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Heat transfer enhancement using SiO_2/water nanofluid in an engine cooling system

Sourabh S. Ghorpade[1], P. G. Patole[2]

[1] PG student, Department of Mechanical Engineering, SCOE, Savitribai Phule Pune University, Maharashtra, India
[2] Assistant Professor, Department of Mechanical Engineering, SCOE, Savitribai Phule Pune University, Maharashtra, India

Abstract

In this paper, heat transfer enhancement using SiO_2 powder suspended in the pure water is presented. The objective of the experimental study is to discuss the thermal performance of car radiator using SiO_2/water nanofluid in the temperature ranges from (60^0C-80^0C) with different volume concentrations of nanoparticles 1%, 1.5%, 2%. The size of nanoparticle used is 30 nm. By changing the amount of SiO_2 nanoparticles blended with base fluid water, three different concentrations of nanofluids were obtained. The flow rate has been changed in the range of 2-8 lpm. In this study, heat transfer with the water based nanofluid is experimentally compared with that of the pure water as a coolant in an automobile radiator. The results show that Nusselt number increases with an increase in volume flow rate, nanoparticle volume concentration and slightly with increase in inlet temperature.

Keywords: Heat Transfer Enhancement, Nanofluid, SiO2, Radiator

1. Introduction

Cooling is one of the most facing challenges in numerous industries like automobile, manufacturing, electronics. Increasing thermal loads and requiring faster cooling are the new developments in the technologies in the automobile industry. The conventional methods of cooling like fins and micro-channels stretched their limits. Hence for achieving high performance cooling, there is need for new and advanced coolant. The thermal conductivities of traditional heat transfer coolants are very low. So it is needed to industries to develop energy efficient heat transfer fluid with the high thermal conductivities than available fluids to compete with rising global competition. The new coolants could reduce the overall size of the heat exchanger/radiator and possible to decrease automotive fuel consumption with their higher thermal performance. For that nanofluids are novel concept. Nanofluids are suspended nanoparticles, which are developed to overcome more demanding cooling challenges. Nanofluids are solid-liquid composites containing nanometer sized solid particles (<100 nm) suspended in heat transfer fluids like water, ethylene glycol, propylene glycol. Many researchers showed that convective heat transfer coefficient increases for nanofluids.

Due to the trend towards more powerful output, heat rejection requirement of automobile and trucks are continuously increasing. The benefits of using nanofluids in the heat exchangers and the heat transfer devices are: reduced weight, which improves fuel economy; smaller components, which requires small space under the bonnet and for greater latitude in aerodynamic styling, increases component life and more effective cooling. Also mining activities will be lower because less metal is required, which minimizes environmental impact and saves energy in metal production.

Traditional heat transfer fluids like water, oil, and ethylene glycol mixture are poor heat transfer fluids. There is a warm need to produce sophisticated heat transfer fluids, with importantly higher thermal conductivities and better heat transfer characteristics than are presently available. Despite considerable previous research and development focusing on industrial heat transfer requirements, major improvements in heat transfer capabilities have been held back on account of a fundamental limits in the thermal conductivity of conventional fluids. It has been known that the metals in solid form have thermal conductivities that are higher than those of fluids by orders of magnitude. For example, a thermal conductivity of a copper at the room temperature is around 700 times greater than that of water and about 3000 times greater than that of engine oil even the oxides like alumina (Al_2O_3), which are good thermal insulators as compared to metals like copper, has thermal conductivities more than an order of magnitude more than water. Therefore, fluids containing suspended solid particles are likely to show significantly enhanced thermal conductivities as compared to those of formal heat transfer fluids.

Nanoparticles are expected to revel superior properties compared to those of conventional heat transfer fluids and fluids containing micrometer sized particles. As the heat transfer takes place at the surface of particle, it is to be desired to use particle with large surface area. Particle with 10 nm diameter size has 1000 times lager surface area to volume ratio than that of the 10 μm diameter. This large surface area not only increases the heat transfer capability but also stability of suspension. Nanoparticles offers extremely large surface area, hence they have much potential for application in the heat transfer. Due to tendency to settle quickly and to clog off mini and micro channels, the use of conventional mini and micro channel is limited.

2. Literature Review

Nor Azwadi Che Sidik et al [1] has reported the review on application of the nanofluids in a vehicle engine cooling system to enhance heat transfer performance. A complete review has centered on experimental and numerical studies by previous researchers and suggest amount of the nanoparticles for optimum performance in vehicles. A heat transfer enhancement was represented for different nanofluids at various concentrations of nanoparticles.

Masoud Bozorg Bigdeli et al [2] reported the review on experimental, computational and physical evidences on heat transfer phenomena in nanofluids. He discussed the challenges to harnessing the benefits nanotechnology. The author highlighted the advantages of the nanofluids in the automotive heat exchanger as a coolant. The study represents theoretical and empirical models which describes thermo physical properties of nanofluids.

Dinesh Kumar Devendrian et al [3] were represented exhaustive review on the recent developments in the nanotechnology, the research gap in nanotechnology field. He discussed different nanoparticle manufacturing techniques, characterization technique used by different researchers, and recent theoretical models for thermo physical properties of the nanofluids.

Ravikanth S. Vajjah et al [4] was discussed the influence of the temperature and the concentration of the nanofluid on the thermo physical properties, heat transfer and the pumping power. He developed the correlations of thermo physical properties from measurements of three nanofluids (CuO, Al_2O_3, SiO_2 in 60:40 EG/W). And using these correlations he studied the variation of the nanofluids properties with change in temperature and concentration.

S. Lee and J. A. Eastman [5] was studied the thermal conductivity measurement of oxide nanoparticles. Transient hot wire method was used to measure the thermal conductivity of nanofluid. The results obtained through experiments were compared with Hamilton and Crosser model for four different concentrations of Al_2O_3 and CuO nanoparticles with water and ethylene glycol as a base fluid. The major difference between the experimental and theoretical model was the rate of increase of thermal conductivity strongly depends on particle size. The experimental result was also shown that the small amount of nanoparticles had substantially higher thermal conductivities than the same liquids without nanoparticles.

K. Y. Leong et al. [6] investigated the automotive car radiator performance operated with nanofluid as coolant. The Cu nanoparticles were scattered in the ethylene glycol base fluid up to 2% volume fraction. The complete mathematical formulation was done for evaluating radiator with cross flow heat exchanger. The air heat capacity, heat transfer coefficient, overall heat transfer coefficient, pumping power and total heat transfer rate were evaluated to predict the performance of radiator for nanofluid. As volume concentration of copper particles increased, the overall heat transfer coefficient also gets increased up to 40%. The effect of air and the coolant Reynolds number on thermal performance of radiator found the significant increase in heat transfer rate. About 3.8% heat transfer enhancement and the 18.7% reduction in frontal area was achieved at 2% copper particles dispersion.

Devireddy Sandhya et al [7] investigated experimental study of TiO_2 (0.1, 0.3 and 0.5% volume concentration) nanoparticle to base fluid ethylene glycol water in a car radiator. The effect of fluid inlet temperature, flow rate and nanoparticles volume concentration are considered for improving thermal efficiency of engine. The results shows that increasing the fluid circulation rate can improve the heat transfer performance while the fluid inlet temperature to the radiator has little or no effect. He investigated that, with low concentration of nanofluids, heat transfer rate enhances up to 37%.

Hafiz Muhammad Ali et al. [8] was studied the heat enhancement for ZnO-water nanofluids. The experiments were conducted to measure the heat transfer enhancement in an automotive radiator by using ZnO-water nanofluid (0.01, 0.08, 0.2 and 0.3% volume concentrations) with fluid flow rate 7-11 LPM and fluid inlet temperature in the range of 45 to 55 ^{0}c. The nanofluids show the heat transfer enhancement compared to that of base fluid. The heat transfer enhancement observed 46% at 0.2% volume concentration.

M. M. Elias et al. [9] was investigated the thermo physical properties of Al_2O_3 nanofluid through experiments. At the start, the Al_2O_3 nanoparticles dispersed in water and ethylene glycol base fluid in 0 to 1% volume concentrations. The thermo physical properties were investigated through experimental result and different correlation obtained from the literature survey. The results obtained for thermal conductivity from experiments shows higher percentage than compare to Hamilton-Crosser model. The other properties viscosity, specific heat, density measurement showed the little deviation from standard model results. The temperature effect was discussed for density, viscosity, specific heat at various volume fraction percentages of nanoparticles. The important result was obtained that the thermal conductivity increases with increase in temperature from 10 ^{0}C to 50 ^{0}C and higher thermal conductivities were found for higher volume concentrations of nanoparticles.

S. M. Peyghambarzadeh et al [10] had studied the effect of nanofluid concentration on the cooling system of vehicle radiator with alumina water nanofluid. The experimental investigation was done for three cases corresponding to different heat loads, coolant flow rates and different concentration of nanofluid. The parameters like Nusselt number, heat lost by coolant, heat transfer coefficient were studied to check the radiator performance. It was a complete experimental and mathematical procedure discussion of different parameters discussed above for a nanofluid and heat transfer enhancement by using nanofluid at different volume fraction percentage. He observed 45% heat transfer enhancement with 1% volume concentration compared to pure water.

3. Nanofluid preparation

For this experiment, nanofluid is prepared in the two steps. The measured quantity of the water and nanoparticles was mixed thoroughly. The mixture is stirred with mechanical stirrer. To avoid accumulation problem, mixture is kept in sonicator. And mixture kept for three days. After that it is stirred again.

4. Estimation of nanofluid properties

By considering nanoparticles dispersed well within the water; physical properties of nanofluid can be evaluated by using classical formulae which are used for two phase fluids. In this paper, following formulae are used to compute the physical properties of nanofluid like density, thermal conductivity, specific heat, viscosity for different concentrations and temperature.

$$\rho_{nf} = (1-\phi)\rho_f + \phi\rho_p \qquad (1)$$

$$C_{pnf} = \frac{(1-\phi)(\rho c_p)_f + \phi(\rho c_p)_p}{\rho_{nf}} \qquad (2)$$

$$\mu_{nf} = \mu_f(1 + 7.3\phi + 123\phi^2) \qquad (3)$$

$$K_{nf} = \frac{k_p + (z-1)k_f - \phi(z-1)(k_f - k_p)}{k_p + (z-1)k_f - \phi(k_f - k_p)} \qquad (4)$$

In above equations subscripts “p”, “f”, “nf” stands for particles, base fluid, nanofluids respectively. And “z” represents empirical shape factor. The nanoparticles in this experiment are nearly spherical in shape; we take value of “z” as 3. At a room temperature, water and SiO_2 nanoparticles have following characteristics:

Table 1

Properties of base fluid water and SiO_2 at room temperature (300 ^{0}k)

Property	Base fluid (water)	Nanoparticles (SiO_2)
Density ρ (Kg/m^3)	998	2220
Specific heat C_P (J/Kg ^{0}c)	4180	745
Thermal conductivity k (W/m^{0}k)	0.606	1.38
Viscosity (Pas)	0.0014	-

5. Experimental Setup and Procedure

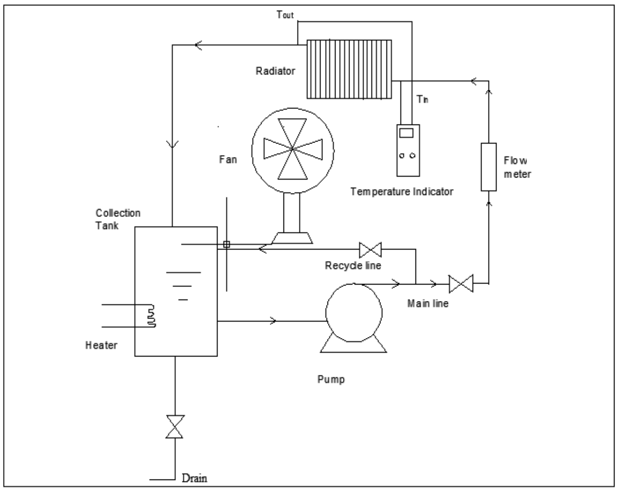

Fig.1 Schematic layout of Experimental Setup

As shown in the fig.1 experimental setup includes flow lines, storage tank, a centrifugal pump, an electric heater, flow control valve, flow meter, D.C. power supply, flow control valves, fan; 9 thermocouples type T to measure the temperature and the heat exchanger (automotive radiator). A heater (1500W) which represents the engine, heats the fluid. A controller (voltage regulator) is provided to control the temperature in the radiator (40-80^{0}c). The flow meter (0-10 lpm) is used to measure the flow rate. And the flow control valve is used to control the flow rate. Three layer insulated pipe is used as a connecting pipe. Two T type thermocouples attached to the flow line to measure inlet and the outlet temperatures. Six T type thermocouples were attached to surface of a radiator to measure a temperature of radiator surface. As the thickness of radiator tubes is very small, the inner and outer surface temperatures are equal. Calibration of thermocouples is done by using constant temperature water bath. A radiator has louvered fins with 49 vertical aluminum tubes. Thermal properties of nanofluids are calculated and used in the study. For cooling the liquid, a forced fan (1500 rpm) is installed near and face to face to radiator and air and fluid have cross flow contact. Constant temperature and velocity of air are considered in the experiment. To run the fan we use D.C. power supply instead of car battery. The nanofluids are prepared with volume concentration 1, 1.5, and 2 % volume concentrations having 30 nm size diameters. The thermal properties of base fluid water and the SiO_2 nanoparticles are given in the Table 1.

(a)

(b)

Fig. 2 Photographic view of total setup

The experimental setup is as shown in the fig. 1 and Fig. 2. The specifications of the radiator used in this experiment are shown in the Table 2.

Table 2

Radiator specifications

specification	Radiator of 4-strock, 4-cylinder petrol engine	Volume of coolant	5 liters
make	Maruti 800	Nanoparticle	SiO_2
Radiator size	380mm x 370mm x 17mm	Purity	99%
Tube side area	330905.3 mm^2	Blower	Axial Fan
Fin side area	2310000 mm^2	Water dispersibiity	95% and above

6. Experimental data analysis

According to the Newton's cooling law, heat transfer coefficient and corresponding Nusselt number are obtained as follows:

$$Q = hA\Delta T = hA_S(T_b - T_S) \tag{5}$$

Where A_S is the surface area of tube and T_b is a bulk temperature .

$$T_b = \frac{T_{in} + T_{out}}{2} \tag{6}$$

T_{in} and T_{out} are the inlet and outlet temperatures and T_S is the tube wall temperature which is average value measured by 6 surface thermocouples as:

$$T_s = \frac{T_1 + - - - + T_6}{6} \tag{7}$$

Heat transfer rate is calculated by:

$$Q = mC\Delta T = \dot{m}C(T_{in} - T_{out}) \tag{8}$$

$\dot{m}$ is mass flow rate(Kg/s) which is calculated as:

$$\dot{m} = \rho * V \tag{9}$$

V is the volume flow rate (m^3/s)

The heat transfer coefficient is evaluated by using Eqs. (5) and (8)

$$h_{exp} = \frac{\dot{m}C(T_{in} - T_{out})}{A_s(T_b - T_s)} \tag{10}$$

Nusselt number is calculated as

$$N_u = \frac{h_{exp} D_h}{k} \tag{11}$$

D_h is a hydraulic diameter of the tube

$$D_h = \frac{4\ X\ area}{perimeter} \tag{12}$$

7. Result and discussion

First experimental setup is run with the pure water. The experimental result for constant inlet temperature of 60 ^{0}c is shown in the Fig.3. It is seen that, Nusselt number increases with the increase in the volume flow rate for the water.

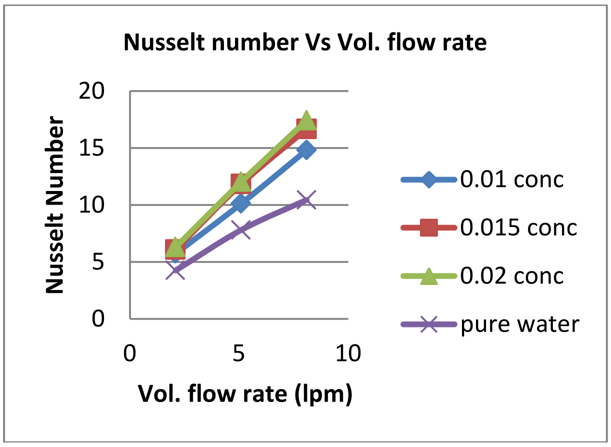

Fig.3 Nu no. variation of the nanofluid at different concentrations as function of the volume flow rate

Heat transfer enhancement is investigated experimentally in automotive radiator by using SiO_2 mixed with the water as a base fluid. Concentrations of the nanofluids 1%, 1.5% and 2% of SiO_2 are used in this experiment. And the flow rate is varied from 2 lpm to 8 lpm. Results obtained are shown in the fig. 3.
Effect of the nanofluid concentration on the Nusselt number at the constant inlet temperature is shown in the Fig.3. From the Fig.3, it is clear that addition of the nanofluids concentrations from 1% to 2%, enhances the heat transfer rate. It is observed that about 42% heats transfer enhancement is achieved.
Effect of the fluid flow rate with different volume concentrations of the nanofluids on the Nusselt number is shown in the Fig.3. It is clear from the figure that, heat transfer enhances with increase in volume flow rate of the fluid.

8. Conclusion

In this paper, heat transfer enhancement in the automotive radiator has been measured by using two working fluids: pure water and water based nanofluid (SiO_2 nanoparticles in the water) at different volume concentrations, temperatures and flow rates and the following conclusions are made from the experiment.

1. The SiO_2 nanoparticle in the water with water as a base fluid can enhance the heat transfer rate of automotive radiator. The heat transfer enhancement depends upon amount the of nanoparticles added to the pure water, volume flow rate and the inlet temperature to the radiator
2. The heat transfer enhancement is observed with increase of nanoparticle volume concentration from 0% to 2%.
3. Increasing the working fluid flow rate enhances the heat transfer rate for nanofluid and pure water considerably.
4. Nearly 30-42% heat transfer enhancement can be achieved using SiO_2 nanofluid.

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