Title: Heat Transfer Enhancement using Nanofluids in Automotive Cooling System

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ABSTRACT

Nanofluid is the leading technique which has been widely used for enhancement of heat transfer rate in various applications. This paper gives review regarding properties of nanofluids and experimental study on heat transfer rate enhancement in automotive cooling system. Nanofluids are produced by suspending nanoparticles in base fluid.
Suspension of nanofluid in base fluid totally changes the properties of base fluid and one can get the fluid with better performance as a resultant fluid. In this paper comparison between TiO2-W and SiO2-W nanofluids used to enhance heat transfer rate in automotive cooling system. The result shows that the Nusselt number increases with volume flow rate and slightly increaseswith inlet temperature and nanofluid volume concentration. By using nanofluids up to 22.1% heat transfer rate has been increased.

Keywords: Automotive cooling system, Nanofluid, Heat transfer, Performance

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1. INTRODUCTION

According to recent studies, Nanofluids are performing major role in enhancement of the heat transfer rate in many applications such as cooling, power generation, defense, nuclear, space, microelectronics and biomedical appliances
Nanofluids are produced by dispersing the particles of metallic or non-metallic nanoparticles or nanofibers of smaller size (<100nm)in base fluid. Nanoparticles present in base fluid contribute better flow of mixing and higher thermal conductivity compared to pure fluid. Even a small amount of nanoparticles can noticeably enhance the effective thermal conductivity of the nanofluid. Most of nanoparticles have greater thermal conductivities than most of the liquids used as base fluids.A substantial reduction in energy consumption could be made possible by improving the heat transfer rate. The presence of nanoparticles in the base fluids contributes better flow of mixing and higher thermal conductivity compared to pure fluid. It is obvious that solid particles having thermal conductivities several hundred times higher than these conventional fluids.To improve thermal conductivity of a fluid, suspension of ultrafine solid particles in the fluid can be a creative idea. Different types of particles (metallic, non-metallic and polymeric)can be added into fluids to form slurries. Due to the fact that sizes of these suspended particles are in the millimetre or even micrometre scale, some serious problems such as the clogging of flow channels, erosion of pipelines and an increase in pressure drop can occur. Moreover, they often suffer from rheological and instability problems. Especially, the particles tend to settle rapidly. For that reason, though the slurries have better thermal conductivities but they are not practical.
A property causing significant concern is thermal conductivity. The introduction of nanofluids usually represents a significant enhancement in the thermal conductivity of the fluid, which represents an enhancement in the heat transfer of a determined application. Even a small amount of nanoparticles can significantly enhance the effective thermal conductivity of the nanofluid once most solids have greater thermal conductivities than most of the liquids used as base fluids. Also, many studies report that the introduction of Nano metric-sized particles in base fluids results in a fluid with higher thermal conductivity than the thermal conductivity expected from the simple combination of the solid particles and the fluid, obtained from the weighted mean of the thermal conductivities of the base fluid and the nanoparticles. Also, recent studies show that the use of nanofluids represents a significant enhancement not only in the conduction heat transfer but also in the convection heat transfer. Hence to improve heat

transfer rate in different areas and to improve efficiency of systems like automotive cooling system collaboration of nanofluids in the system is the technique evolving now a days.

Drawbacks of conventional fluids over nanofluids are:

1. Fluid The particle settles rapidly, forming a layer on the surface and
2. Reducing the heat transfer capacity of the fluid.
3. If the circulation rate of the fluid is increased, sedimentation is reduced, but the erosion of the heat transfer device, pipe line etc. increased rapidly.
4. The large size of the particle tends to clog the flow channels, particularly if the cooling channels are narrow.
5. The pressure drop in the fluid increases considerably.
6. Inherently Poor Thermal Conductivity
7. Do Not Work With Miniaturized Technologies
8. Surface Area Per Unit Volume Lesser
9. Rapid Settlement Of Particles

In case of automotive cooling system nanofluids pay important role in enhancement of heat transfer rate. With the use of nanofluids optimization in use of energy as well as compact devices can be achieved. In the present review effect and comparison between two nanofluids such as TiO2-W and SiO2-W in automotive cooling system is noted.

2. NANOFLUIDS

Nano fluids are fluids containing nanometer-sized particles called nanoparticles. i.e.Nano fluids are produced by suspending Nano particles in base fluid.

Potential Features of Nano fluids :

1. More stability than other colloids.
2. Reduced rate of erosion and clogging in micro channels.
3. Reduction in pumping power
4. Reduction in friction coefficient.
5. Better lubrication properties
6. Increase in thermal conductivity beyond exception and much higher than theoretical predictions.
7. Ultrafast heat transfer capacity.

2.1 Preparation of Nanofluids

Nanofluids can be prepared by using two methods

a) Two Step Method
b) One Step Methods

Two-Step Methods

According to recent studies regarding Nano fluids, used a two-step process in which nanoparticles are first produced as a dry powder either by physical or chemical method. Next step is to suspend nanoparticles into the base fluid by using magnetic force agitation, ball milling or by some other techniques This method is more widely used to produce Nano fluids because Nano powders are commercially available nowadays. Various types of physical, chemical, and laser-based methods are used for the production of the nanoparticles to be used for Nano fluids.

Nanoparticles can get agglomerate during the process. Hence to stabilize the nanoparticles surfactants are used. Though surfactants are used in this process it is quite difficult to produce stable nanofluid by using two step method Figure 2.1.a shows diagrammatic representation of two step method.

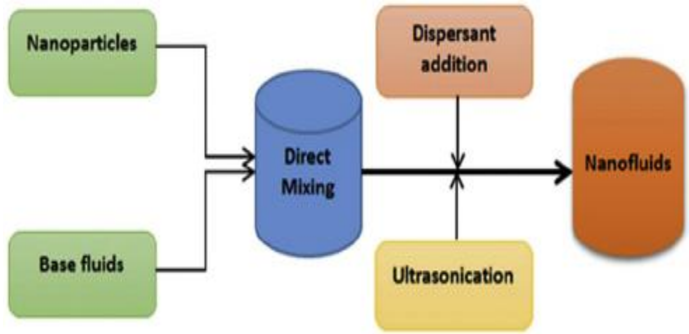

Fig 2.1.a:Preparation using Two Step Method

One Step Method

- Need of one step method

a) Agglomeration of nanoparticles in two step method (mixing in bulk during drying storage and transportation process)

b) Difficulties in dispersion stage in one step method.

c) Stability and thermal conductivity of Nano fluid is not ideal

Hence to overcome these effects one step method is developed. In one step method nanoparticles are made and dispersed at the same time which avoids agglomeration. This process includes drying, storage, transportation and dispersion in base fluid. Figure 2.1.b shows experimental setup for one step method. Use of this method gives highly dispersed, uniformly stable nanofluid. Though one step method has merits over two step method, it is not found successful in case of bulk production.

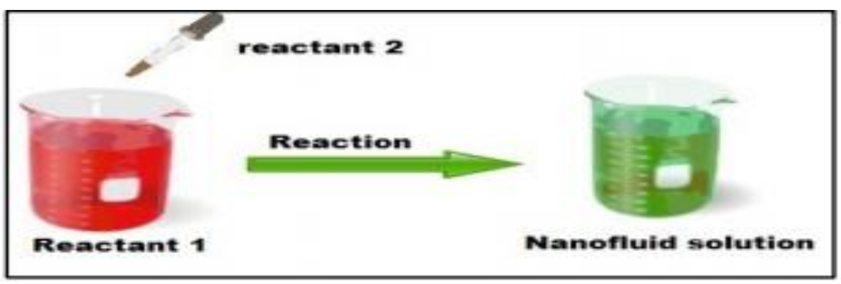

Fig.2.1.b: Preparation using one step method

2.2Factors Influencing Thermal Conductivity Enhancement

- **Nanoparticle size**

The size of the nanoparticle is an important factor to determine the thermal conductivity of the Nano fluid. The general trend in the experimental data is that the thermal conductivity of Nano fluids is inversely proportional with particle size. Hence lesser the size of particles suspended in a base fluid while creating the nanofluid more will be the ability of fluid to conduct the heat. Graph no. 2.2.1 shows the inverse relation of nanoparticle size and thermal conductivity of nanofluid

- **Nanoparticle Shape**

Enhancement in thermal conductivity is dependent on the geometrical shape of the nanoparticles. It was found that the nanoparticles having elongated and extended shapes have more thermal conductivity than spherical shaped nanofluids. Graph no. 2.2.2 shows the relation between nanoparticle shape and thermal conductivity.

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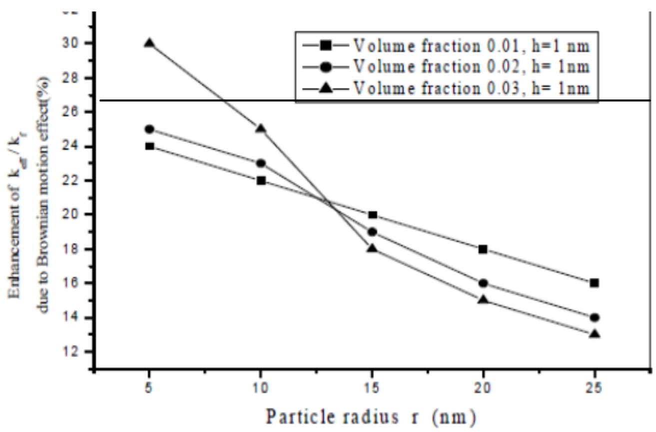
- **<u>Surfactant/Stabiliser</u>**

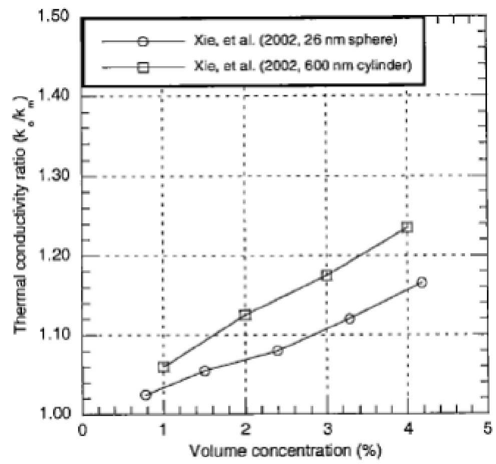
Stability of the nanofluid is a very important factor in deciding the thermal conductivity. If the nanofluid is not stable then the nanoparticles will show a tendency to get agglomerated and form a cluster and after certain limit it gets saturated. It is observed that freshly prepared Cu nanofluid shows more enhancement than the older one. The reason behind this is, in the freshly prepared nanofluids, nanoparticles are well. Graph no 2.2.3 shows relation between volume fraction and thermal conductivity and effect of stability of nanofluid.

- **<u>Nanoparticle Temperature</u>**

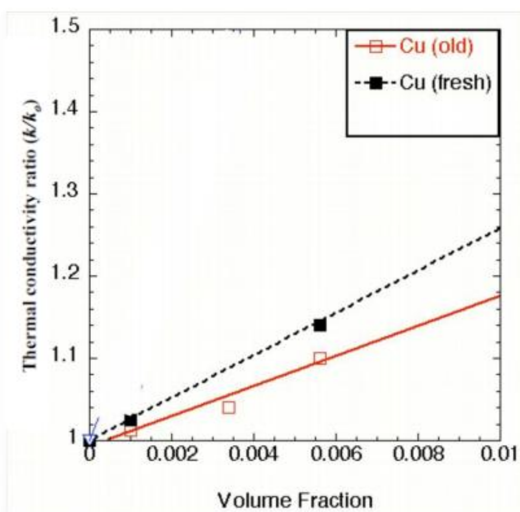
In conventional micro fluids thermal conductivity is dependent on operative temperature is only due to the dependence of the constituting part's thermal conductivity on the temperature. But in case of nanofluids various other factors emerges like clustering and Brownian motion of the nanoparticles which results in the dramatic change in the thermal conductivity with temperature. Graph no. 2.2.4 shows that nanoparticle temperature plays important role leading to improve thermal conductivity significantly.



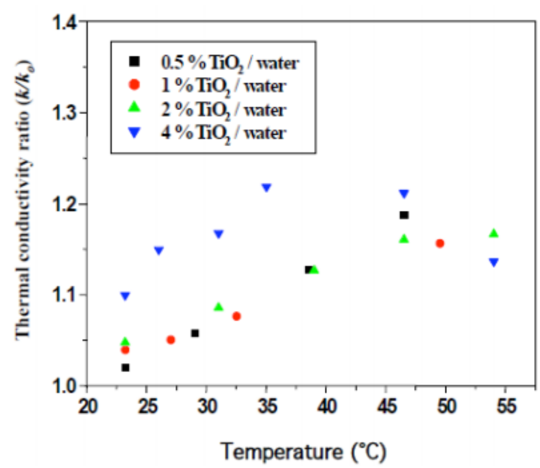
Graph 2.2.1



Graph 2.2.2



Graph 2.2.3



Graph 2.2.4

3. ADVANTAGES OF NANOFLUIDS

Nanofluids cause tremendous change in the properties of the base fluid so, the following benefits are expected to get on.

- Pressure drop is minimum, due to Nano size of particles.
- High thermal conductivity of nanoparticles Increases the heat transfer rate.
- Successful employment of nanofluid leading to lighter and smaller heat exchanger.
- Heat transfer rate is increased due to large surface area of the nanoparticles in the base fluid.
- Nanofluids are most suitable for rapid heating and cooling systems.
- Because of Nano size particles, fluid is considered as integral fluid.
- Well dispersed nanofluids will give better heat transfer.
- Nanofluids are not only a better medium for heat transfer in general but they are also ideal for micro channel applications where high heat loads are needed.
- Cost and energy saving.
- Successful use of nanofluids will result in significant energy and cost savings because heat exchange systems can be made smaller and lighter.

4. APPLICATIONS OF NANOFLUIDS

There is wide range of applications of nanofluids in industries now a days such as heat exchanging devices appear promising with these characteristics. Nanofluids can be used in following specific areas:

1. Heat-transfer nanofluids.
2. Tribiological nanofluids.
3. Surfactant and coating nanofluids.
4. Chemical nanofluids.
5. Process/extraction nanofluids.
6. Environmental (pollution cleaning) nanofluids.
7. Bio- and pharmaceutical-nanofluids.
8. Medical nanofluids (drug delivery and functional tissue–cell interaction).
9. Engine cooling
10. Nuclear cooling system
11. Cooling of electronic circuit
12. . Refrigeration
13. Enhancement of heat transfer exchange
14. Thermal storage
15. Biomedical application

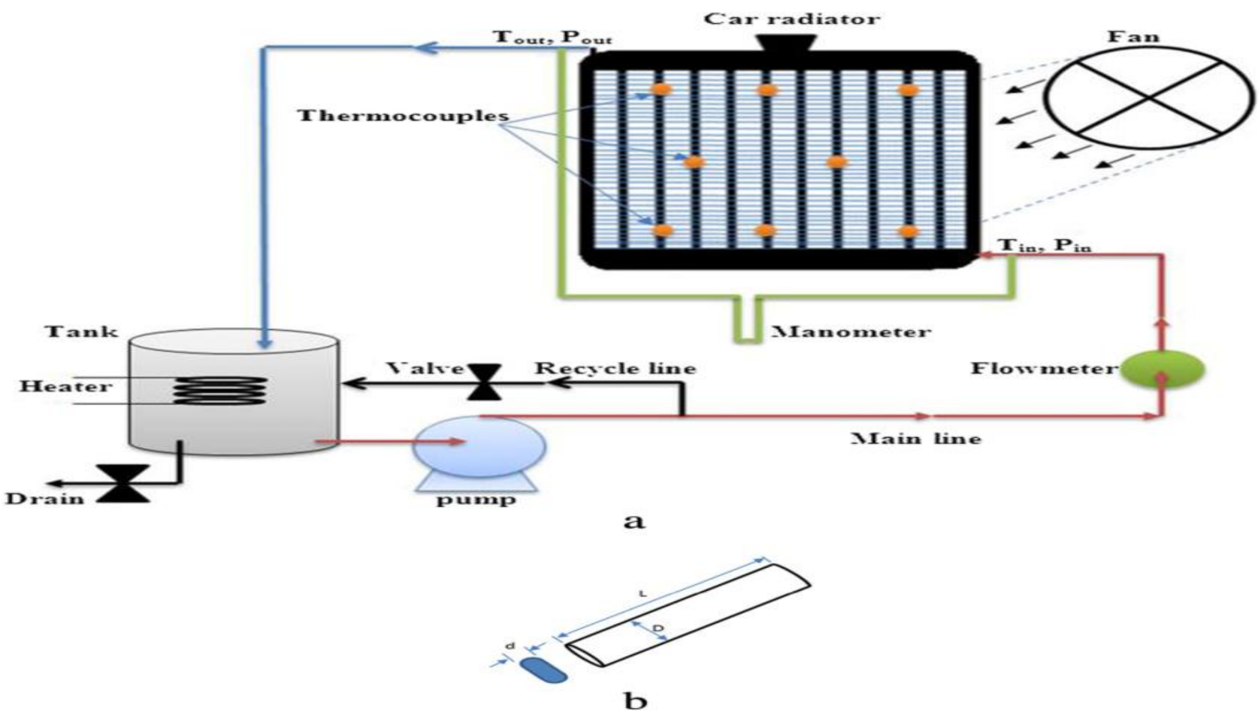
5. APPLICATION IN AUTOMOTIVE COOLLING SYSTEM

The increase in effective thermal conductivity is Important in improving the heat transfer behavior of fluids. A number of other variables also play key roles. For example, the heat transfer coefficient for forced convection in tubes depends on many physical quantities related to the fluid or the geometry of the system through which the fluid is flowing. These factors include intrinsic properties of the fluid like its thermal conductivity, specific heat, density, and viscosity, along with extrinsic system parameters such as tube diameter and length and average fluid velocity. Therefore, it is necessary to measure the heat transfer performance of nanofluids directly under flow conditions. Researchers have observed nanofluids have not only better heat conductivity but also greater convective heat transfer capability than that of base fluids. Figure 5.1 represents experimental setup to get results related to heat transfer enhancement using nanofluids

This experimental setup contains a plastic reservoir tank, an electric heater, a centrifugal pump, a flow meter, tubes, valves, a fan, a DC power supply, ten T-type thermocouples for temperature measurement, and a heat exchanger (automobile radiator). An electric heater (1500W) is kept inside a plastic storage tank (40 cm height and 30 cm diameter) represents the engine and to heat the fluid. A voltage regulator (0–220 V) provided the power to regulate the temperature in the radiator (60–80 °C). A flow meter (0–70 LPM) and two valves measure and control the flow rate. The fluid flow was measured through plastic tubes (0.5 in.) by a centrifugal pump (0.5 hp and 3 m head) from

the tank to the radiator at the flow rate range of 2–8 LPM. The total volume of the circulating fluid (3 l) was constant in all experimental steps. Two T-type thermocouples (copper–constantan) were connected to the flow line to record inlet and outlet temperatures of fluid. Eight T-type thermocouples also connected with the radiator surface for the surface area measurement. Due to the very small thickness and high thermal conductivity of the copper flat tubes, the inner and outer surfaces of the tube are equal temperature. A hand-held (−40 °C to 1000 °C) digital thermometer with the accuracy of±0.1% was used to read all the temperatures from thermocouples. Calibration of thermocouples and thermometers was carried out using a constant temperature water bath, and their accuracy was estimated to be 0.15 °C Peyghambarzadeh et al. Two small plastic tubes with a 0.25 inch diameter were connected at the inlet and outlet of the radiator and joined to U-tube mercury manometer with accurately scaled 0.5mmHg to measure the pressure drop at the inlet and outlet.
The car radiator has louvered fins and 32 flat vertical copper tubes with a flat cross-sectional area. The distance between the tube rows was filled with thin perpendicular copper fins. For the
air side, an axial force fan (1500 rpm) was installed close on axis line of the radiator. The DC power supply (type Teletron 10–12 V) was used instead of a car battery to turn the axial fan.

Fig. 5.1 Experimental Setup



5.1 Experimental data collection

According to Newton's cooling law the following procedure was followed to obtain the heat transfer coefficient and corresponding Nusselt number as :

$$Q = hA\Delta T = hA(T_b - T_a)\ldots\ldots\ldots.(1)$$

A is surface area of tube, Tb is the bulk temperature:

$$T_b = \frac{T_{in} - T_{out}}{2} \quad \ldots\ldots\ldots.(2)$$

(Tin, Tout) are inlet and outlet temperatures and Ts is the tube walltemperature which is the mean value measured by the two surface thermocouples as:

$$T_s = \frac{T_1 + \cdots\cdots T_8}{8}\ldots\ldots\ldots.(3)$$

Heat transfer rate is calculated by:

$$Q = mC\Delta T = m^{\blacksquare} C(T_{in} - T_{out}) \quad \ldots\ldots\ldots.(4)$$

$m^{\blacksquare}$ is the mass flow rate, which is determined as:

$$m^{\blacksquare} = \rho \times V^{\blacksquare} \quad \ldots\ldots\ldots.(5)$$

The heat transfer coefficient can be evaluated by collecting Eqs. (1)and (4):

$$h_{exp} = \frac{m^{\blacksquare} C(T_{in} - T_{out})}{nA_s(T_b - T_a)}$$

Where n is a number of radiator tubes, and the Nusselt number can be calculated as,

$$Nu = \frac{h_{exp} \times D_h}{k}$$

Dh - hydraulic diameter of the tube which estimated by description of the problem undertaken as cylindrical geometry

Assuming all thermal properties are estimated at the bulk temperatureof the fluid

Reynolds number (Re) is determined as:

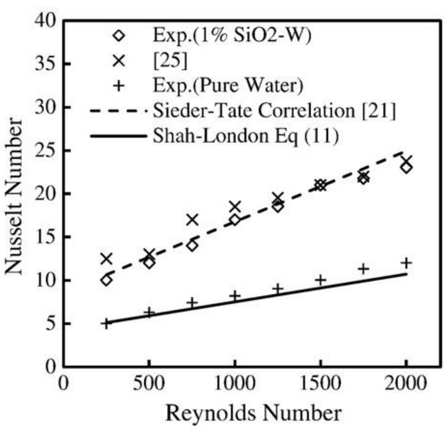
$$Re = \frac{\rho \times D_h \times u}{\mu}$$

Where u is the velocity at the inlet of the radiator

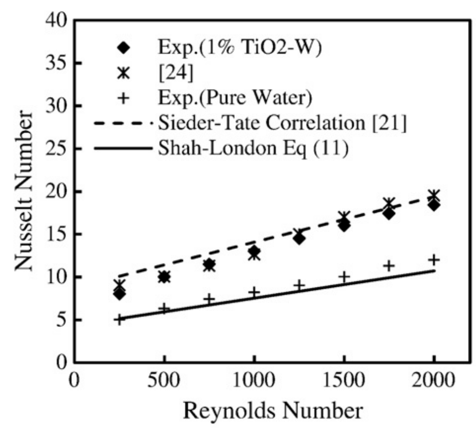
5.2 EXPERIMENTAL RESULTS

Materials	Density(Kg/m^3)	Sp. Heat(J/kg k)	Thermal conductivity (W/mK)	Viscosity (Pa.s)
Pure Water	998	4180	0.6067	.0014
TiO2	4175	692	8.4	-
SiO2	1009	4110	0.56	-

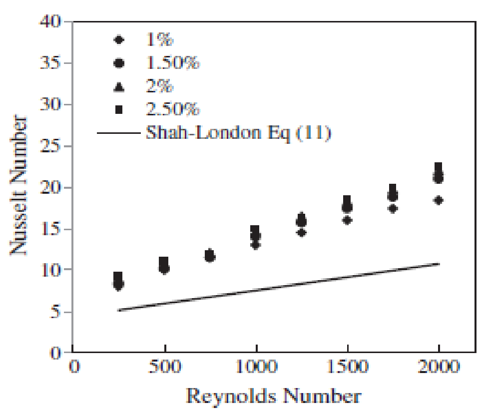
Table no 5.1



Graph no 5.1.1

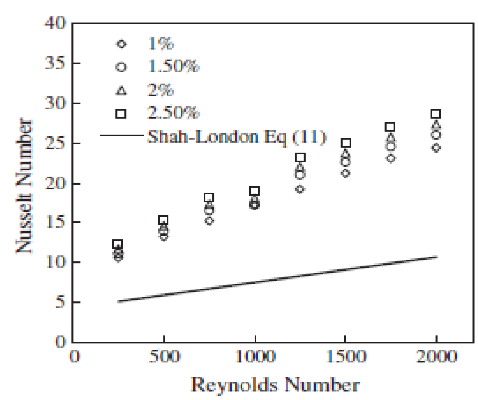


Graph no 5.1.2



b) TiO_2-W

Graph no 5.1.3



c) SiO_2-W

Graph no 5.1.4

Nusselt Number

1. $TiO_2 - W = 18.1733$
2. $SiO_2 - W = 20.63152$

Hence, by seeing observing the results it is clear that thermal conductivity of $SiO_2 - W$ is more than $TiO_2 - W$. Though thermal conductivity of SiO_2 is lesser than TiO_2 (from table no 5.1). Hence we can conclude that nanoparticles completely recreate the base fluid after dispersion and there is surely heat transfer enhancement in automotive cooling system when nanofluids are dispersed into radiator.

6. RESULTS AND CONCLUSION

- Heat transfer rate is directly proportional to Reynolds number
- Pressure drop increases with increase in volume concentration
- Spherical shaped nanomaterial give better heat transfer rate than other shapes
- Increase in size of nanoparticles leads to decrease in heat transfer rate due to low area per unit volume.
- The maximum enhancement of the Nusselt number is **22.5%** when Nano fluids and pure water are compared.
- Minimum pressure drop
- Higher thermal conductivity
- Lighter and smaller heat exchanger systems
- Suitable for rapid cooling systems
- Micro channel cooling without clogging
- Cost and energy saving

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