CONTRACTION OF RADIATOR LENGTH IN HEAVY VEHICLES USING CERIUM OXIDE NANOFLUID BY ENHANCING HEAT TRANSFER PERFORMANCE

by

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Original scientific paper
DOI: 10.2298/TSCI16S4037R

In this present investigation, heat transfer performance of CeO_2-ethylene glycol as coolants in heat pipes are analyzed. Various concentrations of 0.5, 0.75, 1.0, 1.25, 1.5, and 2.0 vol.% with different volumetric flow 1.0, 2.0, 3.0, 3.5, and 4.0 lpm at a temperature of 40 °C, are investigated experimentally and the results are numerically analyzed by means of cross tube heat exchanger and horizontal flow with twist plate insert. The results are scrutinized to evaluate the best concentration which will reduce the size of the existing radiator length. The results demonstrated that, for 0.75 vol.% combination of CeO_2-ethylene glycol resulted in increase of heat transfer coefficient compared to the combination of water-ethylene glycol. Increase in volumetric flow rate of the coolant increase the heat transfer coefficient results in the contraction of radiator length. Replacing the original coolant with the proposed combination, it is estimated that the size of the radiator, inventory of the fluid, and pumping power is reduced, thus, making this nanofluid an energy efficient fluid for the engine cooling system.

Key words: *ceria nanoparticles, ethylene glycol, nanofluid, viscosity, heat transfer performance introduction*

Introduction

The several studies revealed the fact that thermal energy is precious among all the energies in Earth. The transfer of heat in thermal management systems results in increase of cost and decrease in the overall efficiencies. The technology with high capacity of cooling in less time with more efficient procedures called transfer of heat through heat pipes is implemented nowadays. This technology is given priority than heat conducted by metals like silver and copper because of its noiseless operations and weightless fixed components. This technology is foremost important in the design of various engineering components like radiator, shell and tube heat exchanger to enhance the heat transfer coefficient.

It is an apparatus with a sealed cylindrical pipe having a wick like structure inside it through which heat transfer fluids like ethylene glycol, water, and engine oils are used commonly. In terms of comparison of thermal conductivity, it is obvious that a metallic solid will be

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higher than that of a fluid. Experiments on years prove that combination of particles of nanometer size with the heat transferring fluid will increase the overall thermal conductivity. In recent years combinations like water with alumina and water with copper oxide has been tested in heat pipes and the results are analyzed because of their higher value of k.

Combustion produces power within an engine which is transmitted to dynamic motion. The power developed by this will not be completely transferred to motion because of heat dissipation through exhaust. Viscosity breakdown and overheating will occur if the heat generated by means of combustion is not removed properly. In automotive cooling system, the radiator plays a vital role in exhausting the heat by means of fins. By increasing the number of fins and by reducing the radiator length without causing any reduction in heat transfer performance is the cost effective method. If this is achieved, the size of the radiator will be reduced to some extent which will increase in the efficiency of the vehicles.

Leong *et al*. [1] analyzed experimentally on the application of ethylene glycol based copper nanofluids in an automotive cooling system and obtained relevant input data, nanofluid properties and empirical correlations from literature to investigate the heat transfer enhancement of an automotive car radiator operated with nanofluid-based coolants. They observed that the coolants pressure drop increased with the addition of copper nanoparticles and heat transfer rate is increased with increase in volume concentration of nanoparticles. Ali *et al*. [2] reported for water based ZnO nanofluids to enhance the heat transfer performance of a car radiator in different volumetric concentrations (0.01, 0.08, 0.2, and 0.3%) and observed significant increase in heat transfer rate using ZnO water nanofluids compared to base fluid. The best heat transfer enhancement up to 46% is achieved using 0.2 vol.% by volume of nanofluid.

Sandesh *et al*. [3] studied experimentally the convective heat transfer enhancement of carbon nanotube (CNT)-water nanofluid inside an automobile radiator and reported for 1.0% by vol. nanoparticle concentration and coolant flow rate of 5 l/min, the maximum enhancement in heat transfer of FCNT-water nanofluid was found to be 90.76% higher compared with water.

Hussein *et al*. [4] investigated the friction factor and forced convection heat transfer enhancements of SiO_2 nanoparticle dispersed in water as a base fluid conducted in a car radiator experimentally and numerically for four different concentrations of nanofluids in the range of 1-2.5% by vol and found that the maximum values of friction factor increased to 22% for SiO_2 nanoparticles dispersed in water with 2.5% volume concentration. Narakiet *et al*. [5] investigated experimentally the overall heat transfer coefficient of CuO/water nanofluids is under laminar flow regime and the results are statistically analyzed using Taguchi method by implementing Qualitek-4 software. The maximum value of the overall heat transfer coefficient with nanofluid, effect of each operating parameter on the overall heat transfer coefficient and the optimum values of each parameter are determined.

Delavari and Hashemabadi [6] presented numerical study simulated turbulent and laminar flow heat transfer in nanofluids (Al_2O_3 particles in water and ethylene glycol-based fluid) passing through a flat tube in 3-D using CFD for single and two-phase approaches. The numerical results were the same as for the experimental data, indicating that increasing the concentration of nanoparticles in the base fluid increased the heat transfer coefficient and the Nusselt number. Elias *et al*. [7] presents new findings on the thermal conductivity, viscosity, density, and specific heat of Al_2O_3 nanoparticles dispersed into water and ethylene glycol based coolant used in car radiator. They suggested that it would be better if the effect of particle size and shape could be considered with the variation of temperature and particle concentrations for the investigation of the thermo-physical properties. It has been noted that improving the cooling performance and heat transfer enhancement in car radiators using nanofluids like zinc oxide, CuO, and Al_2O_3 are the major research focus areas nowadays [8-12]. Moreover, researches are going on to reduce the radiator size using nanofluids like TiO_2 and CeO_2. This include the effect of electric field in the heat transfer performance of automobile radiator [13-24]. Insufficient rates of heat dissipation in automotive radiators is the major problem which result in overheating the engine, which leads to the breakdown of lubricating oil, metal weakening of engine parts, and significant wear between engine parts. In order to reduce the stress on the engine as a result of heat generation, automotive radiators must be redesigned to be more compact while still maintaining high levels of heat transfer performance [25]. Based on this, in this paper reducing the size of the radiator is focused by scruitinizing the nanofluids in various concentraions in the heat exchangers.

Experimental investigation

Nanofluids and its preparations

Typically solid particles ranging from 1 to 100 nm made-up of composite materials in solid-liquid condition called nanofluids which are used by suspended with working fluid in heat pipes. Reducing the ratio of mass and volume of the solids and liquids causes the nanofluid to occur in a free stable state for a long time. The viscosity of the fluid was increased resulting unchanged chemical reactions in the base fluid. Due to its increased thermal properties, nanofluids are used in various types of heat exchangers as thermo-fluids. Precious heat energy and the components used to transfer heat are conserved by these fluids by increasing heat transfer coefficient. The characteristics of heat transfer like specific heat (c_p), density (ρ), thermal conductivity (k), and viscosity (μ) influencing the heat transfer depends on the operating temperature. Figure 1 shows the testing of CeO_2 with blends like diesel, ethanol, acids, and water. After some time, the particles settle down with diesel and shows an inappropriate mixing with water and ethanol.

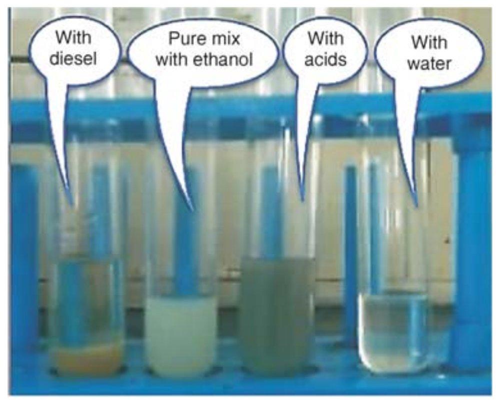

Figure 1. Testing with blends

Figures 2 and 3 shows the sonification process of CeO_2 which was carried for various concentrations 0.5, 0.75, 1.0, 1.25, 1.5, and 2.0% and the view of cross tube with twist tape inserted.

The copper tube of length 2 m and diameter 10 mm is used as a heat exchanging device and also improving the heat transfer rate inserting a twisted tape inside the copper tube of width 5 mm and thickness of 0.5 mm, the fluids flow through the pipe.Thenanofluid is allowed to pass through this tube and the readings are noted. Ultrasonic bath is a piece of industrial or laboratory equipment that consists of a con-

Figure 2. Ultrasonic bath

Figure 3. Cross tube with twist tape inserted

tainer, or bath, used for cleaning, or mixing things inserted into the bath, by means of sending ultrasonic vibrations through the liquid in the bath.These methods can change the surface properties of the suspended particles and can be used to suppress the formation of particle clusters in order to obtain stable suspensions. The use of these techniques depends on the required application of the nanofluid (tab. 1).

Both the values of k and μ increases by using nanofluids compared to base fluid. The effective value of k for nanofluids can be determined by the equation

Table 1. Measured thermo physical properties of water and the nanofluids (40 °C)

Fluid	Thermal conductivity k [Wm^{-1}K^{-1}]	Viscosity μ [mPa·s]	Density ρ [kgm^{-3}]	Heat capacity c_p, [Jkg^{-1}K^{-1}]	Temperature [K]
CeO_2, 0.5 vol.%	0.662	0.68	1008	4046	313
CeO_2, 0.75 vol.%	0.67	0.69	1032	3998	313
CeO_2, 1.0 vol.%	0.684	0.71	1048	3938	313
CeO_2, 1.25 vol.%	0.69	0.73	1059	3909	313
CeO_2, 1.5 vol.%	0.701	0.75	1071	3831	313
CeO_2, 2.0 vol.%	0.718	0.79	1101	3752	313

$$K_{\mathrm{eff}} = \frac{k_{\mathrm{p}} + 2k_{\mathrm{bf}} + 2\varphi(k_{\mathrm{p}} - k_{\mathrm{bf}})}{k_{\mathrm{p}} + 2k_{\mathrm{bf}} - 2\varphi(k_{\mathrm{p}} - k_{\mathrm{bf}})} k_{\mathrm{bf}} \tag{1}$$

An average size of 50 nm CeO_2 nanoparticles was obtained from Annamalai University, Chidambaram is utilized to determine the characteristics of heat transfer performance. Figure 4 shows the scanning electron micrograph of synthesized ceria nanoparticles captured from the scanning electron microscope with EDS of model JEOL-JSM-5610LV with INCA EDS (magnification: ×18 to 300000.

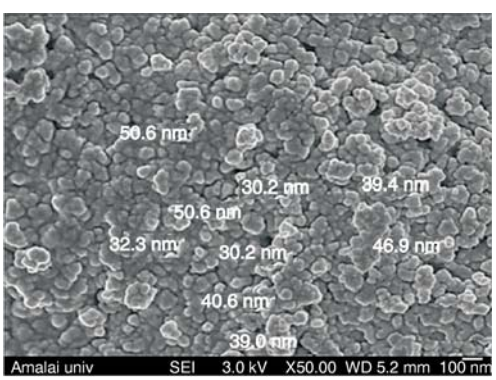

Figure 4. Scanning electron micrograph of synthesized ceria nanoparticles

Experimental set-up and procedure

From the figs. 5 and 6, the combination of CeO_2 with ethylene glycol is allowed to flow through the copper tube with twist tape inserted and to the storage vessel by means of a pump. In fig. 5 follows cross flow heat exchanger and in fig. 6 is for horizontal flow heat exchanger.

A Nichrome heater is placed inside the storage vessel for maintaining the temperature at particular degree. The pump circulates the

Figure 5. Cross tube with twist tape inserted

Figure 6. Horizontal heat exchanger

nanofluid through this arrangement at different flow rates such as1.0, 2.0, 3.0, 3.5, and 4.0 lpm at a temperature of 40 °C. Experiments are conducted for nanofluids at constant temperature with various flow rates to determine the heat transfer coefficient for flow in a tube.

Result and discussion

Heat transfer coefficient for cross flow heat exchanger

The effect of increasing the particle volume concentration on experimental tube side or inner Nusselt number in turbulent flow is shown in figs. 7-10. It is clear that the tube side Reynold's number increases over the particle volume concentration. The enhancement of tube side experimental Reynold's number, heat transfer coefficient and heat transfer were found to be 1, 2, 3, 3.5, 4 lpm flow rate at 0.75% particle volume concentration, respectively. This is due to the better fluid mixing and higher effective thermal conductivity of nanofluid. This secondary flow provides proper mixing to enhance heat transfer. It is observed the increasing trend of experimental Nusselt number for 1.0% particle volume concentration of nanofluid.

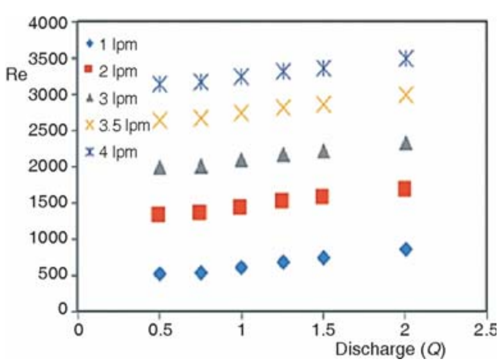

Figure 7. Discharge (*Q*) *vs.* Reynolds number

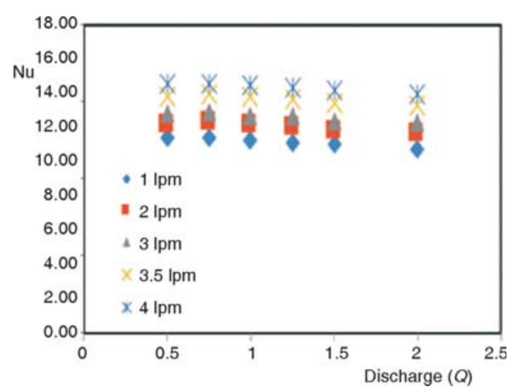

Figure 8. Discharge (*Q*) *vs.* Nusselt number

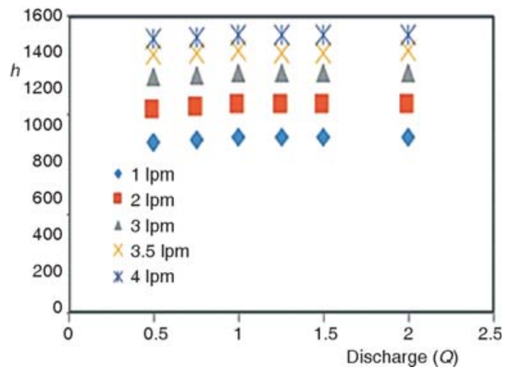

Figure 9. Discharge (*Q*) *vs.* heat transfer coefficient (*h*)

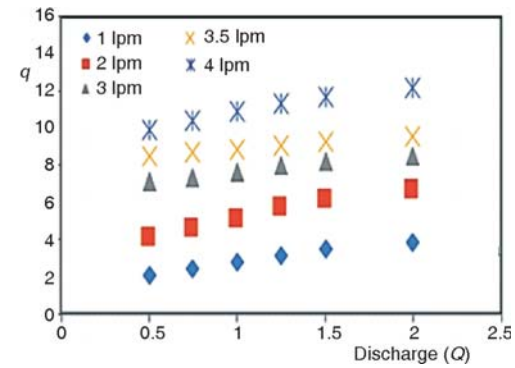

Figure 10. Discharge (*Q*) *vs.* heat transfer rate (*q*)

Heat transfer coefficient for horizontal flow heat exchanger

The following graph (figs. 11-14) shows that the effect of increasing the particle volume concentration on experimental tube side Nusselt number in turbulent flow. It is clear that the tube side Reynold's number increases over the particle volume concentration. The enhancement of tube side experimental Reynold's number, heat transfer coefficient, and heat transfer are found to be 120, 180, 240, and 300 lph flow rate at 1.0 vol.% compared to all (0.5, 0.75, 1.0, 1.25, 1.5, and 2.0 vol.%) particle volume concentration respectively. This is due to the better fluid mixing and higher effective thermal conductivity of nanofluid. This secondary flow provides proper mixing to enhance heat transfer. Results enhanced heat transfer coefficient. It is observed the increasing trend of experimental Nusselt number for 0.75% particle volume concentration of nanofluid. Comparing these results with the values predicted by MAPLE soft [24], it is clearly visible that the use of nanofluids will reduce the length of the radiator.

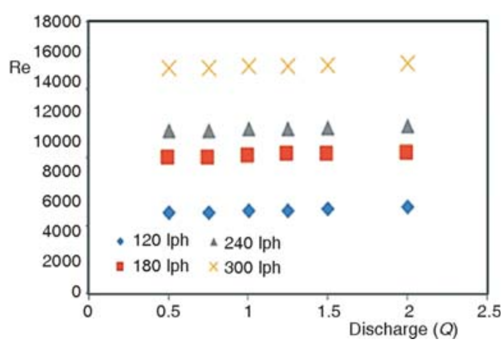

Figure 11. Discharge (*Q*) *vs.* Reynolds number

Conclusions

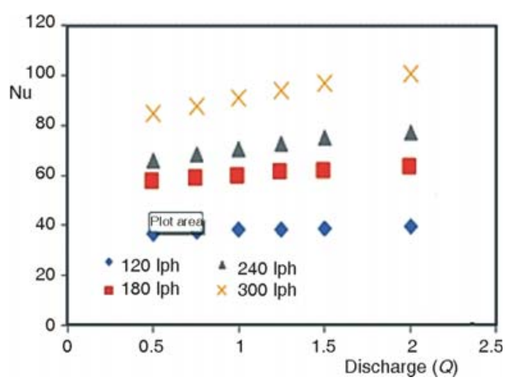

Figure 12. Discharge (*Q*) *vs.* Nusselt number

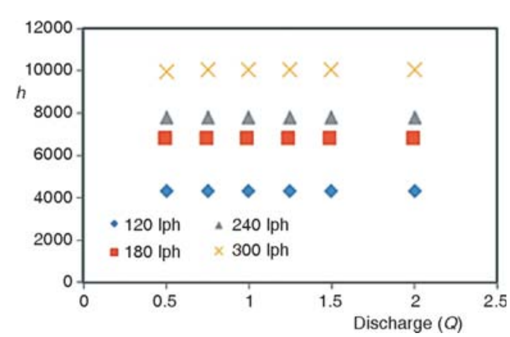

Figure 13. Discharge (*Q*) *vs.* heat transfer coefficient (*h*)

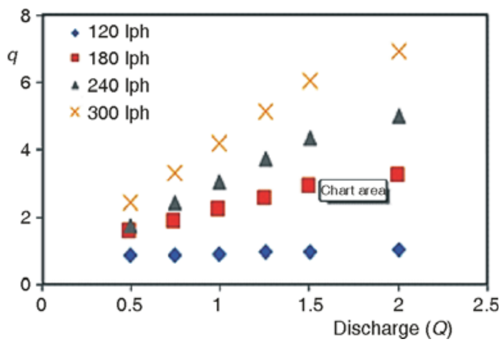

Figure 14. Discharge (*Q*) *vs.* heat transfer rate (*q*)

In this paper, we have experimentally investigated the heat transfer studies of cross tube heat exchanger and horizontal flow with twist plate insert with CeO_2/ethylene glycol nanofluid under turbulent region. For this purpose, we synthesized CeO_2 nanoparticles having an average diameter of 50 nm and with various volume concentrations of 0.5, 0.75, 1.0, 1.25, 1.5 and 2.0% using a two-step method with ultra-sonication. For parameters like Reynolds number, Nusselt number, heat transfer coefficient and heat transfer rate, experiments was conducted and the results are summarized:

- The increase of experimental inner Reynold's number is found to be 1, 2, 3, 3.5, and 4 lpm and 120, 180, 240, and 300 lph at 0.75% of CeO_2/ethylene glycol nanofluid, respectively.
- The main reason is due to higher effective thermal conductivity of nanofluid, Brownian motion of particles and better fluid mixing. This is due to the improved viscosity while adding more nanoparticles in base fluid.
- Based on the experimental data, tube side Reynold's number and heat transfer coefficient correlations are developed.
- It is concluded that the CeO_2/ethylene glycol nanofluid 1.0% volume concentration can be applied to heavy vehicle's radiator as a coolant.
- Applying all the parameters in the design of radiator length means the length of radiator can be reduced which reduces to overall weight of the vehicle. This will increase the overall efficiency of the automotive vehicles.

Nomenclature

c_p – specific heat, [$Jkg^{-1}K^{-1}$]
k – thermal conductivity, [$Wm^{-1}K^{-1}$]
Q – heat supplied to the heat pipe, [W]

Greek symbols

μ – viscosity of the base liquid, [mPa·s]
ρ – liquid density, [kgm^{-3}]

Subscripts

bf – base fluid
hp – heat pipe
nf – nanofluid
np – nanoparticle
f – fluid

References

[1] Leong, K. Y., *et al*., Performance Investigation of an Automotive Car Radiator Operated with Nanofluid-Based Coolants (Nanofluid as a Coolant in a Radiator), *Applied Thermal Engineering, 30* (2010), 17-18, pp. 2685-2692
[2] Ali, H. M., *et al*., Experimental Investigation of Convective Heat Transfer Augmentation for Car Radiator Using ZnO Water Nanofluids, *Energy, 84* (2015), May, pp. 317-324
[3] Sandesh, S., *et al*., Thermal Performance of Automobile Radiator Using Carbon Nanotube-Water Nanofluid – Experimental Study, *Journal of Thermal Science and Engineering Applications, 6* (2014), 4, pp. 041009-041014
[4] Hussein, A. M., *et al*., Study of Forced Convection Nanofluid Heat Transfer in the Automotive Cooling System, *Case Studies in Thermal Engineering, 2* (2014), Mar., pp. 50-61
[5] Naraki, M., *et al*., Parametric Study of Overall Heat Transfer Coefficient of CuO/Water Nanofluids in a Car Radiator, *International Journal of Thermal Sciences, 66* (2013), Apr., pp. 82-90

[6] Delavari, V., Hashemabadi, S. H., CFD Simulation of Heat Transfer Enhancement of Al_2O_3/Water and Al_2O_3/Ethylene Glycol Nanofluids in a Car Radiator, *Applied Thermal Engineering, 73* (2014), 1, pp. 380-390
[7] Elias, M. M., *et al*., Experimental Investigation on the Thermo-Physical Properties of Al_2O_3 Nanoparticles Suspended in Car Radiator Coolant, *International Communications in Heat and Mass Transfer, 54* (2014), May, pp. 48-53
[8] Sonage, B. K., Mohanan, P., Miniaturization of Automobile Radiator by Using Zinc-Water and Zinc Ozxide-Water Nanofluids, *Journal of Mechanical Science and Technology, 29* (2015), 5, pp 2177-2185
[9] Peyghambarzadeh, S. M., *et al*., Improving the Cooling Performance of Automobile Radiator with Al_2O_3/Water Nanofluid, *Applied Thermal Engineering, 31* (2011), 10, pp. 1833-1838
[10] Peyghambarzadeh, S. M., *et al*., Experimental Study of Overall Heat Transfer Coefficient in the Application of Dilute Nanofluids in the Car Radiator, *Applied Thermal Engineering, 52* (2013), 1, pp. 8-16
[11] Peyghambarzadeh, S. M., *et al*., Experimental Study of Overall Heat Transfer Coefficient in the Application of Dilute Nanofluids in the Car Radiator, *Applied Thermal Engineering, 52* (2013), 1, pp. 8-16
[12] Ravikanth, S., *et al*., Numerical Study of Fluid Dynamic and Heat Transfer Performance of Al_2O_3 and CuO Nanofluids in the Flat Tubes of a Radiator, *International Journal of Heat and Fluid Flow, 31* (2010), 4, pp. 613-621
[13] Oliet, C., *et al*., Parametric Studies on Automotive Radiators, *Applied Thermal Engineering, 27* (2007), 11-12, pp. 2033-2043
[14] Saidur, R., *et al*., A Review on Applications and Challenges of Nanofluids, *Renewable and Sustainable Energy Reviews, 15* (2011), 3, pp. 1646-1668
[15] Moraveji, M. K., *et al*., Modeling of Convective Heat Transfer of a Nanofluid in the Developing Region of Tube Flow with Computational Fluid Dynamics, *International Communications in Heat and Mass Transfer, 38* (2011), 9, pp. 1291-1295
[16] Demir, H., *et al*., Numerical Investigation on the Single Phase Forced Convection Heat Transfer Characteristics of Tio2 Nanofluids in a Double-Tube Counter Flow Heat Exchanger, *International Communications in Heat and Mass Transfer, 38* (2011), 2, pp. 218-228
[17] Dehghandokht, M., *et al*., Flow and Heat Transfer Characteristics of Water and Ethylene Glycol-Water in a Multi-Port Serpentine Meso-Channel Heat Exchanger, *International Journal of Thermal Sciences, 50* (2011), 8, pp. 1615-1627
[18] Vithayasai, S., *et al*., Effect of Electric Field on Heat Transfer Performance of Automobile Radiator at Low Frontal Air Velocity, *Applied Thermal Engineering, 26* (2006), 17-18, pp. 2073-2078
[19] Hussein, A. M., *et al*., Heat Transfer Enhancement Using Nanofluids in an Automotive Cooling System, *International Communications in Heat and Mass Transfer, 53* (2014), 4, pp. 195-202
[20] Nieh, H.-M., *et al*., Enhanced Heat Dissipation of a Radiator Using Oxide Nano-Coolant, *International Journal of Thermal Sciences, 77* (2014), 3, pp. 252-261
[21] Hussein, A. M., *et al*., Study of Forced Convection Nanofluid Heat Transfer in the Automotive Cooling System, *Case Studies in Thermal Engineering, 2* (2014), 3, pp. 50-61
[22] Elis, Josna Mary, E., *et al*., Cerium Oxide-Ethylene Glycol Nanofluids with Improved Transport Properties: Preparation and Elucidation of Mechanism, Journal of the Taiwan Institute of Chemical Engineers, 49 (2015), Apr., pp. 183-191
[23] Senthil, R., *et al*., Contemplation of Thermal Characteristics by Filling Ratio of Al_2O_3 Nanofluid in Wire Mesh Heat Pipe, *Alexandria Engineering Journal, 55* (2016), 2, pp. 1063-1068
[24] Tiwari, A. K., *et al*., Heat Transfer and Pressure Drop Characteristics of CeO_2/Water, Nanofluid in Plate Heat Exchanger, *Applied Thermal Engineering, 57* (2013), 1-2, pp. 24-32
[25] ***, Designing a More Effective Car Radiator, Maplesoft 2008

Received submitted: September 15, 2015
Revised revised: January 12, 2016
Paper accepted: February 08, 2016