

# **Experimental Study for Enhancement the Cooling System and Exhaust Gasses for Gasoline Automotive Engine Using Nano-Fluid.**

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## **Abstract**

Adding of nanomaterial to car radiator fluid for 4-stroke gasoline engine was investigated experimentally at different Nanofluid concentrations with different flow rates for variable car speeds and number of passengers. The fluid temperature and exhaust gases emissions have been carried out. Results demonstrate that the increasing of Nanofluid concentration and high fluid circulation rates can improve the heat transfer of the engine radiator response; also using Nanofluids reduces the CO and NO<sub>x</sub> emissions of the engine exhaust gasses, while the CO<sub>2</sub> ratio has been increased.

**Keywords:** Nanofluid; Car Radiator; Emissions; Nusselt Number

## **Introduction**

Continues technology development in automotive manufacture has been increased dramatically the demand for high efficiency of engines. The high efficiency of engine is not only based on its performance but also for less fuel consumption and low rate emission. As result reducing a vehicle volume by optimizing design and size of a radiator is a necessity for making the world green. So far, few studies are reported for nanofluids heat transfer enhancement for Car Radiator (CR) with real load applications, car on a road and link this performance with engine emission levels.

The fluids used for transferring heat such as water and ethylene glycol exhibit very low thermal conductivity. So, there is a need for new and innovative heat transfer fluids for enhancement the process of heat transfer rate in CR. Nanofluids seem to be potential replacement of conventional coolants in automotive engine cooling systems. Recently there have been considerable experiments highlighting the effect of Nanofluids in enhancement the heat transfer rate. **Ali et al.** [1] have experimentally investigated the performance of an aluminum CR using water based Zinc Oxide ZnO Nanofluids. They studied its heat transfer performance. It ensured that heat transfer enhancement compared to pure water at the best concentration of 0.2 % vol., which enhance the heat transfer up to 46 % compared to the base fluid. **Ebrahimi et al.** [2] have experimental studied Silicon Oxide SiO<sub>2</sub> Nanofluids flowing in CR for different working conditions. Increase of liquid inlet temperature, nanoparticle volume fraction, and its Reynolds number they observed that Nusselt number increased. **Sandhya et al.** [3] reported heat transfer enhancement utilizing ethylene glycol and water based Titanium Oxide TiO<sub>2</sub> Nanofluids as an automobile radiator coolant for range of Re = 4000-15000. Increasing in the fluid circulation rate improves the heat transfer response. **Sany et al.** [4] have investigated the performance of compact heat exchanger (CR) experimentally.  $\epsilon$ -NTU method was used to perform the values of Nusselt number and heat transfer coefficient in a wide range of operation conditions. The heat transfer coefficient and Nusselt number improved by 50 % due to better air distribution in radiator compared with actual conditions in an automobile. **Tomar and Tripathi** [5] carried out an experimental study using mixture of ethylene glycol + water (50+50) combination with Aluminum Oxide AL<sub>2</sub>O<sub>3</sub> Nanoparticles in a CR. AL<sub>2</sub>O<sub>3</sub> Nanoparticles size 40 nm were used with volume concentration of (0.1%, 0.5%, 1.0%) and flow rate range 2-5 l/min. They found that the thermal conductivity of the fluid increased almost linearly with temperature. Heat transfer rate was increased with increasing volume concentration of Nanoparticle. **Leong et al.** [6] investigated the effect of ethylene glycol-based copper Nanofluids in an automotive cooling system with volume concentration 0.2% - 2.0%. They found that heat transfer rate increased with increasing in volume concentration of nanoparticles where 3.8% heat transfer enhancement achieved with addition of 2% copper Nanoparticles. The thermal performance of radiator is enhanced about 42.7% and 45.2% for pure ethylene glycol and ethylene glycol with 2% of copper Nanoparticles respectively. By adding 2% copper Nanoparticles reduction by 18.7% of air frontal area is achieved. **Raja et al.** [7] studied the effect of heat transfer enhancement and NO<sub>x</sub> emission in single cylinder Diesel engine using AL<sub>2</sub>O<sub>3</sub> Nanofluid as coolant under laminar flow conditions and Nanofluid volume concentrations 0.5%, 1.0%, 1.5% and 2.0%. Overall heat transfer coefficient at that Nanofluid concentration was enhanced by 11%, 18%, 23% and 25% respectively under no load conditions. Also, the utilization of nanofluids resulted in 12.5% reduction of NO<sub>x</sub> emissions at full load and about 3-5% at no load and part load. **Hussein et al.** [8] investigated the enhancement of heat transfer using Nano-powders of TiO<sub>2</sub> and SiO<sub>2</sub>, the test was on CR under certain conditions. Their results showed that with increasing volume flow

rate Nusselt number increased. **Senthilraja et al.** [9] performed an experimental work to study the exhaust emissions of NO<sub>x</sub>, exhaust gas temperature and specific fuel consumption under different load conditions utilizing Copper Oxide CuO/water Nano-fluid for three different volume concentrations of 0.05, 0.1, and 0.2% vol. They illustrated that even at low volume concentrations, have a significant influence on exhaust emissions. The specific fuel consumption reduced by 8.6%, 15.1% and 21.1% with specific Nanofluid volume concentrations. NO<sub>x</sub> emissions were found that it decreased by all volume concentrations of CuO/water Nanofluids respectively. Ahmed M. [10] replaced the conventional cooling system by electronically controlled components, electrical variable speed pump and variable speed fan. A PID controller and linear quadratic regulator are proposed to design an engine cooling system operation with different concentrations of AL<sub>2</sub>O<sub>3</sub> Nano-Fluid in an automobile radiator. **Naraki et al.** [11] searched laminar flow regime ( $100 \leq Re \leq 1000$ ) in a car radiator. The overall heat transfer coefficient of CuO/water Nanofluids was detected, where the overall heat transfer coefficient increases. Each of Nanofluid volumetric flow rate, inlet temperature and concentration has 23%, 22% and 13% contribution in the overall heat transfer coefficient, respectively.

The above literature review showed that most previous work related to utilize Nanofluid inside a CR without incorporation with car load and /or real complete car engine just a CR inside wind tunnel attached with source of heating. Consequently, the novelty of the present work depends on these two main concepts: first, carryout the performance of real car engine with various loads on the road to find out the heat transfer rate and engine exhaust emission for different Nanofluid concentrations

In this study, Aluminum Oxide AL<sub>2</sub>O<sub>3</sub> / water Nanofluid are prepared for different concentrations of 0.2%, 0.6% and 1.0% vol. also, for different car speeds 30, 60 and 90 km/h. with 2 and 4 passengers to study the heat transfer enhancement and engine emission variations.

### Nanofluid Preparation

Assuming that the Nano-powder is fully dispersed within the base fluid, i.e. the particles distribution can be considered homogeneous throughout the system. Preparation of stable Nano-fluids is of great significance in heat transfer applications of nanofluids. Un-well prepares Nanofluid will render two phase heat transfer (i.e. sold-liquid). Also, there is another problem which is aggregation of nanoparticles so it creates large particles (in micrometer), thus terminate the Nano related discussions. Aluminum Oxide (AL<sub>2</sub>O<sub>3</sub>) nanoparticles used in this study are approximately spherical with diameter of about 50 nm. The amount of Nano-powder required for a certain percentage of volumetric concentration  $\varphi$  is estimated from equation (1) as a function of the volume of the Nano particles  $Volume_p$ ;

$$volume\ concentration, \varphi (\%) = \frac{Volume_p}{Volume_{Total}} \quad (1)$$

$$\text{volume concentration, } \varphi (\%) = \left[ \frac{\frac{m_p}{\rho_p}}{\frac{m_p}{\rho_p} + \frac{m_f}{\rho_f}} \right] \times 100 \quad (2)$$

The Nanofluid solution as function of the particles and fluid masses  $m_p, m_f$  and their densities  $\rho_p$ , and  $\rho_f$  was kept in a sonication continuously for about 8 hours to achieve uniform dispersion. The effective physical properties of the studied mixtures can be evaluated using some classical formulas as usually used for two phase fluids. These relations have been used to predict Nanofluid physical properties like density, viscosity, thermal conductivity and specific heat at different concentrations [10]. In this paper, the following correlations were used to calculate these physical properties of Nanofluid:

$$\rho_{nf} = (1 - \varphi) \rho_f + \varphi \rho_p \quad (3)$$

$$C_{p_{nf}} = \frac{\varphi (\rho C_p)_p + (1 - \varphi) (\rho C_p)_f}{\rho_{nf}} \quad (4)$$

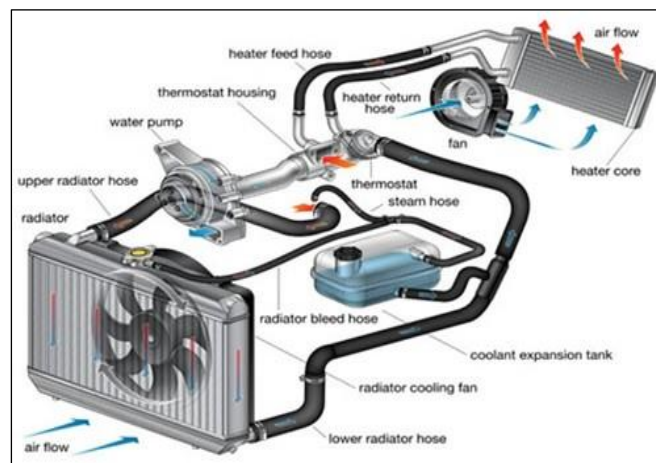
$$\mu_{nf} = \mu_f (1 + 2.5 \varphi) \quad (5)$$

$$\frac{K_{nf}}{K_f} = \frac{k_p + 2k_f + 2(k_p - k_f)\varphi_{eff}}{k_p + 2k_f - 2(k_p - k_f)\varphi_{eff}} \quad (6)$$

In the above equations, the subscripts “p”, “f” and “nf” refer to the particles, water, and Nanofluid respectively.

## Experimental Setup

BYD Automobile, 4-stroke and 4-cylinder Spark ignition engine is used to investigate the heat performance and exhaust gases emission. A complete cooling system for automobile engine is illustrated in Figure 1.



**Fig.1:** Schematic diagram of automobile cooling system

The main components of cooling system consist of CR, fan, water pump and flow pipes to connect inlet and outlet of CR to engine body where cooling liquid extract

heat from engine. Flow meter is attached to flow line to measure flow rate of cooling liquid where pump gives a certain flow rate at a certain engine speed. 4 Thermocouples were used; 2 of them installed to the radiator inlet and outlet flow pipes as shown in Figure 2 to detect radiator inlet and outlet coolant temperatures. The other 2 thermocouples are installed at the center of the radiator surfaces (both sides). The temperatures are measured by 4 digital multimeters AUTONICS Temperature Controller TC4M-14R. After installation of all thermocouples the CR was placed again.



**Fig.2:** Fixing CR in its original place after mounting thermocouple sensor

The CR is charged with specific amount of Nanofluid with certain value concentration from 0.0 to 1.0 % vol. The vehicle start motion on a level road with certain occupants of 2 or 4 at travel speeds 30, 60, and 90 km/h. At high steady temperature, all radiator thermocouples readings and ratios of engine exhaust gas emission were carried out from. The experiments have been performed for different recharging of the CR with another Nanofluid concentration.

### Uncertainty Analysis

Experimental uncertainties are calculated utilizing the method developed by **Kline and McClintock** [12]. The uncertainty range of Reynolds number comes from the errors in the measurement of volumetric flow rate hydraulic diameter of tubes. Also, the uncertainty of Nusselt number refers to the errors in the measurements of volume flow rate, and all detected temperatures. The maximum calculated uncertainties in Reynolds no. and Nusselt no. were found to be  $\pm 3.1\%$  and  $10.2\%$  respectively. The accuracies of various measuring devices are shown in Table1.

Table 1: Accuracies of the detection devices

| Sensor / type                  | Reference  | Description | Accuracy                          |
|--------------------------------|------------|-------------|-----------------------------------|
| Water flow meter (F-44750L-12) | Blue-White | Flow rate   | $\pm 4\%$                         |
| Digital thermometer (TC4M-14R) | AUTONICS   | Temperature | $\pm 0.1\text{ }^{\circ}\text{C}$ |
| Digital air flow meter (DVM+)  | Supco      | Air speed   | $\pm 3\%$                         |

|                               |           |               |   |
|-------------------------------|-----------|---------------|---|
| Calibrated Ruler              | Local     | Tube length   | ±0.88%  |
| Exhaust Gas Analyzer (AGS200) | Brain Bee | Exhaust gases | CO ±0.01 %<br>CO <sub>2</sub> ± 0.1 %<br>NO <sub>x</sub> ±0.1 % |

## Mathematical Modeling

The heat transfer coefficient in the radiator is estimated for the Nanofluid coolant as well as the air flowing over the fins of the radiator. To get heat transfer coefficient and congruent Nusselt number, the following steps has been performed.

$$Q = hA(T_b - T_w) \quad (7)$$

$$\text{peripheral area , } A = 2[(L \times H) + (L \times W)] \quad (8)$$

Where

$L$  is the length,  $W$  is the width and  $H$  is height of flattened tube of CR.

$$Q = mC_p\Delta T = mC_p(T_{in} - T_{out}) \quad (9)$$

Regarding the equality of heat in above equations

$$Nu = \frac{h_{exp} \cdot d_{hy}}{k} = \frac{mC_p(T_{in}-T_{out}) D_{hy}}{A(T_b-T_w) k} \quad (10)$$

$$D_{hy} = \frac{4 \times \text{Tube surface area}}{\text{Perimeter of the tubes}} \quad (11)$$

$$Re = \frac{\rho u D_{hy}}{\mu} = \frac{4 m}{\pi D_{hy} \mu} \quad (12)$$

In Equation (10), Nu is average Nusselt number for the whole radiator,

## Result Presentation and Discussion

The results were divided into two categories where the first deal with heat transfer and the second one deal with emissions of gases. Before conducting systematic experiments on the application of Nanofluids in the radiator, some experimental runs with pure water were carried out in order to check the reliability and accuracy of the experimental setup. Comparison was made between the experimental data and three well-known empirical correlations: one of them suggested by **Gnielinsky [13]** and the other developed by **Petukhov et al. [14]** and **Dittus-Boelter [15]** as shown in Figure 3. These three relations are shown in Equations (13, 15 and 17) respectively.

$$Nu = \frac{\left(\frac{f}{8}\right) Re \cdot Pr}{1.07 + 12.7 \left(\frac{f}{8}\right)^{0.5} \left(Pr^{\frac{2}{3}} - 1\right)} \quad \text{Gnielinsky eq.} \quad (13)$$

Where  $3 \times 10^3 < Re < 5 \times 10^6$ , and  $0.5 < Pr < 2000$

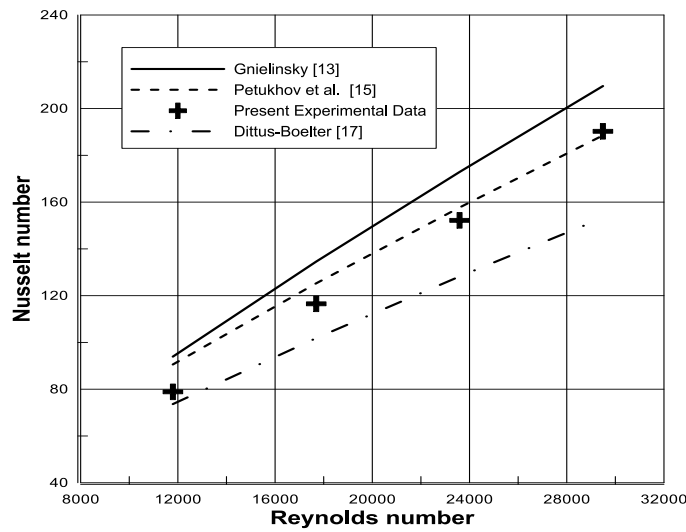
$$f = (1.82 \log(Re) - 1.64)^{-2} \tag{14}$$

$$\overline{Nu} = \frac{\left(\frac{f}{2}\right)(Re-1000)Pr}{1+12.7\left(\frac{f}{2}\right)^{0.5} (Pr^{\frac{2}{3}}-1)} \quad \text{Petukhov et al. eq.} \tag{15}$$

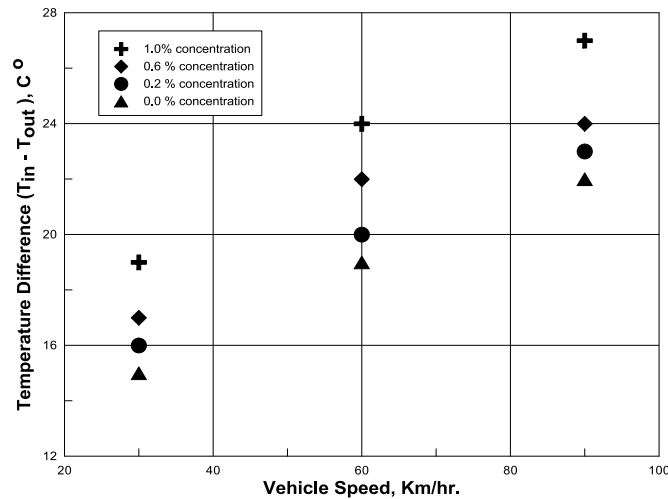
For  $2300 < Re < 5 \times 10^6$ , and  $0.5 < Pr < 2000$

$$f = (1.58 \ln(Re) - 3.82)^{-2} \tag{16}$$

$$\overline{Nu} = 0.0236 Re^{0.8} Pr^{0.3} \quad \text{Dittus-Boelter eq.} \tag{17}$$



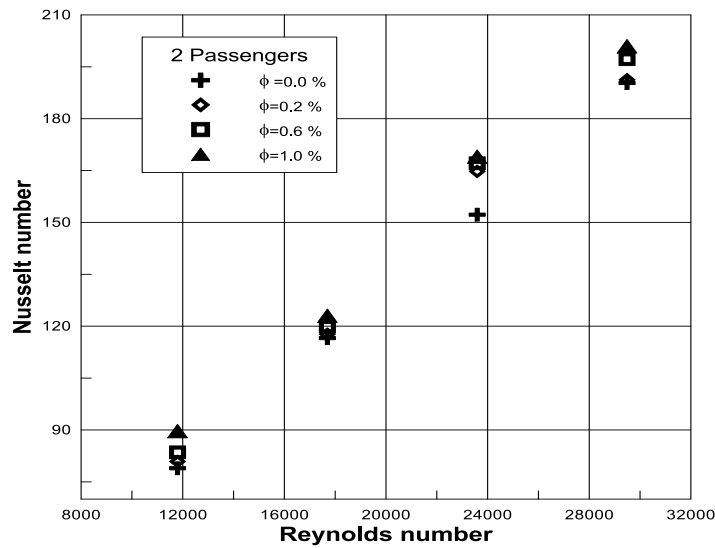
**Fig.3:** Experimental results of pure water in comparison with the existing correlations.



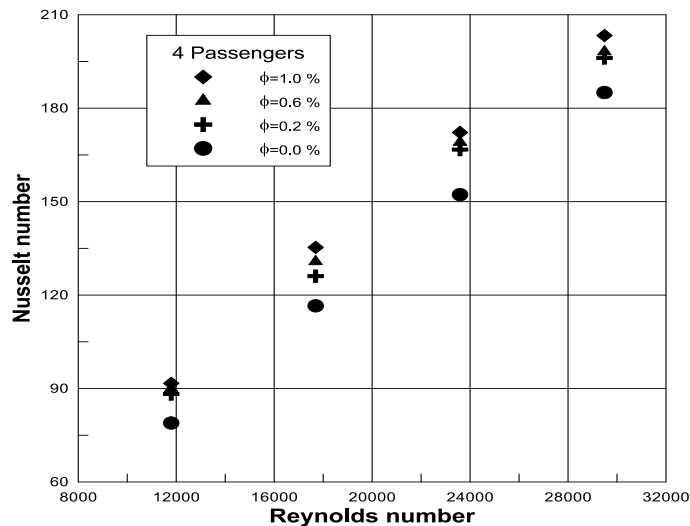
**Fig.4:** Variation of temperature difference with vehicle speed with different Nanofluid concentrations with 2 passengers

Figure 4 shows the temperature difference between inlet and outlet of radiators as a function of vehicle speed for pure water and three different Nanofluid concentrations. It shows that the temperature difference increase it means more heat dissipated from car radiator at certain vehicle speed (same water flow rate) .one can clearly observe at the same vehicle speed temperature difference increase with augmentation of Nanoparticle volume concentration.

Variation of Nu number with Reynolds number for both 2 and 4 passengers at variable Nanofluid concentrations is shown in Figures (5, and 6). Both illustrate that with increasing Reynolds number Nusselt number increase and also increase with increasing Nanofluid concentration.



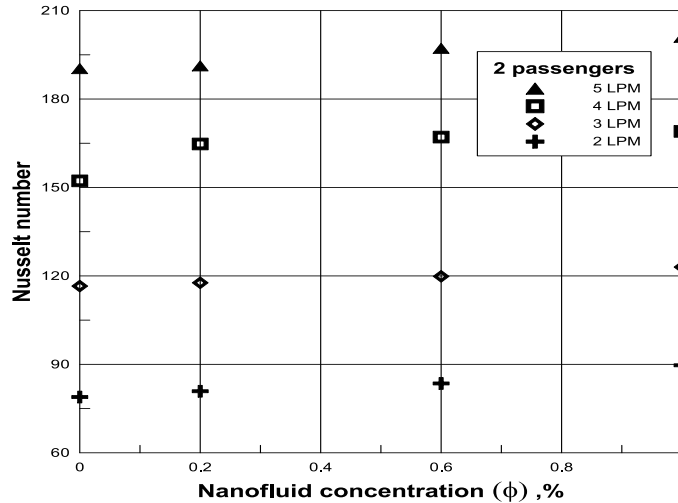
**Fig.5:** Variation of Nu number with Re number for 2 passengers at variable Nanofluid concentrations



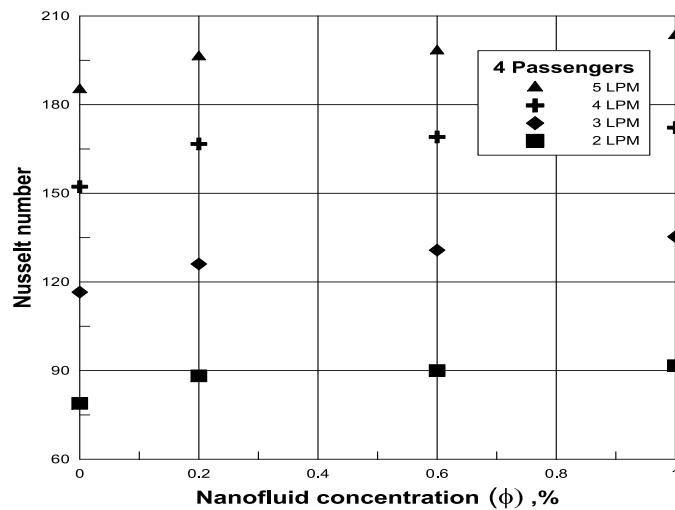
**Fig.6:** Variation of Nu number with Re number for 4 passengers at variable Nanofluid concentrations



Variation of Nu number with variable Nanofluid concentrations for 2 and 4 passengers at variable water flow rate is shown in Figures (7, and 8). Both illustrate that with increasing Nanofluid concentration Nusselt number increased according to the water flow rate inside car radiator.



**Fig.7:** Variation of Nu number with variable Nanofluid concentrations for 2 passengers at variable water flow rate

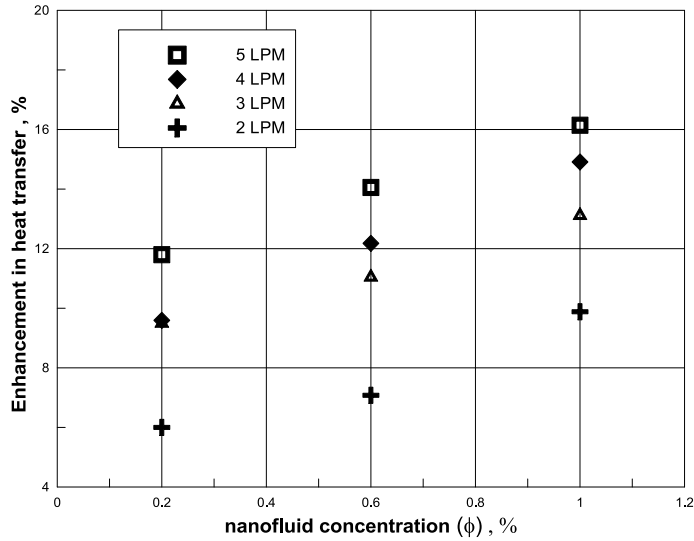


**Fig.8:** Variation of Nu number with variable Nanofluid concentrations for 4 passengers at variable water flow rate

The enhancement in the system for Nusselt number was calculated using equation (18) where a comparison between using Nanofluid in the system and without using it. As shown in Figure (9) illustrates the enhancement percentage in Nusselt number with variation of Nanofluid concentration for different flow rates, where enhancement percentage increases with increasing volume concentration and flow rate.

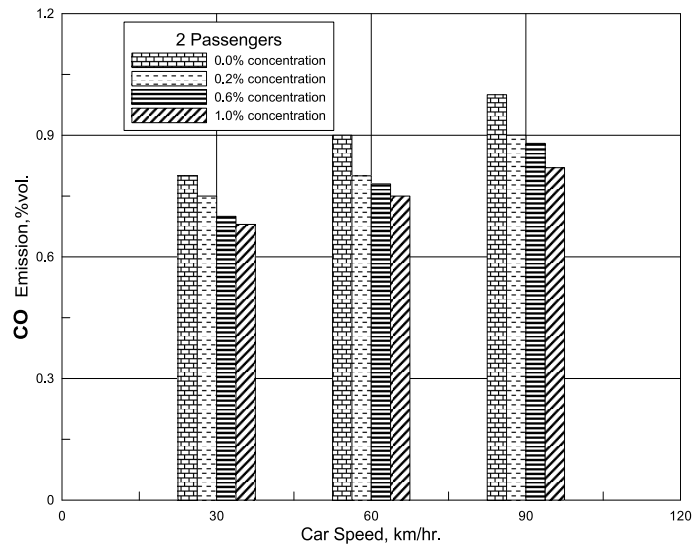
$$E = \frac{Nu(\phi) - Nu(basefluid)}{Nu(basefluid)} \times 100 \tag{18}$$

Where E is the enhancement in the heat transfer.

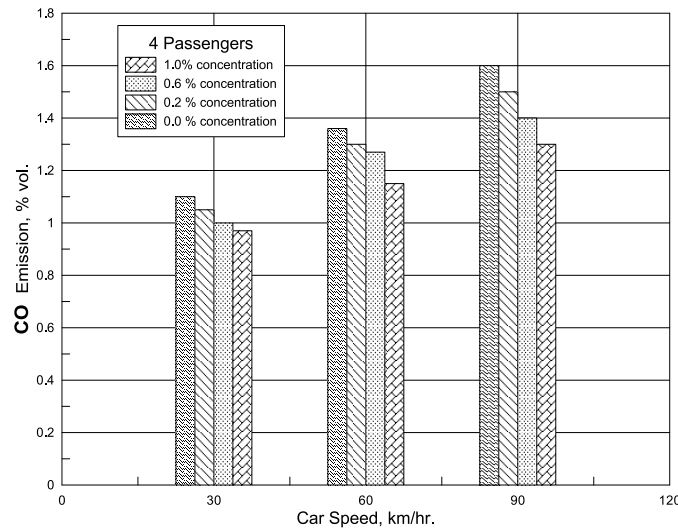


**Fig.9:** Effect of Nanofluid concentrations and water flow rate on enhancement in heat transfer

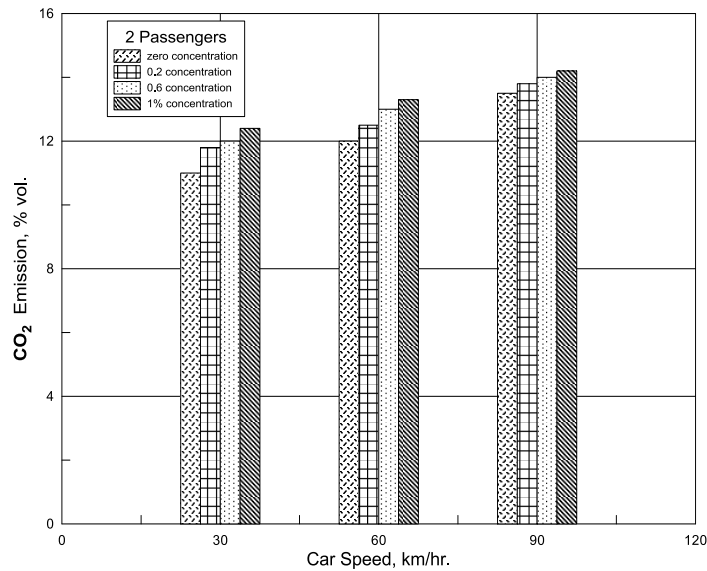
The second part for results was to monitor the gases emissions by using Nanofluids inside CR. As shown in Figures (10, and 11) carbon monoxide emissions increase with increasing vehicle speed but decrease with number of passengers and Nanofluid concentration.



**Fig.10:** Variation of CO emission with vehicle speed at different Nanofluid concentration for 2 passengers

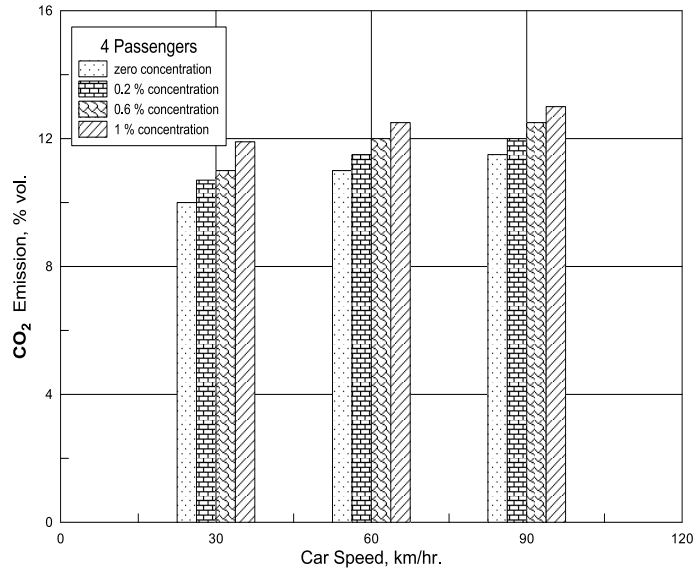


**Fig.11:** Variation of CO emission with vehicle speed at different Nanofluid concentration for 4 passengers



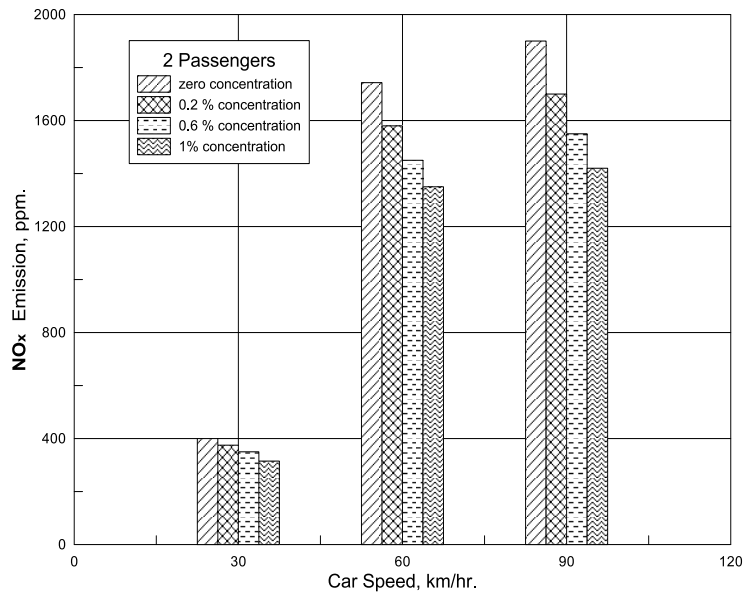
**Fig.12:** Variation of CO<sub>2</sub> emission with vehicle speed at different nanofluid concentration for 2 passengers

Variation of CO<sub>2</sub> emissions was plotted with vehicle speed as shown in Figures (12,13) for 2 and 4 passengers, where the carbon dioxide decrease with increasing nanofluid concentration and number of passengers for decreasing vehicle speed.

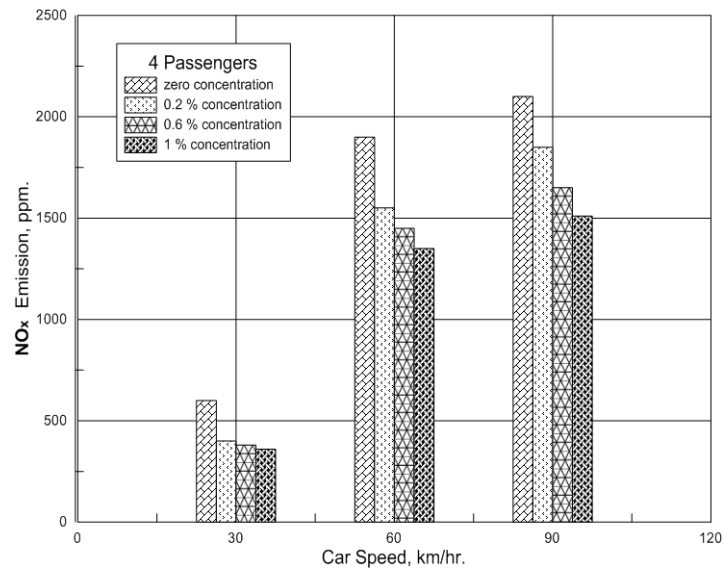


**Fig.13:** Variation of CO<sub>2</sub> emission with vehicle speed at different Nanofluid concentration for 4 passengers

Nitrogen oxide is an irritant gas, which at high concentrations causes inflammation of the airways. So, it is important to minimize its emissions to atmosphere. As vehicle speed increase NO<sub>x</sub> emission increases as shown in figures (14, and 15) for both 2 and 4 passengers but with using nanofluids as cooling fluid inside CR its noticed that amount of nitrogen oxide decreases with increasing nanofluids.



**Fig.14:** Variation of NO<sub>x</sub> emission with vehicle speed at different nanofluid concentration for 2 passengers



**Fig.15:** Variation of NO<sub>x</sub> emission with vehicle speed at different Nanofluid concentration for 4 passengers

## Conclusion

Analysis of the obtained results illustrates that:

- Using AL<sub>2</sub>O<sub>3</sub> Nanofluid inside car radiator enhance the heat transfer characteristics as represented in Nusselt number for both 2 and 4 passengers are applied with variable flow rate and Reynolds number.
- As volume nanofluid concentration increase the Nusselt number increases so as this result the bulk volume of car radiator can be decreased. Also, on other side the gas emissions were reduced with increasing nanofluid concentration
- High car speeds generate higher rates of NO<sub>x</sub> emissions which reached more than 4 times at 90 km/hr. related to that concentration at 30 km/hr.
- High Nano-material concentrations generated lower NO<sub>x</sub> emissions for all test speeds
- Low car speed generated relative low NO<sub>x</sub> emission for the Nano-material additives.

## Nomenclature

|                |                                 |                     |
|----------------|---------------------------------|---------------------|
| A              | Area,                           | m <sup>2</sup>      |
| C <sub>p</sub> | Specific heat,                  | J/kg.K              |
| Q              | Heat transfer rate,             | W                   |
| m              | Mass flow rate                  | kg/Sec              |
| T              | Temperature,                    | °C                  |
| K              | Thermal conductivity,           | W/m.K               |
| h              | Heat transfer coefficient,      | W/m <sup>2</sup> .K |
| L              | Length of flattened tube of CR, | m                   |

|   |                                 |   |
|---|---------------------------------|---|
| W | Width of flattened tube of CR,  | m |
| H | Height of flattened tube of CR, | m |
| d | Hydraulic Diameter              | m |

### Greek Symbols

|           |                       |                   |
|-----------|-----------------------|-------------------|
| Re        | Reynolds number,      |                   |
| $\varphi$ | Volume concentration, | %                 |
| $\mu$     | Viscosity,            | kg/m.s            |
| $\rho$    | Density,              | kg/m <sup>3</sup> |
| Nu        | Nusselt number,       |                   |

### Subscripts

|    |           |
|----|-----------|
| f  | Fluid     |
| p  | Particle  |
| nf | Nanofluid |
| hy | Hydraulic |

### Abbreviation

|                 |                 |
|-----------------|-----------------|
| NF              | Nanofluid       |
| CR              | Car Radiator    |
| CO              | Carbon Monoxide |
| CO <sub>2</sub> | Carbon Dioxide  |
| NO <sub>x</sub> | Nitrogen Oxide  |

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