An Experimental Study on the Influence of Operating Parameters on the Heat Transfer Characteristics of an Automotive Radiator with Nano Fluids

C Kannan, T Raja Jayasingh, M Vinoth & T Vijayakumar

Abstract: **In this research work, the heat transfer with water based nanofluids was experimentally compared to that of pure water as coolant in an automobile radiator. By varying the amount of Al2O3 nano particles blended with base fluid water, two different concentrations of nanofluids 0.25 % and 0.5 % (by vol.) were obtained. These nanofluids were allowed to flow through the vertical tubes present in the radiator. The flow rate ranges from 0.05 to 0.15 kg/s. The fluid inlet temperature was varying from 35°C to 59°C to find the optimum inlet condition. The increased rate of heat transfer was observed with an increase in volume flow rate, nano particle concentration. Rate of heat transfer was also found to be increasing with a decrease in temperature of hot nanofluid at the inlet.**

Keywords: **Cooling Performance, Flow Rate, Heat Transfer, Nano Fluids, Radiator.**

I. INTRODUCTION

Day by day, the need for improving the heat transfer rate from thermal equipments has been increasing for an effective cooling process. Even though, several methods are available at present to increase the heat transfer rate like introducing fins at the outer periphery of the thermal systems, increased flow rate of coolant through the thermal systems, these methods do have their own limitations. The increased flow rate of coolant also increases pump work thus results in low cyclic efficiency. The introduction of fins leads to undesirable size increase in thermal management system. The conventional fluids like water, engine oil, refrigerants are not satisfying need of high compactness and effectiveness.

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S Zeinali Heris et al [1] reported that heat transfer coefficient of a nanofluid increases with an increase in their nano particles concentration. However thermal conductivity is not the sole reason for heat transfer enhancement but other properties such as dispersion, chaotic movement of particles, brownian motion and particle migration are equally important.

Weerapun Duangthongsuk et al [2] conducted an experimental study on forced convective heat transfer of nanofluid where the nano fluid is a blend of water and 0.2% TiO_2 (by Vol.) under turbulent flow conditions. The final results confirmed an increased heat transfer coefficient with an increase in the mass flow rate of hot water and decrease in nano particle temperature.

Kim et al [3] investigated the effect of nanofluid on the performance of convective heat transfer coefficient of a circular straight tube having laminar and turbulent flow with constant heat flux. Authors have found that the convective heat transfer coefficient of alumina nanofluids is improved in comparison to the base fluid by 15% and 20% in laminar and turbulent flow respectively.

Rea et al [4] studied the convective heat transfer coefficient of alumina/water and zirconia/water nanofluids in a flow loop with a vertical heated tube. The heat transfer coefficient in the entrance region and in the fully developed region was found to increase by 17% and 27% respectively for alumina/water nanofluid at 6% (by vol.) whereas it was 2% in the entrance region and 3% in the fully developed region for zirconia/water nanofluid at 1.32% (by vol.) with respect to pure water.

Farajollahi et al [5] measured the heat transfer characteristics of g-Al_2O_3/water and TiO_2/water nanofluids in a shell and tube heat exchanger under turbulent flow condition. According to their report, the maximum enhancement of the overall heat transfer co efficient of g-Al2O3/water nanofluids was approximately 20% which occurred at 0.5% volume concentration. At the Peclet number of 50,000, the enhancements of the overall heat transfer coefficient at 0.3%, 0.75%, 1%, and 2% nano particle volume concentrations were about 14%, 16%, 15% and 9% respectively. For TiO_2/water nanofluids the maximum enhancement was observed at 0.3% particle volume concentration.

S M Fotukian et al [6] experimentally studied convective heat transfer of diluted CuO/water nanofluid inside a circular tube. They used nanofluids with nano particles of volume fraction less than 0.3%. The heat transfer coefficient increased about 25% when compared to that of pure water.

Xie et al [7] demonstrated that using Al_2O_3, ZnO, TiO_2 and MgO nanofluid with a mixture of 55% (by vol.) distilled water and 45% (by vol.) ethylene glycol as the base fluid in laminar flow inside a circular copper tube with constant wall temperature could enhance the convective heat transfer. MgO, Al_2O_3 and ZnO nanofluids exhibited superior enhancements of heat transfer coefficient, with the highest enhancement up to 252% at a Reynolds number of 1000 for MgO nanofluid.

Leong et al [8] investigated the performance of Cu/Ethylene Glycol nanofluids in an automotive car radiator. They revealed that overall heat transfer coefficient of 164 W/m2K can be achieved for 2% (by vol.) Cu/Ethylene Glycol nanofluid compared to that 142 W/m2K with the base fluid.

In this work, the objective of increased heat transfer rate from automobile radiator was analyzed using different nanofluids and at different concentrations. The influence of operating parameters like varying inlet temperature, varying flow rate and different concentration of nano fluids on the effective heat transfer rate from the radiator was also studied. The heat transfer correlations for different operating parameters were also developed and presented in this paper.

II. NANOFLUID PREPARATION AND STABILIZATION

The preparation of a stabilized nanofluid is of great importance in heat transfer applications which utilizes that nanofluid. Inappropriate preparation of nanofluid will render biphasic heat transfer and also poses the danger of nano particle aggregation Furthermore, particle instability results in particle fouling in reservoir, pipes, pumps and other equipment of thermal cycle, all of which are considered undesirable factors in our experiment. Al_2O_3 nano particles used in this study are approximately spherical with an average diameter of about 45 nm. Some other properties of the nano particle are shown in Table 1. The nanofluid under investigation was purchased in the form of colloidal dispersion from Alfa Aesar, US and the same was dispersed in the base fluid water using ultrasonicator for 2 hours prior to the experimentation. It has been found that the nanofluid had the lowest nano particle sedimentation and highest stability even after 60 h in a stationary state.

Table 1 Physical Properties of Nanofluid

Description	Value
Al_2O_3 Purity	99.5 %
Avg. Particle Size	45 nm
Specific Surface Area (m^2/g)	45
Bulk Density (kg/m^3)	260
True Density (kg/m^3)	3600
Morphology	Spherical
Crystal Phase	70 Delta: 30 Gamma
Thermal Conductivity (W/m°K)	25
Thermal Expansion Coefficient (/°C)	8.2×10^{-6}

III. EXPERIMENTAL SET UP

The schematic of the experimental system used in this research is shown in Fig 1. It includes a reservoir tank, a feed pump, an electrical heater, a flow meter, a forced draft fan, a temperature controller, two thermocouples and an automobile radiator. The test section of the radiator was placed in front of the forced draft fan and its configuration is the louvered fin-and-tube type. Nanofluid was allowed to pass through the 57 vertical tubes with stadium-shaped cross section. The fins and the tubes are made with aluminum.

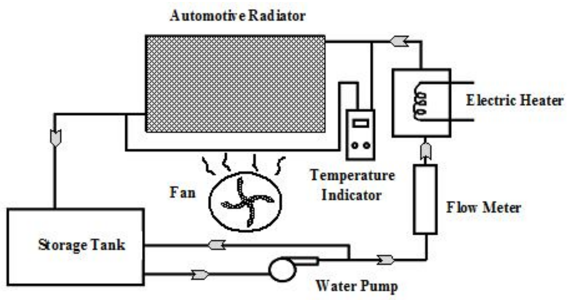

Fig 1.schematic of experimental setup

The size and dimensions of the radiator is shown in Table 2. For cooling the liquid, a forced draft fan (Almonard 1440 rpm) which is capable of producing air delivery of 270 m^3/hr was installed facing the radiator core. The inlet air temperature was about 27°C in the whole experiments. The pump was driven at constant speed to deliver a constant flow rate of 0.24 m^3/h, and the flow rate to the test section was being regulated by using an appropriate flow meter. The reservoir tank is having the storage capacity of approximately 32L in which, the working fluid always fills 62.5% of storage capacity. The connecting lines were covered with insulating materials to reduce heat loss to the surrounding. A flow meter (RMS Controls India) was used to control and manipulate the liquid flow rate with high precision. For heating the working fluid, an electrical heater (3000 W) and a temperature controller were used to vary the temperature between 35 and 59°C. Two K type thermocouples were implemented on the flow line to record the radiator fluid inlet and outlet temperatures. The temperatures from the thermocouples were measured by using a digital multimeter (RMS Controls India) with accuracy of 0.1 °C.

Table 2 Geometrical Properties of radiator

Description	Value
Fin type	Ruffled
Fin thickness (m)	0.04×10^{-3}
Hydraulic diameter (m)	0.6×10^{-3}
Frontal area of radiator (m^2)	129.8
Number of tubes	57

Uncertainty analysis

Errors and uncertainties in the experiments can arise from instrument selection, condition, calibration, environment, observation, reading and test planning. The percentage uncertainties of various parameters like coolant flow rate, air flow rate, coolant inlet temperature and outlet temperature were calculated using the percentage uncertainties of various instruments.

Total percentage uncertainty of this experiment is = Square root of {(uncertainty of coolant flow rate)^2 + (uncertainty of air flow rate)^2 + (uncertainty of inlet temperature)^2 + (uncertainty of outlet temperature)^2} = square root of {$(1)^2 + (1)^2 + (0.5)^2 + (0.5)^2$ } = 1.58%. Furthermore, to check the reproducibility of the experiments, some runs were repeated later which proved to have excellent repeatability.

IV. ESTIMATION OF NANOFLUID PROPERTIES

In this research, the nano particles had been dispersed within the base fluid using ultrasonicator and further it was assumed uniform particle concentration throughout the system. The effective physical properties of nanofluid like density, specific heat, viscosity and thermal conductivity at different temperatures and concentrations were calculated using the following relations

$$\rho_{nf} - \varphi.\rho_p + (1-\varphi).\rho_w \quad (1)$$

$$(\rho C_p)_{nf} = \varphi.(\rho C_p)_p + (1-\varphi).(\rho C_p)_w \quad (2)$$

$$\mu_{nf} = \mu_w(123\varphi^2 + 7.3\varphi + 1) \quad (3)$$

$$k_{nf} = \frac{k_p + (n-1)k_w - \varphi\,(n-1)\,(k_w - k_p)}{k_p + (n-1)k_w + \varphi\,(k_w - k_p)}\, k_w \quad (4)$$

In the above equations, the subscripts p, w and nf refer to the particles, water, and nanofluid respectively. n is empirical shape factor given by n = 3/ψ where ψ is the particle sphericity and is defined as the ratio of the surface area of a sphere with volume equal to that of the particle, to the surface area of the particle, and in this paper n considered to be 3 and φ is volume fraction of the nano particle added to the water.

V. RESULTS AND DISCUSSION

In order to check the accuracy and reliability of the experimental set up, some experiments were conducted with pure water as coolant prior to the usage of nanofluids in the radiator. These experiments were conducted for varying flow rate and varying inlet temperature the water. The results were shown in the Fig 2

The experimental runs were extended to the usage of nanofluids in the radiator but with different concentrations of nanofluids. The concentration of nanofluids used in this experiments were 0.25 % and 0.5 % Al_2O_3 in Water (Vol %). While the flow rate was varied from 0.05 kg/s to 0.15 kg/s, the inlet temperature was varied from 35°C to 59°C in these runs. The results were shown in Fig 3 and 4.

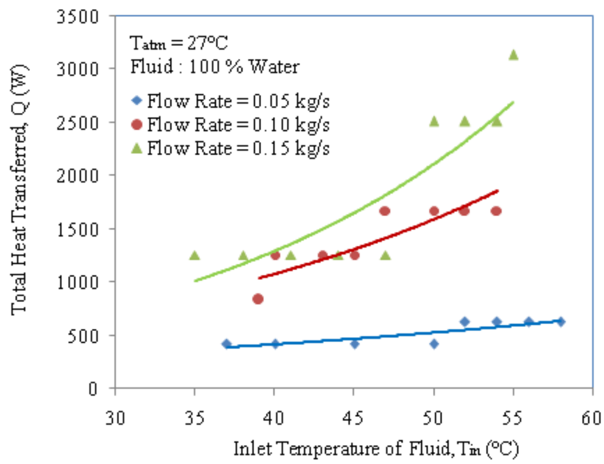

Fig 2. The influence of inlet temperature and flow rate of water coolant on the total heat transferred from radiator

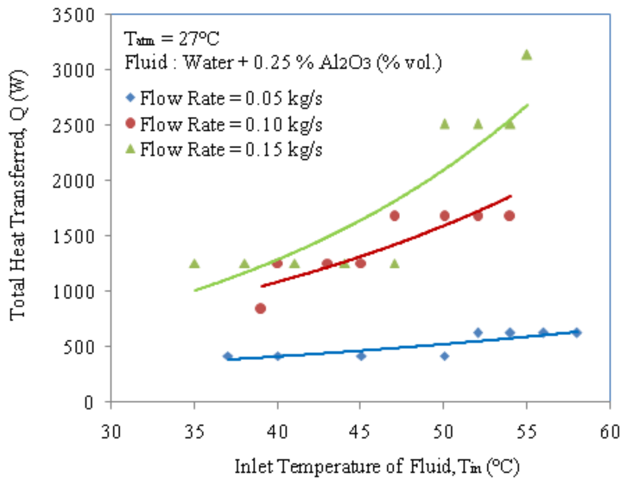

Fig 3. The influence of inlet temperature and flow rate of Al_2O_3 nanofluid (0.25 % Vol) on the total heat transferred from radiator

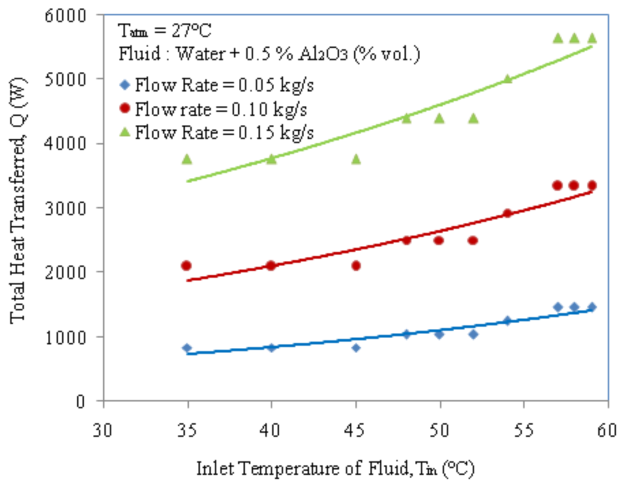

Fig 4. The influence of inlet temperature and flow rate of Al_2O_3 nanofluid (0.50 % vol) on the total heat transferred from radiator

The effect of flow rate and nano fluid concentration on the amount of heat transferred from the automotive radiator for a constant inlet coolant temperature of 50°C was shown in Fig 5. From the figure, it was evident that an increase in the coolant flow rate optimistically influenced the amount of heat transferred. The same trend was observed in all the three cases, when the nano fluid concentration was increased from 0 % to 0.25 % and then next to 0.50 % (vol.). This may be due to the fact that increased thermal conductivity due to the addition of nano particles in the base fluid water. The thermal conductivity was increased 0.7 % and 1.4 % for 0.25 % and 0.50 % nanofluid concentrations respectively.

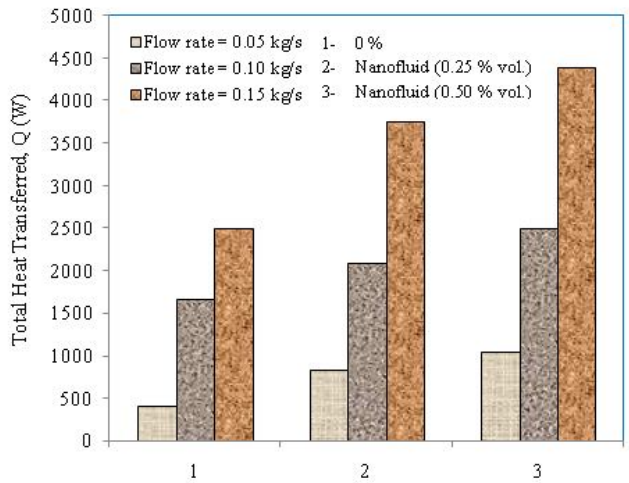

Fig 5. Effect of flow rate and concentration of nanofluid on the total heat transferred

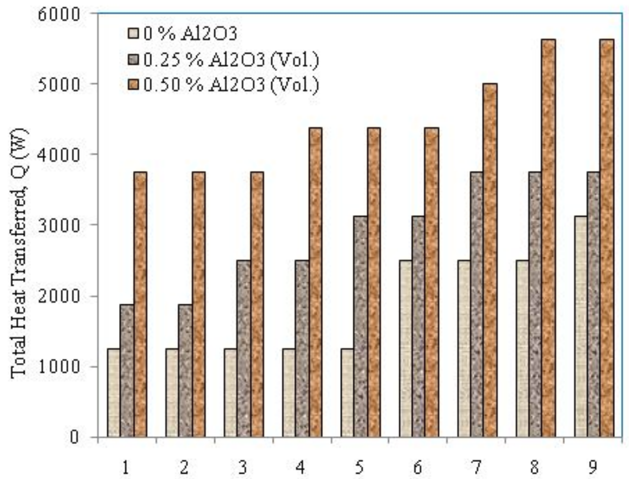

Fig 6. Effect of nanofluid concentration of nanofluid on the total heat transferred for varying inlet temperature

The effect nano fluid concentration on the amount of heat transferred from the automotive radiator for varying inlet temperature of coolant from 35°C to 57°C was shown in Fig 6. The outlet temperature was measured for every 3°C increase in the inlet temperature. From that, the amount of heat transferred from the radiator was calculated. An increase in heat transfer was observed for the increase in coolant temperature. As the concentration of nanofluid increases, the amount of heat transferred was also found to be slightly increased.

VI. CONCLUSION

In this experimental research work, the total heat transferred from an automotive radiator was determined using two working fluids: water and water based nanofluid (Al_2O_3) at two different concentrations 0.25 and 0.50% on volume basis. From the experimental work, the following conclusions were made.

1. The addition of Al_2O_3 nano particles to the base fluid water significantly improves the heat transfer characteristics. This might due to the improved thermal conductivity of water based nanofluid when compared to pure water as coolant.
2. The total heat transferred was also found to be increasing with an increase in the flow rate of circulating coolant. The same trend was observed for both working fluids: water and water based nanofluid irrespective of their concentrations.
3. The total heat transferred also found to be increasing with an increase in the inlet temperature of the coolant. This trend was observed with all working fluids under all concentrations.
4. Out of the three operating parameters considered, total amount of heat transferred was much dominated by nanofluid concentration rather than the other two operating parameters: flow rate and inlet temperature of coolant.
5. For constant flow rate of coolant (0.10 kg/s), an increase of 24 % and 49 % in total of heat transferred was observed with 0.25 % and 0.50% nanofluid concentrations.

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