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An Experimental Investigation on Heat Transfer in Automobile Radiator Using the Reinforcement of Titanium Dioxide Nano-Fluid in Coolant

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Abstract : Now days Internal Combustion (I C) Engine produces power by combustion of fuel. Most of the I.C Engines are cooled using either water or liquid or air through heat exchangers. Only 25% of heat is converted to useful power & the remaining heat is dissipated. If the heat dissipation is not done properly it will cause a serious damage to the engine. With the advancement of nanotechnology the new generation of heat transfer fluids are known as "Nano fluids" has been developed which made researchers to next level. These fluids offer higher thermal conductivity compared to that of conventional coolants. This study is focused on the application of Titanium Dioxide Nanoparticles (TiO_2) in Ethylene Glycol as base fluid in an automotive cooling system. Nano fluid properties and empirical correlations were known from literatures to investigate the heat transfer enhancement of an automotive radiator operated with Nano fluid based coolant. Experimentation is carried out to comparison of overall heat transfer coefficient and the heat transfer rate in cooling system of engine radiator with and without application of TiO_2 nano fluids in different volumes when mixed with base fluid i.e., Ethylene Glycol.

Keywords*:* IC Engines, Nano Fluids, TiO_2, Ethylene Glycol.

1. INTRODUCTION

Continuous research in automotive industries has raised the demand for high efficiency engines. A high efficiency engine is not only based on its performance but also in terms of better fuel economy and less emissions. There are many systems that influence the performance of engine like method of fuel injection system, emission system, cooling system, etc. one of the parameters which affects the performance of engine is the cooling rate of radiator in engine cooling system. The automotive industry is continuously involved in strong research and development to obtain the best in multiple aspects like performance, fuel consumption, aesthetics, safety, etc. By Jadhao, J. S etal[1] air-cooled heat exchangers that are found in a vehicle (radiator, AC condenser and evaporator, charge air cooler, etc.) plays an important role in its weight and also in the design of its front-end module, which also gives a greater impact on the aerodynamic behavior of automobile. George et al [2] in their research considered these as challenges, and concluded that an optimization process is mandatory to obtain the best design. In researching for the ways to improve the aerodynamic designs of vehicles, and subsequently the fuel economy, manufacturers must reduce the amount of energy needed to overcome wind resistance on the road. Pawan, et al[3] work depicts that at high speeds, about 65% of the total energy output from a truck is expended in overcoming the aerodynamic drag. This fact is partly due to the large radiator in front of the engine positioned to maximize the cooling effect of oncoming air. With the advancement of nanotechnology, the new generation of heat transfer fluids called, "Nano fluids" have been developed and researchers found that these fluids are making higher thermal conductivity compared to that of conventional coolants. Nano fluids which consist of carrier liquids such as water, ethylene glycol are dispersed with tiny nano-scale particles known as nanoparticles. Nano fluids seem to be a potential replacement for the conventional coolants in engine cooling system for automobiles. Recently there has been considerable research findings are reported, that the superior heat transfer performances of Nano fluids. Beck[4] referred that nano fluids are potential heat transfer fluids which enhances the thermo physical properties and heat transfer performance. It can be applied in many areas for better performances for energy, heat transfer and other performances.

Nanofluids helps in conserving heat energy in heat exchanger material. The important parameters which influence are the heat transfer characteristics of nanofluids which include thermal conductivity, viscosity, specific heat and density. The thermo physical properties of these nanofluids also depend on operating temperature of nanofluids. Hence, the accurate measurement of temperature dependent properties of nanofluids is mandatory.

Thermo physical properties of nanofluids is pre-requisite for estimation of heat transfer coefficient and the Nusselt number. Wiggle et al [5] claimed that the radiator is a heat exchanger which transfers heat from the coolant to the air. An adequate flow of both coolant and air is needed for proper exchange of heat. After the engine is warmed up, all of the additional heat absorbed in the water jackets must be dissipated at the radiator itself, otherwise temperature of coolant increases rapidly. Evaporation of coolant is at a faster rate if the coolant temperature reaches boiling point and sufficient quantity of coolant is not available for heat transfer and overheating of engine takes place. Heat transfer coefficient for air is about seven times less than for water and hence the air side limits heat transfer in automobile radiator. Peyghambarzadeh et al [6] work states that hotter the radiator, the better is the heat transfer with the sorrounding air. With water as the coolant, the highest temperature a radiator could operate is 373K, i.e., the boiling point of water. Addition of ethylene-glycol with water in a sealed radiator can substantially raise coolant pressure along with boiling point.

This work is focused on the addition of Titanium Dioxide Nano fluid to Ethylene Glycol based coolant in an automotive cooling system. Relevant data, nano fluid properties and empirical correlations were obtained from literatures to investigate the heat transfer enhancement of an automotive or radiator operated with Nano fluid based coolants. Experimentation is done for the comparison of overall heat transfer coefficient and the heat transfer rate of the engine cooling system with and without application of TiO_2 nano fluid in base fluid i.e., Ethylene Glycol in different volumes.

2. METHODOLOGY

2.1 Estimation of nanoparticle volume concentration

The amount of TiO_2 nanoparticles i.e., required in preparation of Nano fluid based coolant is calculated using the law of mixture formula. A sensitive balance with a 0.1mg resolution is used to weigh the TiO_2 nanoparticles. The weight of the nanoparticles required for preparation of 100 ml TiO_2 nanofluid of a particular volume concentration, using water-propylene glycol base fluid is calculated by using the following relation below

$$\%\text{ volume concentration} = \frac{\left[\frac{W_{TiO_2}}{\rho_{TiO_2}}\right]}{\left[\frac{W_{TiO_2}}{\rho_{TiO_2}} + \frac{W_{bf}}{\rho_{bf}}\right]} = \frac{\left[\frac{W_{TiO_2}}{6300}\right]}{\left[\frac{W_{TiO_2}}{6300} + \frac{100}{1036}\right]} \quad \text{----(1)}$$

The amount of TiO_2 nanoparticles required to prepare Nano fluids of different percentage volume concentration in a 100 ml of base fluid is summarized in the Table 1below

S.No.	Volume concentration (%)	Weight of nanoparticles (W_{TiO2}), Grams
1	0.1	0.60872
2	0.2	1.21865

2.2. Nanofluid preparation using TiO_2 nanoparticles

The TiO2 Nano particles having an approximate size of 50 nm and density of 6.3 gm/cm^3 is procured from a US based company (Sigma-Aldrich Chemicals Private Ltd) and is used for investigation in the present experimentation. The photographic view of the nanoparticles shown in the fig.1

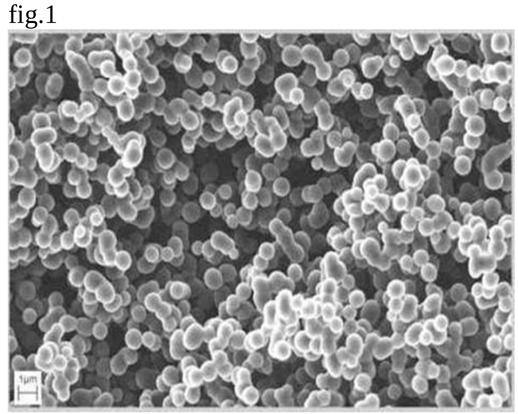

Fig.1 Photographic view of TiO_2 nanoparticles

The distribution of TiO_2 nanoparticles at Nano scale can be observed under a Scanning electron microscope (SEM). The SEM images of TiO_2 nanoparticles at 1 μm magnifications are shown in fig.2. SEM image of TiO_2 nanoparticle on a 500 nm scale is shown below. Preparation of Nano fluids is a crucial stage and Nano fluids are prepared in a systematic and careful manner. A stable Nano fluid with uniform particle dispersion is required and the same is used in measuring the thermo physical properties of Nano fluids.

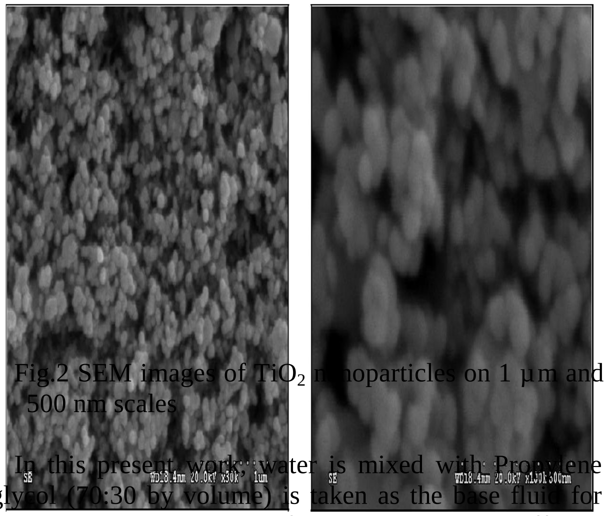

Fig.2 SEM images of TiO_2 nanoparticles on 1 µm and 500 nm scales

In this present work: water is mixed with Propylene glycol (70:30 by volume) is taken as the base fluid for preparation TiO_2 Nano fluids. The three different methods are available for preparation of stable Nano fluids and are listed below.

2.2 Mixing of Nano powder in the base liquid

In this method, the nanoparticles are mixed in the base liquid and thoroughly stirred with stirrer. A Nano fluid prepared in this method gives low suspension stability, because the nanoparticles settle down due to gravity, after sometime of Nano fluid preparation. The time of particle settlement depends on the type of nanoparticles used, density and viscosity properties of the host fluids. Water-propylene glycol based TiO_2 Nanofluids of 0.1%, and 0.2% volume concentrations were prepared to measure the absolute viscosity. The TiO_2 Nano fluids thus prepared are assumed to be an isentropic and their thermo physical properties will be uniform and constant with time all through the fluid sample. These Nano fluids are assumed to act as Newtonian fluids as the concentration of nanoparticles is low. A Newtonian fluid satisfies the equation governing Newtonian behavior of fluids and is given by

$$T=ur \text{----(2)}$$

The objective of this experiment is to analyze and study the effects of the temperature and the volume concentration of TiO_2 Nano fluid on its absolute viscosity. The experimental setup for measurement of viscosity of TiO_2 Nano fluids using water-propylene glycol blend as the base fluid is shown fig 2. It consists of a programmable Brook field viscometer with temperature controlled bath. The viscometer is calibrated using the standard fluids. The spindle type and its speed combinations will produce results with accuracy when the applied torque is in the range of 10% to100% and accordingly the spindle is chosen. Spindle CC45 DIN is used. The TiO_2 Nano fluid under test is poured in the sample chamber of the viscometer. The spindle immersed and rotated in the Nano fluid in the speed ranging from 400 to 540 rpm in steps of 12 seconds each.

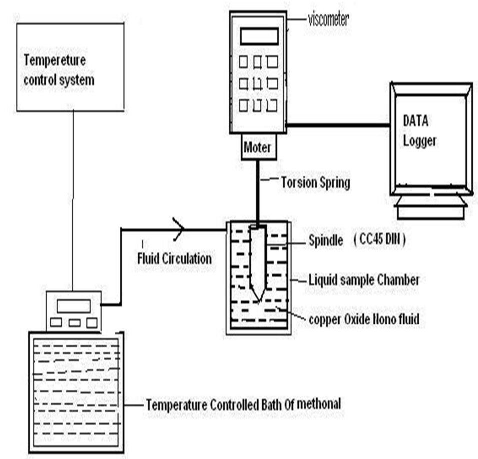

Fig.3. Schematic diagram of experimental setup for measuring TiO_2 nano fluid dynamic viscosity

After measuring the of viscosity of the base fluid and confirming that the viscometer is generating correct reading, the viscosity of TiO_2 Nano fluids of all the concentrations under experimentation is measured in the temperature ranging from -15 ºC to 70 ºC. The measured viscosity of the TiO_2 Nano fluids was observed to be decreasing exponentially with an increase in the Nano fluid temperature and the same is represented in Fig. 4. The Nano fluids with higher concentration of TiO_2 nanoparticles have more viscosity over the base fluid. It is observed from the results that the trend in the change of viscosity with temperature for all the concentrations of TiO_2 Nano fluid is similar.

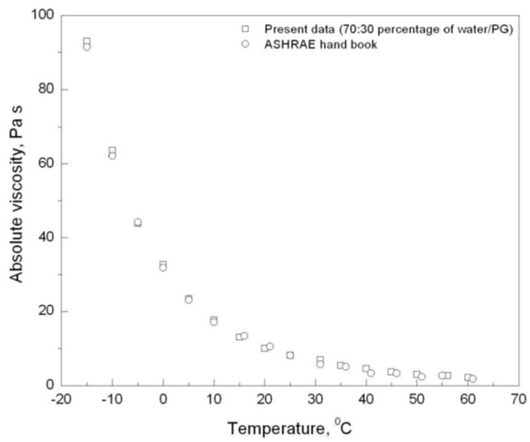

Fig.5 Comparison of experimental viscosity of water-propylene glycol base fluid with ASHRAE viscosity

3. EXPERIMENTAL SETUP

The below fig 6 is Schematic diagram of experimental set up which consists of closed loop circuit. The experimental test rig consists of reservoir with heating element, magnetic drive pump, Rotameter, radiator fan (speed control DC motor) and Automobile radiator. Magnetic drive pump gives the flows 16-18 LPM; the flow rate of the test section is regulated by means of two globe valves which are appropriate adjustable to the recycle line as shown in fig 7. The working fluid fills 30% of the storage tank whose total volume is 38 lit. The total volume of the circulating liquid is constant in all the experiments. The circuit include 0.30m diameter pipeline which is made of the steel pipe. A Rotameter is used to flow measurement through the test section. The specification of the Rotameter is 100-1000 LPH and measurement of 1/2” BSP (M). For heating the working fluid, an electric heater of capacity 2000 watt and controller were used to maintain the temperature 50°-80°C. Two K type thermocouples were used on the flow line to record the radiator inlet and outlet temperatures. Two thermocouples K types are installed in the radiator to measure the wall temperature of the radiator.

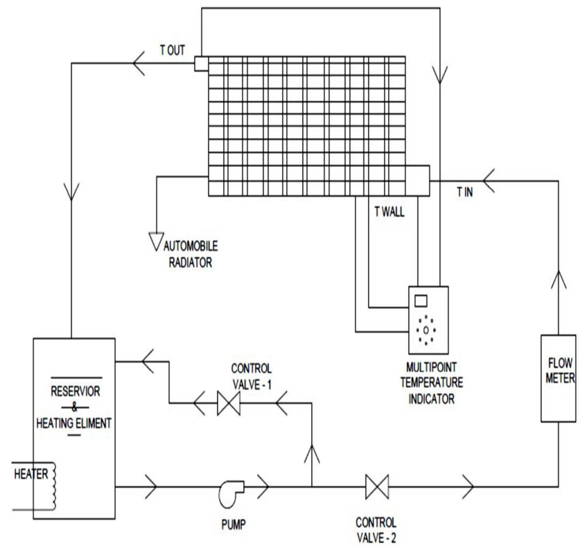

Fig6. Schematic diagram of experimental set up

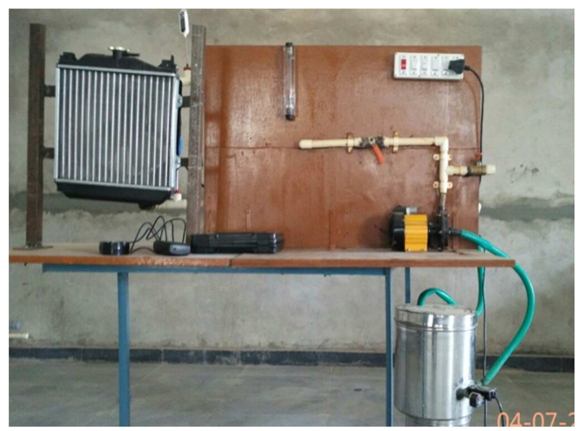

Fig.7.Experimental setup for radiator and flow diagram

Influence of the air Reynolds number on the thermal performance of automobile radiator .Air Reynolds number was varied in the range of 84391 and 91290 while mass flow rate of the coolant was fixed to 0.08 kg/s.

Table 2 Radiator specifications

Sl.no.	Description	Air	Coolant
1	Fluid Inlet Temperature	20-40 (Assume T_a=24)	50-80 (Assume Ta= 60)
2	Core Width	0.35 M	0.35 M
3	Core Height	0.35 M	0.35 M
4	Core Depth	0.016 M	0.016 M
4	Tubes	0.7 Cm X 30 Cm	0.7 Cm X 30 Cm
5	Fin Thickness	0.01 Cm	0.01 Cm
6	Hydraulic Diameter	0.0007 M	0.0007 M
7	Fine Types	Ruffled	Ruffled
8	Tubes Arrangement	Staggered	Staggered

Table 3 Thermo physical Properties of base Fluid and nanoparticles

Sl.no	Properties	TiO2	Mixture of water +propylene glycols
1	Density (Kg/m^3)	3650	1064
2	Specific heat (J/kg K)	873.336	3370
3	Thermal conductivity	31.922	0.363
4	Viscosity (N/^{sm2})	-	4.65 10^{-5}

4. Analysis

The analysis is also done on radiator with Nano fluids at different volume fractions. This is focused on effectiveness and overall heat transfer coefficient based on the air side and total heat transfer of an automobile radiator.

In this study coolant flow rate was fixed at 0.000083 m^3/s and air Reynolds number is 91190 but the volume fraction of TiO_2 nanoparticles was varied. It focuses on the effects of volume fraction of TiO_2 & nanoparticles on the coolant pressure drop and pumping power.

Table :4 Thermo-physical properties of TiO_2Nano fluid

Volume Concentration, ϕ (%)	Density, ρ (kg/m^3)	Specific Heat, C (J/kg.K)	Thermal Conductivity, k (W/m.K)	Viscosity, μ (kg/m.s)
Temperature: 30°C				
0.0	1055.39	3502.0	0.413	0.00240
0.5	1071.26	3446.5	0.418	0.00251
1.0	1087.14	3392.7	0.433	0.00265
1.5	1103.01	3340.4	0.441	0.00279
Temperature: 50°C				
0.0	1045.35	3569.0	0.428	0.00157
0.5	1061.27	3511.7	0.432	0.00164
1.0	1077.20	3456.0	0.448	0.00177
1.5	1093.12	3402.0	0.488	0.00182
Temperature: 70°C				
0.0	1033.37	3636.0	0.438	0.00111
0.5	1049.35	3576.7	0.443	0.00125
1.0	1065.34	3519.1	0.462	0.00143
1.5	1081.32	3463.3	0.501	0.00148

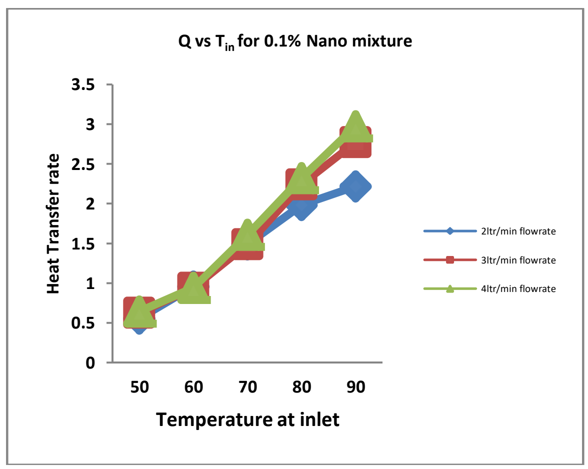

Fig .8 Heat transfer rate for different flow rates of coolant with TiO_2 0.2% by volume

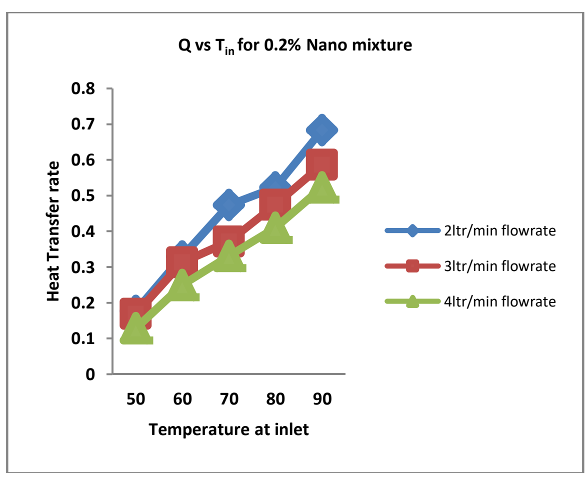

Fig .9. Heat transfer rate for different flow rates of coolant with TiO_2 0.2% by volume

5. CONCLUSION:

From the experimental data and from the analysis of results, it can be concluded that the Nano coolants are very effective when used as a mixture in coolant for automobile radiators.

By addition of small percentage of TiO_2 reinforced Nano coolants by volume improves the quantity of coolant by dissipation of more heat from an automobile radiator. Experiments are underway to quantify the fiction losses and fouling the radiator, if any due to the addition of Nano particles.

From the above study of Nano fluids, following brief conclusions can be drawn as 0.1% and 0.2% of TiO_2 Nano fluid with increase in flow rate of water, the heat transfer coefficient has been increasing.

It has been seen that addition of Nano fluids with coolants suitable for Automobile application.

Nano coolants enable the potential to allow higher temperature coolants and higher heat rejection in the automotive engines. A higher temperature radiator could reduce the radiator size approximately 30%. This translates into reduced, fluid pumping and fan requirements, leading to possibly a 10% fuel savings.

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