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Heat transfer analysis of radiator using graphene oxide nanofluids

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Abstract: As the technology is developing day by day, there is a requirement for enhancement in performance of automobile radiator to have a better performance of the IC Engine and fuel effectiveness. One of the major and recent approach to upgrade the performance of a radiator is that nanoparticles must be suspended in the general coolant (Ethylene Glycol – Water) which form nanofluids. Present work has been carried out by suspending graphene oxide nanoparticles in 50:50 Ethylene Glycol and RO-Water as base fluid. Experimentation is carried out by using three volume concentrations of the nanofluid (0.02%, 0.03% and 0.04%) and at different volumetric flow rates ranging from 3 to 6 LPM. Effect of volume concentration, inlet temperature and flow rate on Effectiveness, pressure drop and friction factor has been studied experimentally. Effectiveness versus NTU curves are plotted for further design calculations. The results show that the nanofluids will enhance the performance of an automobile radiator when compared with base fluid. Results also shows a maximum of 56.45% and 41.47% improvement in effectiveness for 0.03% volume concentration and 5 LPM flow rate at 40 ^{0}C and 50 ^{0}C inlet temperatures respectively.

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1 Introduction

In an automobile the power is produced by combustion of air and fuel mixture. Only 25 - 30% of the power is utilized in petrol engines and about 30% - 35% of the power is utilized in diesel engines, and remaining power is wasted in the form of exhaust and heat. Due to this excess heat, the engine temperature becomes extremely high and that leads to increase in thermal stress of engine parts, lubricant loses its viscosity property. It causes quick wear of engine parts and finally engine may get seized. To avoid all these, it is necessary to remove excess heat from the engine by using engine cooling system. This system consists of radiator, water pump, cooling fan, thermostat and pressure cap. A radiator is basically a single pass cross-flow heat exchanger.

In late 1990's Choi et al [1] made first attempt in developing the new breed of nanoparticle suspended in any base fluid. Their experiment led to conclude that these new breed fluids has better heat transfer coefficient than that of the base fluid alone. Mahendra et al [2] studied the effect of CuO nanoparticles mixed with water and ethylene glycol and found out that there is 4.2% increase in heat transfer by

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addition of 2% CuO nanoparticles. Farajollabhi et al [3] observed the heat transfer characteristics of γ-Al_2O_3/water and TiO_2/water nano-fluids in a shell and tube heat exchanger under turbulent flow conditions. Niza Ahammed et al. [4] conducted experiment on graphene-water nanofluid, having different volume concentration of graphene in water and they observed that, the enhancement of thermal conductivity was about 37.2% for volumetric concentration of 1.5% of graphene at 50^0C.

Sandhya et al. [5], conducted experiments using ethylene glycol and water (40:60%) based fluids and TiO_2 nanofluid (0.1%, 0.3% and 0.5%), and they achieved about 35% improvement in the heat transfer rate when compared with base fluid at 0.5% concentrated nanofluid. Hafiz Muhammad Ali et al. [6], conducted the experiment to enhance the heat transfer performance of a car radiator by using ZnO nanoparticles. In this study, they concluded that the best heat transfer enhancement up to 46% was found compared to base fluid at 0.2% volumetric concentration. M. Raja et al. [7], reviewed the studies done so far on nanofluids characterization like nanofluids preparation, thermal conductivity of nanofluids, viscosity of nanofluids, Challenges and scope for future studies, applications of nanofluids in heat exchanger systems. Peyghambarzadeh et al. [8] have studied the effect of Al_2O_3, CuO and Fe_2O_3 nanoparticles in pure water and EG as the base fluid. They also used the ε-NTU technique for the calculation of overall heat transfer rate of the radiator.

2. Experimental Work

In current section, it has clearly explained about how to prepare the stabilized nanofluid using Ultrasonicator. Using state of art radiator test rig available at PES University, the performance of prepared nanofluid is evaluated. Experimentation had been carried out for various concentrated nanofluid and test cases.

2.1 Nanofluid Preparation

In general, there are two ways of producing the nanofluids. Namely one-step and two-step method. In One-step method for preparation of nanofluids physical vapour condensation technique was adopted. In this method the processes of drying, storage, transportation, and dispersion of nanoparticles were avoided, there by simultaneously making and dispersing the particles in the fluid. Agglomeration of nanoparticles is minimized, and the stability of fluids is increased.

Two-step method is extensively used technique for preparing the nanofluids. In this process, the nanoparticles were produced by physical or chemical methods as dry powders (<100nm). The prepared nanoparticles were dispersed in the base fluid with the help of intensive magnetic force agitation or high-shear mixing as the second step then followed by ultrasonic agitation.

Figure 1 shows the steps involved in preparing the nanofluid by two-step method. In the present work, base fluid (50:50 RO-Water and Ethylene Glycol) is mixed with graphene oxide nanoparticles in magnetic stirrer for about 30 min duration by adding sodium dodecyl sulphate [SDS] surfactants 10% by weight of nanoparticle. Then the mixture is ultrasonicated at 32 kHz for 9 hours to avoid agglomeration effects.

The Experiment is conducted at first with normal RO water and then continued for 50:50 - RO Water and Ethylene Glycol and extended to 0.02 to 0.04% concentrated Graphene oxide nanofluid. Visual inspection is carried out in order to check the stability of the nanofluid and found out that, for about 60-72 hours after preparation of nanofluid, there is no particle settlement.

2.2 Experimental Procedure

Figure 2 shows the radiator test rig facility available at PES University. Once the stabilised nanofluid is prepared, the next step is to study the performance of radiator using nanofluid by varying several parameters like inlet temperature, mass flow rate of both fluids and volume concentration. The main components of the test rig consist are cross flow type staggered fin radiator, high temperature water booster, Rotameter, U-Tube manometer, K-type thermocouples, Stainless Steel [SS] tank fitted with water heater. First the experiment is carried out on the base fluid to compare the results of nanofluid later.

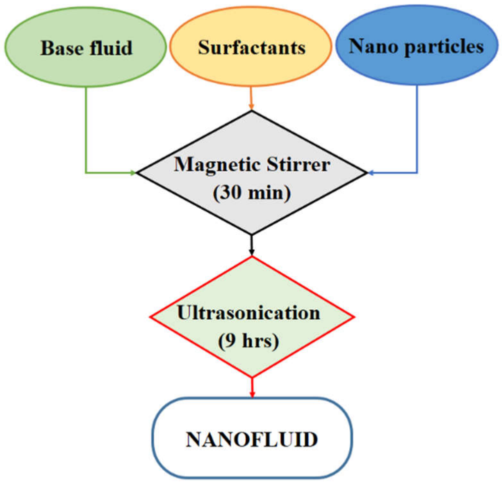

Figure 1 Flowchart of nanofluid preparation


Figure 2 Radiator Test Rig

The experiment consists of following steps:

- The SS tank will be filled with 4-6 litres of test fluid.
- Inlet fluid temperature is pre-set to 40^0C or 50^0C using thermostat.
- Once the test fluid attains the pre-set temperature, pump is switched on and the required fluid flow rate is controlled using Rotameter.
- When the test fluid starts to flow in the radiator, set the initial air flow rate by adjusting the knob in main electrical unit and note down the air velocity by using anemometer.
- Note the readings of thermocouples, Rotameter, Anemometer and U-tube manometer for further calculations.

3. Physical Properties/ Mathematical Modelling

By assuming the nanofluid prepared by using two-step method is well stabilized and particle concentration is assumed to be uniformly spread, below are the correlation have been utilized to obtain nanofluid density, specific heat, thermal conductivity and other different properties.

Correlation for nanofluid:

The volume concentration of nanofluid is provided by [5]

$$\%\ of\ volume\ concentration = \frac{\frac{w_p}{\rho_p}}{\left(\frac{w_p}{\rho_p} + \frac{w_{bf}}{\rho_{bf}}\right)} \quad (1)$$

The effective density is the parameter of concentration of nanofluid, which is cited from [8]

$$\rho_{nf} = (1 \quad \varphi)\rho_{bf} + \varphi\rho_p \quad (2)$$

The specific heat of the nanofluid is a function of concentration of nanofluid and specific heat of base fluid, which is cited from [8]

$$(C_p\rho)_{nf} = \left((1 \quad \varphi)C_p\right)_{bf} + \varphi\left(C_p\rho_p\right) \quad (3)$$

The thermal conductivity of the nanofluid is given by [8]

$$\frac{K_{nf}}{K_{bf}} = 1 + \frac{3\left(\frac{K_p}{K_{bf}} \quad 1\right)\varphi}{\left(\frac{K_p}{K_{bf}} + 2\right) \quad \left(\frac{K_p}{K_{bf}} \quad 1\right)\varphi} \quad (4)$$

The dynamic viscosity of the nanofluid is given by [8]

$$\mu_{nf} = \mu_{bf} \quad (1 + 7.3\varphi + 123\varphi^2) \qquad (5)$$

Correlation for air:
Reynolds's number of air side is given by

$$Re_{air} = \frac{\rho_{air} \quad v \quad D}{\mu_{air}} \qquad (6)$$

Nusselt number for air side by Zukauskas correlation

$$Nu_{air} = c \quad Re^m \quad Pr^n \quad \left(\frac{Pr}{Pr_s}\right)^{0.25} \qquad (7)$$

Above correlation is applied only if the conditions,
$0.7 \leq Pr \leq 500$; $1 \leq Re_{air} \leq 10^6$ are satisfied
The condition of m, n and c for staggered fin radiator used in the present work are
Re_{air} 10^2 10^3; C = 0.27; m = 0.63; n = 3
Convective heat transfer coefficient for air side is given by

$$Nu_{air} = \frac{{}_{air} \quad l}{k_{air}} = c \quad Re^m \quad Pr^n \quad \left(\frac{Pr}{Pr_s}\right)^{0.25} \qquad (8)$$

Correlation for liquid (base fluid / nanofluid):
Reynolds number of nanofluid side is given by

$$Re_{nf} = \frac{\rho_{nf} \quad v \quad D}{\mu_{nf}} \qquad (9)$$

Prandtl number of coolant side is given by

$$Pr_{nf} = \frac{\mu_{nf} \quad Cp_{nf}}{K_{nf}} \qquad (10)$$

Nusselt number for coolant side by Dittus Boelter correlation [9]

$$Nu_{air} = 0.023 \quad {Re_{nf}}^{0.8} \quad {Pr_{nf}}^{0.3} = \frac{m \quad Cp \quad (T1 \quad T2)_{fluid} \times D}{A \quad (T_{bulk} \quad T_{wall}) \times K_{nf}} \qquad (11)$$

Overall heat transfer co-efficient of the radiator by neglecting all the losses is given by

$$\frac{1}{U} = \frac{1}{{}_{air}} + \frac{1}{{}_{nf}} \qquad (12)$$

The effectiveness of the cross-flow heat exchangers with single pass and both fluid unmixed is given by

$$\varepsilon = 1 \quad \exp\left\{\frac{NTU^{0.22}}{C}[exp(\quad C \quad NTU^{0.78}) \quad 1]\right\} \qquad (13)$$

4. Results and Discussion

4.1 Effectiveness vs NTU at 40 ^{0}C Coolant inlet temperature

The variation of effectiveness vs NTU for all the volume concentrations for the coolant flow rate of 3, 4, 5 and 6 LPM at 40^{0}C inlet temperature is shown in Figure 3. For fixed value of flow rate as the volume concentration of nanoparticles in the conventional coolant is increased the effectiveness of the heat exchanger shows a positive trend up to 0.03% volume concentration, further increase in volume concentration leads to decrease in effectiveness. This variation is mainly due to two reasons, firstly at higher volume concentration of nanoparticle, there will be agglomeration of nanoparticles which results in reduction of overall heat transfer coefficient from 45.61 W/m^{2}K for 0.03% to 43.94 W/m^{2}K for 0.04% volume concentration for 3 LPM at 40^{0}C inlet temperature. Secondly there is no proper orientation of graphene oxide nanoparticles in flow direction as volume concentration increases. The maximum value of effectiveness is obtained as 0.265 from 0.03% volume concentration for flow rate of 3 LPM at 40^{0}C inlet temperature.

For fixed volume of concentration, as flow rate increased from 3 LPM to 6 LPM effectiveness decreases. This is due to two counter acting phenomena i.e. as mass flow rate increases, NTU value decreases, as NTU is inversely proportional to mass flow rate. And it is also found that as the mass flow rate increases the heat transfer coefficient between nanofluid and inner tube wall increases from 1742.53 W/m^{2}K to 2210.07 W/m^{2}K, so overall heat transfer coefficient also increases. Since first phenomenon dominating over second phenomenon NTU value decreases, since NTU is a function of overall heat transfer coefficient and mass flow rate. As NTU decreases, effectiveness also decreases.

The maximum value of effectiveness reduces with increase in mass flow rate 3 LPM to 6 LPM for fixed volume concentration of nanofluid because increase in value of overall heat transfer coefficient is comparatively less with increasing the value of mass flow rate. The maximum value of effectiveness for 3 LPM is obtained as 0.265 for 0.03% volume concentration and for 6 LPM is obtained as 0.078 for same volume concentration

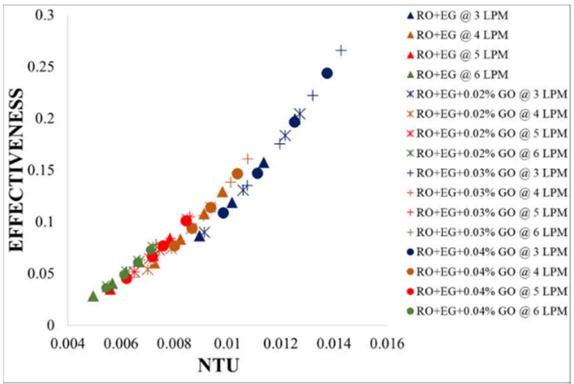

Figure 3: Effectveness vs NTU at 40 ^{0}C coolant temperature

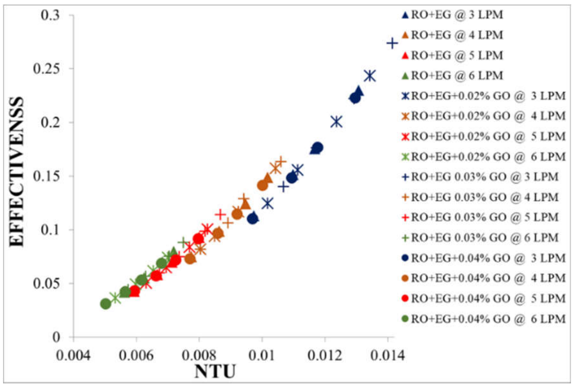

Figure 4: Effectveness vs NTU at 50 ^{0}C coolant inlet temperature

4.2 Effectiveness vs NTU at 50 ^{0}C Coolant inlet temperature

The variation of effectiveness vs NTU for all the volume concentrations for the flow rate of 3, 4, 5 and 6 LPM at 50 ^{0}C coolant inlet temperature is shown in Figure 4. For fixed value of flow rate as the volume concentration of nanoparticles in the base fluid is increased the effectiveness of the heat exchanger shows a positive trend up to 0.03% volume concentration, further increase in volume concentration leads to decrease in effectiveness. This variation is mainly due to two reasons, firstly at higher volume concentration of nanoparticle, there will be agglomeration of nanoparticles which results in reduction of overall heat transfer coefficient from 45.95 W/m^{2}K for 0.03% to 39.93 W/m^{2}K for 0.04% volume concentration for 3 LPM at 50^{0}C inlet temperature. Secondly there is no proper orientation of graphene oxide nanoparticles in flow direction as volume concentration increases. The maximum value of effectiveness is obtained as 0.279 from 0.03% volume concentration for flow rate of 3 LPM at 50^{0}C inlet temperature.

For fixed volume of concentration, as flow rate increased from 3 LPM to 6 LPM effectiveness decreases. This is due to two counter acting phenomena i.e. as mass flow rate increase NTU value decreases, as NTU is inversely proportional to mass flow rate. And it is also found that as the mass flow rate increases the heat transfer coefficient between nanofluid and inner tube wall increases from 1719.48 W/m^{2}K to 2078.44 W/m^{2}K, so overall heat transfer coefficient also increases. Since first phenomenon dominating over second phenomenon NTU value decreases, since NTU value is a function of overall heat transfer coefficient and mass flow rate. As NTU decreases, effectiveness also decreases.

The maximum value of effectiveness reduces with increase in mass flow rate 3 LPM to 6 LPM for fixed volume concentration of nanofluid because increase in value of overall heat transfer coefficient is comparatively less with increasing the value of mass flow rate. The maximum value of effectiveness for 3 LPM is obtained as 0.279 for 0.03% volume concentration and for 6 LPM is obtained as 0.088 for same volume concentration.

4.3 Effect of flow rate of nanofluid on pressure drop:

Figure 5 and Figure 6 shows the effect of mass flow rate on pressure drop for 3, 4, 5 and 6 LPM at 40 ^{0}C and 50^{0}C coolant inlet temperature respectively. The variation of pressure drop vs mass flow rate for different volume concentrations shows a positive trend. As the mass flow rate increases the Reynolds number is also increased which further increase head loss due to friction in riser tubes and head loss due to sudden expansion and contraction in header tube. Therefore, pressure drop increases since head loss is increasing. The maximum pressure drop is obtained as 5.069 kPa for both inlet temperatures (40 ^{0}C and 50 ^{0}C) for flow rate of 6 LPM at 0.04% volume concentration. Similarly, as pressure drop increases pumping power also increases.

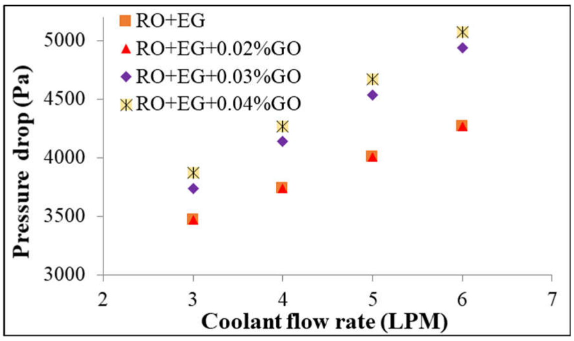

Figure 5: Pressure drop vs coolant flow rate at 40 ^{0}C coolant inlet temperature

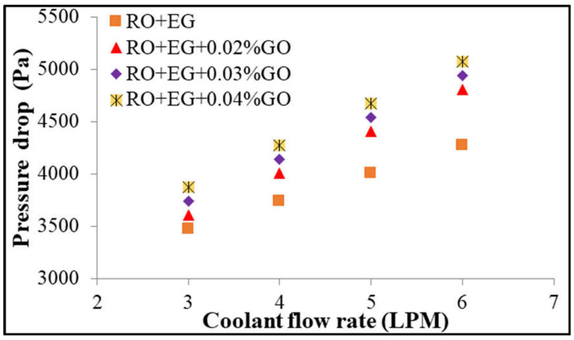

Figure 6: Pressure drop vs coolant flow rate at 50 ^{0}C coolant inlet temperature

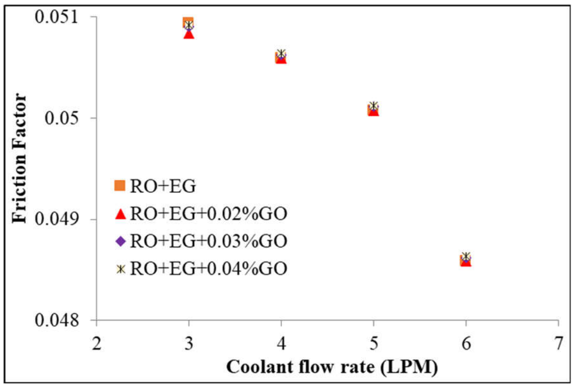

Figure 7: Friction Factor vs coolant flow rate at 40 ^{0}C coolant inlet temperature

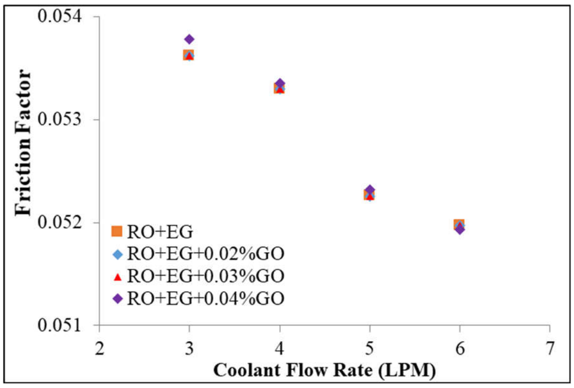

Figure 8: Friction Factor vs coolant flow rate at 50 ^{0}C coolant inlet temperature

4.4 Effect of flow rate of nanofluid on friction factor:

Figure 7 and Figure 8 shows the variation of friction factor for various flow rates at different concentration of carboxyl-graphene nanofluid at fluid inlet temperatures 40 ^{0}C and 50 ^{0}C respectively. The trend for both the fluid inlet temperatures show decrease in friction factor value as the flow rate of fluid increases. In the above figures, comparison is made for conventional fluid over various concentrations of nanofluid. However, the addition of nanoparticles does not affect the friction factor, as the concentration used in the current research is very small.

5. Conclusions

Current work is carried out using Graphene Oxide nanofluid. The inlet fluid temperature is varied between 40 ^{0}C and 50 ^{0}C. The mass flow rate of nanofluid is maintained from 3LPM to 6LPM, in steps of 1 LPM. Parametric studies are carried out in order to determine the performance of nanofluid over conventional base fluid. The outcome of the experimental work is listed below.

- Use of graphene oxide nanofluid has shown significant effect on enhancing the performance of the radiator.
- It is clear that lower mass flow rates of the nanofluid had a greater influence on effectiveness which can be observed at 0.02 vol.%, 0.03 vol.% and 0.04 vol.% nanofluid showed 16.49%, 56.45% and 25.69% improvement in effectiveness value at 40^{O}C inlet temperature. And they showed 14.34%, 26.50% and 1% improvement in effectiveness at 50^{O}C inlet temperature respectively.
- At 40^{O}C inlet temperature of nanofluid, about 56.45% improvement in effectiveness is observed at 0.03 vol.% concentration for 3 LPM flow rate.
- At 50^{O}C inlet temperature of nanofluid, about 41.47% improvement in effectiveness is observed at 0.03 vol.% concentration for 5 LPM flow rate.
- Increase in the mass flow rate beyond 5LPM and inlet temperature 50^{O}C has showed negative effective on effectiveness for concentrations 0.02% and 0.04%.
- Increase in pressure drop due to addition of nanoparticles is minimum when compared with the increase in effectiveness.
- 0.02 vol.% concentrated nanofluid has almost same pressure drop as the basefluid at 40^{O}C inlet temperature.
- If the stability of graphene oxide nanofluid is further increased, then the use of graphene oxide nanofluid in the radiator is recommended.

6. References

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