flow, at air inlet, air outlet respectively a flow rate of 4LPM with 2%CG and 2%GO nanoparticles. It can be seen that after absorbing heat from the fins the temperature of air at the inlet increases significantly.

Figure 4 Variation of nanofluid temperature along the length of the tube

Figure 5 Contour Plot of the temperature (in Kelvin) distribution along the region of air flow

Figure 6. Temperature (in Kelvin) distribution at air inlet

Figure 7. Temperature (in Kelvin) distribution at the air outlet
5.2. Effectiveness

The effectiveness of the radiator is calculated by using the formula, [14]

$$\epsilon = \frac{T_1 - T_2}{T_2 - T_3}$$ (7)

Where, $T_1$, $T_2$ and $T_3$ are the temperatures at the fluid inlet, fluid outlet and ambient air respectively.

Figure 8 shows the variation of effectiveness vs. concentrations of the hybrid nanofluid at different flow rates. Effectiveness increases gradually as the concentration of nanoparticles increase from 2%(1% CG & 1%GO) to 6%(3% CG & 3%GO) at a constant fluid flow rate. This is due to higher thermal conductivity of nanofluid as compared to that base-fluid. It can be seen that for a flow rate of 4 LPM a maximum increase of 10% in effectiveness upon addition of 3% Carboxyl Graphene and 3% Graphene Oxide was obtained as compared to the base fluid. However, as effectiveness depends on NTU, increase in convective heat transfer coefficient is less as compared to increase in flow rate of nanofluid. Hence Effectiveness decreases with increasing flow rates.

5.3. Friction factor

The friction factor, $f$ as mass flow rate increases is given by,

$$f = 0.79 \times \ln(Re_{nf}) - 1.69$$ (8)

Where, $Re_{nf}$ is the Reynolds number of nanofluid for the specified concentration.

Friction factor decreases when the flow rate increases as shown in Figure 9. However, with an increase in concentration of nanoparticles at a constant flow rate, friction factor increases as expected due to increase in viscosity of the nanofluid upon addition of nanoparticles. Therefore, there is a slight increase in pumping power required to compensate for the friction losses.

6. Conclusions

In this study effect of using Carboxyl-Graphene and Graphene-Oxide nanoparticles in automobile radiators at 1%, 2%, 3% volume concentration of each of the nanoparticles for different flow rates of 4,5 and 6 LPM was studied through a numerical approach. The analysis of fluid flow in a radiator can be done by assuming a laminar flow as the results match with the experimental results. From the results obtained, it is clear that addition of graphene oxide and carboxyl graphene will enhance the heat transfer performance of the radiator by increasing the heat transfer. However there is a slight increase in the pumping power required as friction factor increases upon addition of nanoparticles. With high amounts of heat transfer the size of the radiator may be reduced, which provides a higher performance to weight ratio and better cooling to engine. If the problem of agglomeration at the actual temperatures in an automobile can be overcome or reduced by future research, this type of hybrid-nanofluid is ideal to be used in the automotive radiator yielding the best effectiveness when used in the proper concentration.
7. References

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