Scientific Journal Impact Factor (SJIF): 3.518
International Journal of Modern Trends in Engineering and Research
ISSN (ONLINE) : 2349 - 9745 ISSN (PRINT) : 2393 - 8161

Investigation of Heat Transfer Performance Of A Car Radiator Using Nanofluid As Coolant

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Abstract— In this paper, results of experiment carried out on an automotive radiator with water and water based Al_2O_3 nanofluids are compared. The experimentation is done by considering variable parameters so as to study the effect of flow rate, inlet temp of coolant and volume fraction of nanofluids on thermal performance of automotive radiator. 13nm sized Al_2O_3 particle are dispersed in water with 0.5-2.5vol% with twostep method. These fluids are made to flow through a radiator with flow rate of 6-8lpm to have fully turbulent regime. Also the effect of fluid inlet temperature to radiator on heat transfer performance been analyzed by keeping the temperature at 60°C. Results showed improved heat transfer performance with increasing fluid circulation rate. The presence of 13nm sized alumina nanoparticles in water enhances the heat transfer rate of the automobile radiator. At the concentration of 2 vol% the heat transfer enhancement of 38% compared to pure water was recorded.

Key words- Nanofluid, Radiator, Volume fraction, Thermophysical properties.

I. INTRODUCTION

At present, several methods are available to increase the heat transfer rate like incorporating 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. Looking at these challenges, an optimization process is mandatory to obtain the best design enhance performance,and minimize size or shape and weight.

Continuous technological development in automotive industries has increased the requirement for high efficiency engines. An efficient engine is not only based on its performance but also for better fuel economy and less emission. Reducing a vehicle weight by optimizing design of a radiator is a necessity for making the world green. The radiator is an important accessory of an automotive engine. Addition of fins is one of the methods to increase the cooling rate of the radiator. Addition of fins provides greater heat transfer area and enhances the air convective heat transfer coefficient. However, traditional approach of increasing the cooling rate by using fins and micro-channel has already reached to their limit.

Nanofluids have gained attention as a new generation of heat transfer fluids in automotive cooling applications, because of their excellent thermal performance. A Nano fluid is a mixture of base fluid and suspended metallic/metal oxide nanoparticles. Since the thermal conductivity of metallic solids are typically orders of magnitude higher than that of fluids it is expected that a solid/fluid mixture will have higher effective thermal conductivity compared to the base fluid. Thus, the presence of the nanoparticles changes the transport properties of the base fluid there by increasing the effective thermal conductivity and heat capacity, which ultimately enhance the heat transfer rate of nanofluids. Because of the small size of the nanoparticles (10^{-9} m), nanofluids incur little or no penalty in pressure drop and other flow characteristics when used in low concentrations.

Nano fluids are extremely stable and exhibit no significant settling under static conditions, even after weeks or months. Advancements in material technology have provided the opportunity to produce material particles at the nano (10^{-9}) scale. These particles have very different properties, like mechanical and electrical, than their full scale parent materials. Nanoparticles are a particle consisting of dimensions approximately 0.1-1000 nm in size. Some of the common oxide nanoparticles being used in heat transfer research are Zinc Oxide (ZnO), Copper Oxide (CuO), Aluminium Oxide (Al_2O_3), and Titanium Oxide (TiO_2) while some of the metal nanoparticles are Gold (Au), Silver (Ag), and Copper (Cu). Enhancement of heat transfer mechanism of nanofluids are attributed to chaotic movement of the ultra-fine particles and increase in thermal conductivity due to the suspension of nanoparticles, nanofluids have the potential to revolutionize the way heating or cooling needs are met in the future. Nanofluids that are able to increase the efficiency of heat transfer will lead to lower operational and capital costs, which translates into cost savings, reduction of waste and positive environmental impact. Nanoparticles have unique properties, such as large surface area to volume ratio, dimension-dependent physical properties, and lower kinetic energy, which can be exploited by the nanofluids. At the same time, the large surface area make nanoparticles better and more stably dispersed in base fluids. Compared with micro-fluids or mili-fluids, Nano fluids stay more stable, so nanofluids are promising for practical applications without causing problems mentioned above. Nanofluids well keep the fluidic properties of the base fluids, behave like pure liquids and incur little penalty in pressure drop due to the fact that the dispersed phase (nanoparticles) are extremely tiny, which can be very stably suspended in fluids with or even without the help of surfactants (Xuan and Li 2003). A most attractive characteristic of nanofluids is that even by the addition of small amount of nanoparticle, they show anomalous enhancement in thermal conductivity over 10 times more than the theoretically predicted. Eastman et al (Eastman et al. 2001) reported a 40% thermal conductivity increase in ethylene glycol by adding only 0.3 vol. % of copper nanoparticles with a diameter smaller than 10 nm. Following are some of the research paper of the researcher on the investigation for enhancing the thermal performance of automotive cooling system by studying the different parameters.

R. S. Vajjha et al [1] numerically studied a three-dimensional laminar flow and heat transfer with two different nanofluids, Alumina (Al2O3) and Copper oxide (CuO), in an ethylene glycol and water mixture circulating through the flat tubes of an automobile radiator. They validated numerical results from the simulation for the flow of water by comparing the friction factor and the Nusselt number in flat tubes, for which accurate results were available in the literature. Then, the model was applied to study the peripheral variations of shear stress and convective heat transfer coefficient. Convective heat transfer coefficient in the developing and developed regions along the flat tubes with the nanofluid flow showed marked improvement over the base fluid. Results for the local and the average friction factor and convective heat transfer coefficient showed an increase with increasing particle volumetric concentration of the nanofluids. Also they observed increased heat transfer coefficient and the friction factor with increasing volumetric concentrations of nanofluids at various Reynolds numbers.

A. M. Hussein et al [2] studied the variation of friction factor in forced convection heat transfer of Silver oxide (SiO2) nanoparticle dispersed in water. They conducted an experiment on a car radiator. Four different concentrations of nanofluids in the range of 1-2.5 vol% have been used for experimentation. The flow rate was varied in the range of 2-8 LPM to have Reynolds number with the range 500-1750. Their results showed that the friction factor decreases with an increase in flow rate and increase with increasing in volume concentration. Furthermore, the inlet temperature to the radiator has insignificantly affected the friction factor. On the other side it noted that, Nusselt number increases with increasing flow rate, nanofluid volume concentration and inlet temperature. Also, application of SiO2 nanofluid with low concentrations enhanced heat transfer rate up to 50% as a compared to pure water.

S. M. Peyghambarzadeh et al [3] investigated the heat transfer performance of pure water and pure Ethylene glycol compared with their binary mixtures. Furthermore, different amounts of Al2O3 nanoparticle were added into these base fluids and its effects on the heat transfer performance of the car radiator have been determined experimentally. Authors changed the liquid flow rate in the range of 2-6 liter per minute and the fluid inlet temperature was varied for all the experiments. The results demonstrate that nanofluids clearly enhance heat transfer compared to their own base fluid. In the best conditions, the heat transfer enhancement of about 40% compared to the base fluids has been recorded.

A. M. Hussein et al [4] performed an experiment to find out heat transfer enhancement using TiO2 and SiO2 nanopowders suspended in pure water. The effects on heat transfer enhancement under the operating conditions were analyzed under laminar flow conditions. The volume flow rate, inlet temperature and nanofluid volume concentration were maintained in the range of 2-8 LPM, 60-80 °C and 1-2% respectively. The results showed that the Nusselt number increased with volume flow rate and slightly increased with inlet temperature and nanofluid volume concentration. These experimental results were found to be in good agreement with other researchers' data, with a deviation of only approximately 4% .

P. K. Namburu et al [5] studied heat transfer of three different nanofluids (Copper oxide, aluminium oxide and silver oxide) in an ethylene glycol and water mixture flowing through a circular tube under constant heat flux condition. From experimentation they developed new correlations for viscosity up to 10% volume concentration for these nanofluids as a function of volume concentration and temperature. Computed results are validated with existing well established correlations. Nusselt number prediction for nanofluids agrees well with Gnielinski correlation. It is found that nanofluids containing smaller diameter nanoparticles have higher viscosity and Nusselt number. Comparison of convective heat transfer coefficient of Copper oxide (CuO), aluminium oxide (Al2O3) and silver oxide (SiO2) nanofluids have been presented. At a constant Reynolds number, Nusselt number increases by 35% for 6% CuO nanofluids over the base fluid.

M. Naraki et al [6] conducted an experiment to investigate, the overall heat transfer coefficient of CuO/water nanofluids under laminar flow regime ($100 < Re < 1000$) in a car radiator. The nanofluids in all the experiments have been stabilized with variation of pH and use of suitable surfactant. The results showed that the overall heat transfer coefficient with nanofluid is more than the base fluid. The overall heat transfer coefficient is increased with the increase in the nanofluid concentration from 0 to 0.4 vol.%. Conversely, the overall heat transfer coefficient decreased with increasing the nanofluid inlet temperature from 50 to 80 °C. The implementation of nanofluid increases the overall heat transfer coefficient up to 8% at nanofluid concentration of 0.4 vol.% in comparison with the base fluid.

C. Oliet et al [7] developed a set of parametric studies performed on automotive radiators by means of a detailed rating and design heat exchanger model. This numerical tool was verified and validated using a wide experimental data bank. A part of the analysis was focusing on the influence of working conditions on both fluids (mass flows, inlet temperatures) and the impact of the selected coolant fluid. Their work provides an overall behaviour report of automobile radiators working at usual range of operating conditions, while significant knowledge based design conclusions have also been reported. The results showed the utility of numerical model as a rating and design tool for heat exchangers manufacturers, being a reasonable compromise between classic E — NTU methods and CFD.

K. Y. Leong et al [8] focused on the application of ethylene glycol based copper nanofluids in an auto-motive cooling system. Relevant input data, nanofluid properties and empirical correlations were obtained from literatures to investigate the heat transfer enhancement of an automotive car radiator operated with nanofluid-based coolants. It was observed that, overall heat transfer coefficient and heat transfer rate in engine cooling system increased with the usage of nanofluids (with ethylene glycol the basefluid) compared to ethylene glycol (i.e. basefluid) alone. It is observed that, about 3.8% of heat transfer enhancement could be achieved with the addition of 2% copper particles in a basefluid at the Reynolds number of 6000 and 5000 for air and coolant respectively. In addition, the reduction of air frontal area was estimated.

S. M. Peyghambarzadeh et al [9] experimentally compared the performance of forced convective heat transfer in a water based nanofluid to that of pure water in an automobile radiator. Five different concentrations of nanofluids in the range of 0.1-1 vol.% have been prepared by the addition of Al2O3 nanoparticles into the water. The test liquid was allowed to flow through the radiator consisted of 34 vertical tubes with elliptical cross section and air was allowed to flow in a cross direction inside the tube bank with constant speed. Liquid flow rate has been changed in the range of 2-5 lpm to have the fully turbulent regime (9 x 103 < Re < 2.3 x 104). Additionally, the effect of fluid inlet temperature to the radiator on heat transfer coefficient also been analyzed by varying the temperature in the range of 37-49 °C. Results demonstrate that increasing the fluid circulating rate can improve the heat transfer performance while the fluid inlet temperature to the radiator has trivial effects. Meanwhile, application of nanofluid with low concentrations can enhance heat transfer efficiency up to 45% in comparison with pure water.

S. M. Peyghambarzadeh et al [10] experimentally evaluated the heat transfer performance of the automobile radiator by calculating the overall heat transfer coefficient (U) according to the conventional E-NTU technique. Copper oxide (CuO) and Iron oxide (Fe2O3) nanoparticles were added to the water at three concentrations 0.15, 0.4, and 0.65 vol.% with considering the best pH for longer stability. In these experiments, the liquid side Reynolds number is varied in the range of 50-1000 and the inlet liquid to the radiator has a constant temperature which is changed at 50, 65 and 80 °C. The ambient air for cooling of the hot liquid is used at constant temperature and the air Reynolds number is varied between 500 and 700. However, the effects of these variables on the overall heat transfer coefficient are deeply investigated. Results demonstrate that both nanofluids show greater overall heat transfer coefficient in comparison with water up to 9%. Furthermore, increasing the nanoparticle concentration, air velocity, and nanofluid velocity enhances the overall heat transfer coefficient. In contrast, increasing the nanofluid inlet temperature, lower overall heat transfer coefficient was recorded.

II. MODEL OF AUTOMOTIVE COOLING SYSTEM

A cooling system accomplishes the cooling action with the help of coolant. Conventional fluids such as refrigerants, water, ethylene glycol etc have poor heat transfer performance. Recent developments in nanotechnology have allowed new category of fluids called nanofluids. These nanofluids possess good thermal properties as compared to the conventional fluids.

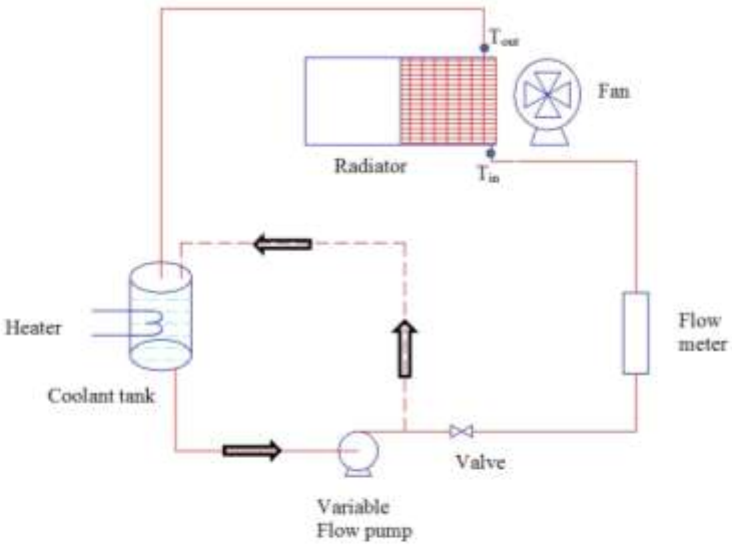

Fig.1 Schematic diagram of experimental set up of automotive cooling system with radiator

In order to measure the liquid side heat transfer coefficients in the car radiator, a flow loop shown in Fig.1 is being used. This experimental rig includes a storage tank, a heater, a pump, a flow meter, a forced draft fan, a cross flow finned tube heat exchanger (car radiator), and flow lines. The test fluid flows through the insulated tubes (0.75 inch diameter) from the feed tank to the radiator by a pump which discharges fluid in the range of 2 lpm to 5 lpm. Storage tank (height of 35 cm and diameter of 30 cm) has volume of 30 liters and the working liquid would fill 25%. Consequently, the total volume of the circulating liquid is constant in all the experiments. A flow meter will be used to control and manipulate the flow rate with the precision of 0.1 liter per minute. For heating the working fluid, an electrical heater and a controller were used to maintain the temperature between 30 and 50 °C. Two RTDs to be implemented on the flow line to record radiator fluid inlet and outlet temperatures. Two other J-type thermocouples also to be used for radiator wall temperature measurement. These thermocouples are to be installed at the centre of the radiator surfaces (both sides). Due to very small thickness and very high thermal conductivity of the flat tubes, it is reasonable to equate the inside temperature of the tube with the outside one. The measured temperatures from these thermocouples and RTDs will be been shown on digital monitors. All used thermocouples and RTDs are thoroughly calibrated by using a constant temperature water bath. For cooling the liquid, an axial forced fan is to be was installed close on axis line of the radiator and consequently air and water have indirect cross flow contact. There is no dispersant or stabilizer added to the nanofluid. This is due to the fact that the addition of any agent may change the fluid properties and the interested area is to simulate the easiest actual condition encountered in the car radiator. Additionally, creating highly turbulent flow condition in the radiator tubes and connecting pipes can improve the stabilization of the nanoparticle in water.

III. EXPERIMENTAL DATA ANALYSIS

To obtain heat transfer coefficient and corresponding Nusselt number, the following procedure has been performed. According to Newton's cooling law:

$$Q = hA\Delta T = hA(Tb - Tw) \tag{1}$$

Heat transfer rate can be calculated as follows:

$$Q = mCp\Delta T = mCp(Tin - Tout) \tag{2}$$

Regarding the equality of Q in the above equations

$$\text{Nusselt number, } Nu = \frac{h \times dh}{k} = \frac{mCp(Tin - Tout)}{A(Tb - Tw)} \tag{3}$$

Nu is average Nusselt number for the whole radiator, m is mass flow rate which is the product of density and volume flow rate of fluid, Cp is fluid specific heat capacity, A is peripheral area of radiator tubes, Ti and Tout are inlet and outlet temperatures, Tb is bulk temperature which is assumed to be the average values of inlet and outlet temperature of the fluid moving through the radiator, and Tw, is tube wall temperature which is the mean value by two surface thermocouples. In this equation, k is fluid thermal conductivity and dh is hydraulic diameter of the tube.

Also, comparison is made between the experimental data and two well-known empirical correlations: one of them suggested by Dittus—Boelter and the other developed by Gnielinsky. These two relations are shown in Eqs. (4) and (5) respectively. In Eq. (5), f is friction factor and is calculated using Eq. (6) suggested by Filonenko.

$$\text{Dittus-Bolter equation, } Nu = 0.0236\ Re0.8\ Pr0.3 \tag{4}$$

$$\text{Gnielinsky equation, } Nu = \frac{\frac{f}{8}(Re - 1000)Pr}{1 + 12.7(f/8)^{0.5}(Pr^{2/3} - 1)} \tag{5}$$

$$\text{Where, } f = (0.79 \ln Re - 1.69)^{-2} \tag{6}$$

Fairly good agreement can be seen between Dittus—Boelter equation and the measurements over the Reynolds number range used in this study. The results show the correlation presented by Gnielinsky did not agree with the present experimental values for water flow in flat tubes. Results for all the different water temperatures at the radiator inlet ranging between 50°C to 65°C demonstrated that Dittus—Boelter relation has 5% absolute average error while this value for the correlation of Gnielinsky is 45%. Above 65°C there is major difference in the experimental value of Nu and both the correlations.

IV. RESULTS AND DISCUSSIONS

4.1 Influence of volume flow rate of coolant on temperature of coolant at radiator exit

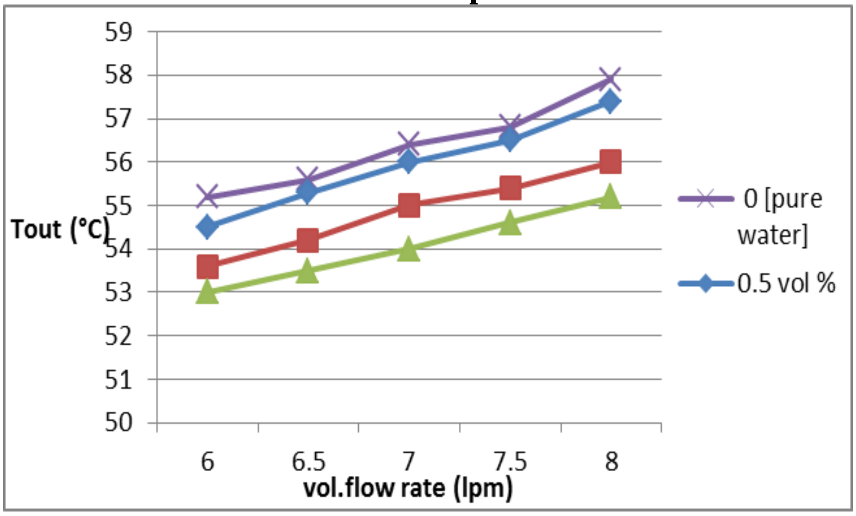

Fig. 2 Comparison of radiator cooling performance when using Nano fluid and pure water at 60°C

Fig. 2 shows the radiator outlet temperature, Tout, as a function of fluid volume flow rate circulating in the radiator. Four series of data shown in the figure belongs to pure water and three different concentrations of nanofluids. The data represented is measured when temperature of coolant entering the radiator was 60°C. From graph it is clearly observe that fluid outlet temperature is decreasing with the increasing volume percentage of nanoparticles into basefluids.

1.2 Influence of Reynolds number of coolant on heat transfer performance of radiator

Fig. 3 shows the enhancement in heat transfer performance of a radiator when water is replaced with nanofluids as a working fluid. Increase in Nusselt number with increasing Reynolds number of coolant can be observed clearly. Nusselt number in all the concentrations is increased with the increase in flow rate and consequently Reynolds number. By the addition of 2 vol% of Al_2O_3 nanoparticle into the pure water, an increase of about 30% to 35% in comparison with the pure water heat transfer coefficient.

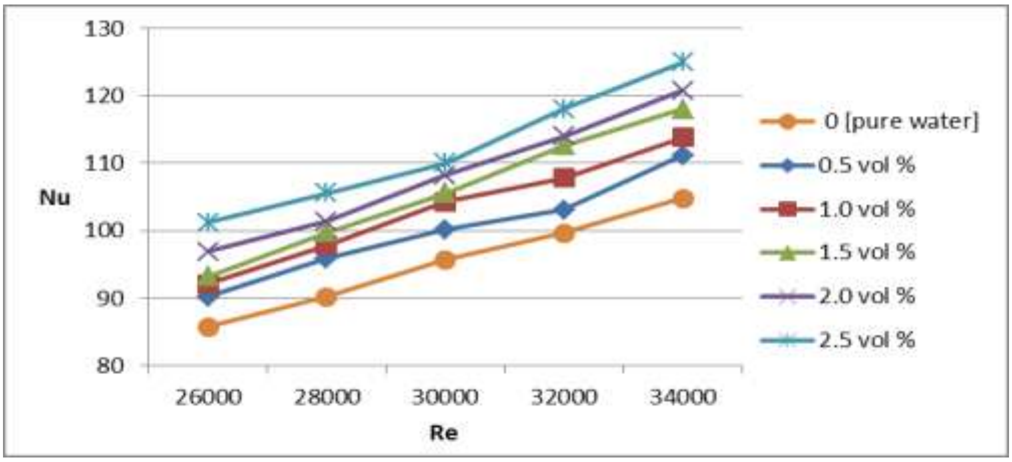

Fig. 3 Nu number variation of nanofluids at different concentrations as a function of Re (Tin=60°C)

V. CONCLUSIONS

In present study, experimental heat transfer coefficients in the automobile radiator have been measured with two different working liquids, pure water and water based nanofluids at different concentrations and temperatures and The main findings of the present study are as follows:

1. The presence of 13nm sized alumina nanoparticles in water enhances the heat transfer rate of the automobile radiator. At the concentration of 2 vol% the heat transfer enhancement of 35% compared to pure water is recorded.
2. Increasing the Reynolds number of working fluid enhances the heat transfer coefficient for both pure water and nanofluids reasonably.

The increase in thermal conductivity is about 6% and the variation of the other thermophysical properties are not responsible for the large heat transfer enhancement.

REFERENCES

[1] R. S. Vajjha, D. K. Das, P. K. Namburu, 'Numerical study of fluid dynamic and heat transfer performance of Al2O3 and CuO nanofluids in the flat tubes of a radiator', International Journal of Heat and Fluid Flow, volume 31, pp.613–621.
[2] A. M. Hussein, R. A. Bakar, K. Kadirgama, 'Study of forced convection nanofluid heat transfer in the automotive cooling system', Case studies in thermal engineering 2, pp.50–61.
[3] S. M. Peyghambarzadeh, S. H. Hashemabadi, S. M. Hoseini, 'Experimental study of heat transfer enhancement using water/ethylene glycol based nanofluids as a new coolant for car radiators', International Communications in Heat and Mass Transfer 38, pp.1283–1290.
[4] A. M. Hussein, R. A. Bakar, K. Kadirgama, 'Heat transfer enhancement using nanofluids in an automotive cooling system', International Communications in Heat and Mass Transfer 53, pp.195–202.
[5] P. K. Namburu, D. K. Das, R. S. Vajjha, 'Numerical study of turbulent flow and heat transfer characteristics of nanofluids considering variable properties', International Journal of Thermal Sciences 48, pp.290–302.
[6] M. Naraki, S. M. Peyghambarzadeh, S. H. Hashemabadi, 'Parametric study of overall heat transfer coefficient of CuO/water nanofluids in a car radiator', International Journal of Thermal Sciences 66, pp.82–90.
[7] C. Oliet, A. Oliva, J. Castro, 'Parametric studies on automotive radiators', Applied Thermal Engineering 27, pp.2033–2043.
[8] K. Y. Leong, R. Saidur, S. N. Kazi, A. H. Mamun, 'Performance investigation of an automotive car radiator operated with nanofluid-based coolants', Applied Thermal Engineering 30, pp.2685–2692.
[9] S. M. Peyghambarzadeh, S. H. Hashemabadi, S. M. Hoseini, 'Improving the cooling performance of automobile radiator with Al2O3/water nanofluid', Applied Thermal Engineering 31, pp.1833–1838.
[10] S. M. Peyghambarzadeh, S. H. Hashemabadi, M. Naraki, 'Experimental study of overall heat transfer coefficient in the application of dilute nanofluids in the car radiator', Applied Thermal Engineering 52, pp.8–16.

