Performance analysis of automobile radiator using carboxyl graphene nanofluids

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Abstract. A feasible solution to increase the effectiveness of the radiator will be the use of stabilized nanofluid. A mixture of small amount of solid particle, whose size is less than 100nm in the fluid phase, is termed as nanofluid. In current work, a small concentration of carboxyl-graphene nanostructure sheets/flakes are used as the solid medium, where conventional Ethylene glycol is used as the fluid medium. Visible checking method has been adopted, to check the stability of the nanofluid. The results showed the promising level of improvement in the values of Nusselt number and Effectiveness of the radiator, without changing the actual design of radiator. Examination of Pressure drop shows, a very small increase in its value even though the nanofluid has been used. About 19% improvement in the value of Effectiveness has been achieved at very small concentrations.

1. Introduction
In Industries like power plant, refineries and in others, cooling system is the heart of performance act. Poor performance of coolant led to a new scope of developing the new era of nanotechnology in this sector. Introducing small solid particles into these coolants will increase their capabilities, since solids have higher heat transfer coefficients than liquids. The development of smaller particles, of nano-sizes, has overcome the negative hydrodynamic effects of solid particles in the fluid. Researchers have found some significant increase in the heat transfer capacity of by using nanofluids.

Modern material technology helps us to produce nanometer sized particles that their thermophysical properties are different from those of the parent materials. Recently, there has been interest in using nanoparticles to modify heat transfer performance of suspensions. Nanofluids are stable suspension of nanometer-sized particles (smaller than 100 nm in at least one dimension) in conventional heat transfer fluids. Nanofluids are suitable for engineering applications and show several potential advantages such as better stability, dramatically high thermal conductivity and no extra pressure drop compared to other suspensions. In late 1990’s Choi et al. [1] attempted the first work with nanofluid. Effective enhancement is observed by Kanjikarat Anoop et al. [2] with the help of SiO2-water Nanofluid. With the different combination of volumetric concentration of graphene nanofluid, Niza Ahammed et al. [3] achieved 37.2% enhancement in thermal conductivity value with 1.5% concentrated nanofluid. About 78% enhancements in the heat transfer coefficient

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for the 7.5% volume fraction by Xuan and Li [4]. Jaafar Albadr et al. [5] observed 57% enhancement in heat transfer coefficient value for Al₂O₃. Rohit S Khedkar et al. [6] studied the effect of nanofluid in 1000 mm copper concentric heat exchanger, which showed enhancement of 47.36% at 3% TiO₂ nanofluid. D. Sandhya [7] observed ethanol based TiO₂ nanofluid performance for 4000-15000 Reynolds number range. They observed that, increased fluid circulation rate will help to improve the heat transfer performance. Hussein [8] experimentally investigated γ-Al₂O₃/water nanofluid for engine cooling and observed that, around 78.67% improvement in heat transfer coefficient for 1% volume concentrated nanofluid. L. Godson [10] observed heat transfer behaviour of silver-water nanofluid for 5000-25000 Reynolds number range, with particle volume concentration of 0.01%, 0.03% & 0.04%. The silver-water nanofluid showed around 12.4% and 6.4% enhancement in heat transfer coefficient and effectiveness value. 

Current experimental work has put more light on functionalised group of graphene based nanofluid. Two graphs have been mainly introduced here to show the performance of nanofluid. First one is Nusselt number of fluid vs Reynolds number of air for different mass flow rate of fluid and second one is Pressure drop vs mass flow rate of fluid for different fluid inlet temperature.

2. Experimental Protocol

To test the performance of the nanofluid over base fluid in present work, a special and dedicated test rig is designed and fabricated. The detailed 2-D sketch of the test-rig is mentioned in Figure 1. Once stabilized nanofluid is ready, by sonication process for about 9 hours, have to check its performance experimentally against the commercial coolant, using state of art test rig.

![Figure 1: Schematic of Radiator Test Rig](image)

| Sl No | Part Description                                |
|------|------------------------------------------------|
| 1    | Staggered Fin Radiator                         |
| 2    | Anemometer                                     |
| 3    | U-tube Manometer                               |
| 4    | Stainless steel tank with heater fitted        |
| 5    | High temperature water pump                    |
| 6    | Flow meter [Rotameter]                         |
| 7    | Fluid inlet valve                              |
| 8    | Fluid outlet valve                             |
| 9    | Main Electrical Control Unit                   |

Material chosen for the analysis of nano-coolant (nanofluid) is carboxyl premium graphene. Below are the test conditions that are followed while conducting the experimentation for the present work.

- A 5 litre of coolant is filled in SS tank having a heater and the lid is closed.
- Inlet fluid temperature is pre-set to 40 °C degree
- Once the coolant attains initial temperature, using pump and rotameter desired flow rate will be maintained.
- Once the fluid starts to flow, set the initial air flow rate by adjusting the knob in main electrical unit and note down the below observation
  - Inlet and outlet temperature of the coolant i.e., T₁ and T₂
  - Air inlet temperature (T₃) and air outlet temperature at 4 different conditions
  - Note down the pressure difference in terms of mm of Hg using U-tube manometer
  - Note down the air side velocity using anemometer at 4 different places, which represent Gaussian points (V₁ to V₄)
Repeat the same experiment for 4 different flow rates i.e., 3, 4, 5&6 LPM
Repeat these conditions for 40°C and 50°C coolant inlet temperature
Repeat these flow rate conditions and inlet temperature conditions for 50:50 Ethylene Glycol - Distilled water (conventional coolant) and for different concentrations of nano-coolant (0.02, 0.03 and 0.04 vol.%).

3. Mathematical Modelling
Assuming that the prepared nanofluid is well stabilized and particle concentration uniformly spread, the below-mentioned correlations are used to obtain nanofluid density, specific heat, thermal conductivity and other different properties.

Volume concentration of nanofluid

\[
\% \text{ of volume concentration} = \frac{w_p}{\rho_p} \left( \frac{w_p}{\rho_p} + \frac{w_{bf}}{\rho_{bf}} \right)
\]

Effective density of nanofluid

\[
\rho_{nf} = (1 + \varphi)\rho_{bf} + \varphi \rho_p
\]

Specific heat of the nanofluid

\[
(C_p\rho)_{nf} = \left( (1 + \varphi)C_p\rho_{bf} \right) + \varphi (C_p\rho_p)
\]

Dynamic viscosity of the nanofluid

\[
\mu_{nf} = \mu_{bf} \left( 1 + 7.3\varphi + 123\varphi^2 \right)
\]

Thermal conductivity of the nanofluid

\[
\frac{K_{nf}}{K_{bf}} = 1 + \left( \frac{3}{K_p \left( \frac{K_p}{K_{bf}} + 2 \right)} \left( \frac{K_p}{K_{bf}} + 1 \right) \varphi \right)
\]

Reynolds number on nanofluid side

\[
Re_{nf} = \frac{\rho_{nf} \cdot \nu \cdot D}{\mu_{nf}}
\]

Prandtl number of nanofluid side

\[
Pr_{nf} = \frac{\mu_{nf} \cdot C_p_{nf}}{K_{nf}}
\]

Nusselt number for nanofluid side by Dittus Boelter correlation

\[
Nu_{air} = 0.023 \cdot Re_{nf}^{0.8} \cdot Pr_{nf}^{0.3}
\]

Experimental Nusselt number on nanofluid side

\[
Nu_{nf} = \frac{n_f \cdot D}{K_{nf}} = \frac{m \cdot C_p \cdot (T1 - T2)_{\text{fluid}} \times D}{A \cdot (T_{\text{bulk}} - T_{\text{wall}}) \times K_{nf}}
\]

Reynolds number on air side

\[
Re_{air} = \frac{\rho_{air} \cdot \nu \cdot D}{\mu_{air}}
\]

Nusselt number for air side by zukauskas correlation

\[
Nu_{air} = \frac{1}{K_{air}} = c \cdot Re^{m} \cdot Pr^{n} \cdot \left( \frac{Pr}{Pr_s} \right)^{0.25}
\]

Above correlation is applied only if the condition 0.7 ≤ Pr ≤ 500 and 1 ≤ Re_{air} ≤ 10^6 are satisfied.

The values of m, n and c for staggered fin is given by Re_{air} \leq 10^2 \rightarrow c = 0.27; m = 0.63; n = 3
4. Results and Discussion

4.1. Experimental Nusselt number vs Reynolds number of air at 40°C coolant inlet temperature

Using equation (9) experimental Nusselt number is calculated for different Reynolds number and concentrations. Figure 1(a) to Figure 1(d) represents the variation of Nusselt number for different Reynolds number at 3, 4, 5 and 6 LPM respectively at 40°C nanofluid inlet temperature.

In Figure 1(a), for a flow rate of 3 LPM the variation of Reynolds number vs the Nusselt number shows as the velocity of air is varied by means of fan regulator, Reynolds number of the radiator increases, which increase the heat transfer coefficient between the outer tube wall and air which further increase the overall heat transfer coefficient between the nanofluid and surrounding air resulting in increasing in Nusselt number value by assuming internal conduction resistance offered by the tube wall is negligible. Maximum increase of Nusselt number is obtained as 18.67% in comparison to the base fluid for 0.03% volume concentration of nanoparticle, similarly maximum increment of 15% for 0.02% volume concentration and 12.79% for 0.04% volume concentration respectively.

![Figure 1(a)](image1.png)

![Figure 1(b)](image2.png)

![Figure 1(c)](image3.png)

![Figure 1(d)](image4.png)

Figure 1(a) – 1(d) Effect of Reynolds number of air on Nusselt number of nanofluid at 40°C nanofluid inlet temperature for 3, 4, 5 and 6 LPM volumetric flow rate of nanofluid.

Figure 1(b) shows the variation of Experimental Nusselt number vs Re of air at 4 LPM. As volume concentration of nanofluid is increased from 0.02% to 0.04%. Maximum increase of Nusselt number is obtained as 32.12% for 0.02% in comparison to the base fluid, similarly decrement of 9.9% for 0.03% and increment of 4.12% for 0.04% volume concentration respectively. The maximum value of Nusselt number is obtained as 33.29 for 0.02% volume concentration of nanofluid at inlet temperature of 40°C for flow rate of 4 LPM. This is mainly because of increase in
the value of overall heat transfer coefficient [38.72 W/m²K to 39.1 W/m²K] and convective heat transfer coefficient has been significantly showed improvement. Figure 1(c) shows the variation of experimental Nusselt number vs Re of air at 5 LPM. As volume concentration of nanofluid is increased from 0.02% to 0.04%. Maximum increase of Nusselt number is obtained as 34.88% in comparison to the base fluid for 0.02% volume concentration of nanoparticle, similarly decrement of 15.79% for 0.03% and improvement of 4.55% for 0.04% volume concentration respectively. The maximum value of Nusselt number is obtained as 56.95 for 0.03% volume concentration of nanofluid at inlet temperature of 40°C for flow rate of 5 LPM. This is mainly because of increase in the value of overall heat transfer coefficient and convective heat transfer coefficient has been significantly showed improvement. The maximum value of Nusselt number is obtained as 16.6% for 0.02% volume concentration of nanofluid at inlet temperature of 40°C for flow rate of 6 LPM.

4.2. Experimental Nusselt number vs Reynolds number of air at 50 °C coolant inlet temperature

As it had been seen from Figure 1, the Reynolds number of air had positive effect on the Nusselt number, the Fig shows the positive trends of Re of air of Nusselt number. Figure 2(a) to 2(d) shows the effect of Reynolds number of air over the Nusselt number of nanofluid for different fluids at 3, 4, 5, and 6 LPM nanofluid flow rate and 50°C inlet temperature. The variation of Reynolds number vs the Nusselt number shows same trend for different LPM values, i.e., the Nusselt number of the heat exchanger increase with increase in Reynolds number. The increase in the value of Reynolds number can be attributed to the increases in increase value of heat transfer coefficient between the nanofluids and inside the wall which is function of volume concentration of nanofluids.
In Figure 2(a) for a flow rate of 3 LPM the variation of Reynolds number vs the Nusselt number shows similar trend. Maximum increase of Nusselt number is obtained as 5.69% in comparison to the base fluid for 0.02% volume concentration of nanoparticle, similarly 4.85% for 0.03% and decrement of -6.59% for 0.04% volume concentration respectively.

In Figure 2(b), for a flow rate of 4 LPM the variation of Reynolds number vs the Nusselt number assuming that internal conduction resistance offered by the tube wall is negligible, Maximum increase of Nusselt number is obtained as 6.8% in comparison to the base fluid for 0.02% volume concentration of nanoparticle, similarly decrement of 2.88% for 0.03% and 7.49% for 0.04% volume concentration respectively.

In Figure 2(c), for a flow rate of 5 LPM the variation of Reynolds number vs the Nusselt number, increase of Nusselt number is obtained as 5% in comparison to the base fluid for 0.02% volume concentration of nanoparticle, similarly 3.37% for 0.03% and decrement of 11.09% for 0.04% volume concentration respectively.

In Figure 2(d), for a flow rate of 6 LPM the variation of Reynolds number vs the Nusselt number, increase of Nusselt number is obtained as 8.45% in comparison to the base fluid for 0.02% volume concentration of nanoparticle, similarly 8% for 0.02% and decrement of 3.09% for 0.04% volume concentration respectively.

From the above observations, it is clearly that, as the Re of air increases the Nusselt number increases, but the most important parameter is the orientation of the particle in fluid phase. It is clear that, the inlet and outlet fluid temperature is very essential. But in order to get maximum temperature difference, the particle should orient parallel to its length to the heat transfer direction. And another important this which has to be observed here is as the mass flow rate of fluid increases the Nusselt number also shows improvement in its value. So, the increase in the Re of air and fluid side will affect positively in favour of Nusselt number.

4.3. *Coolant pressure drop vs coolant flow rate*

Figure 3 shows how the variation of pressure drop with coolant flow rate. In order to measure the pressure drop, two limbs of U-tube manometer are fitted just in inlet and outlet port of radiator. The pressure drop is given by,

\[ P = \rho g h \]

Figure 3(a) and 3(b) shows the effect of nanofluid flow rate on pressure drop for 3, 4, 5 and 6 LPM at 40°C and 50°C inlet temperature respectively. The Fig trend is positive for the pressure drop versus mass flow rate. Here it can be clearly seen that, the pressure difference between the different concentrated nanofluid and conventional base fluid is not very high. As the mass flow rate increases the Reynolds number, which also increases head loss due to friction in riser tubes and head loss due to sudden expansion and contraction in header tube. The addition of nanoparticle to the base fluid had shown very lease increase in the pressure drop value. From the both Fig, the maximum pressure drop of 533.66 Pa is achieved for 0.03% and 0.04% concentrated nanofluid at 3 LPM & 4 LPM and 533.66Pa for 0.04% at 3LPM for 40°C and 50°C inlet temperature respectively.

Since the pressure drop between the base fluid and nanofluid is not up to that mark, the power consumed by using the nanofluid and pressure developed on the tube and motor is consider being very minimal. So, it can be clearly stated that, the use of nanofluid doesn’t requires any special arrangement in order to pump the fluid through the cooling system in the automobile cooling system.
5. Conclusion

Below are the conclusions drawn from the present work,

- Use of carboxyl Graphene nano-powder in fluid phase, showed significant effect upon base fluid.
- The stability of nanofluid is visually checked, and found out to be stable for 72 hours.
- Increase in Reynolds number of air or nanofluid, the Nusselt number showed improvement.
- At 40°C fluid inlet temperature and 5 LPM flow rate, 36.4% improvement in Nusselt number for 0.02 vol.% where as 8.45% improvement for 0.02 vol.% at 50°C fluid inlet temperature and at 6 LPM flow rate.
- At 40°C & 50°C fluid inlet temperature, 0.04% and 0.03% vol. concentrated nanofluid, showed 11.3% and 12.5% increase in Pressure drop value at flow rate of 3LPM.
- Use of carboxyl Graphene as nanofluid is likely to increase the performance characteristic of coolant, which will be recommended to be used, if the stability of nanofluid is increased.

6. References

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