

Comparative thermal performance analysis of water, engine coolant oil and MWCNT-W nanofluid in a radiator

Asif Afzal^{1*}, A. D. Mohammed Samee², R. K. Abdul Razak¹

¹Department of Mechanical Engineering, P. A. College of Engineering, Visvesvaraya Technological University, Mangaluru 574153, India

²Department of Mechanical Engineering, N. K. Orchid College of Engineering and Technology, Solapur, Maharashtra, India

Corresponding Author Email: asif.afzal86@gmail.com

https://doi.org/10.18280/mmc_b.870101

ABSTRACT

Received: 19 June 2017

Accepted: 5 January 2018

Keywords:

MWCNT nanofluid, radiator, engine coolant oil, water, heat transfer

A comparative experimental investigation for thermal performance analysis of three different coolants flowing in a radiator is presented. Water (W) is used as base fluid for 0.01% volume concentration Multi Walled Carbon Nano Tube (MWCNT) nanoparticle. One step method is used to prepare the MWCNT-Water nanofluid. Cross flow unmixed radiator type heat exchanger is considered for the analysis. Performance of radiator subjected to flow of coolants like MWCNT-W nanofluid, and engine coolant oil are compared with water as coolant. Thermal analysis is conducted for different flow rates of 0.25 lpm (liter per minute), 0.5 lpm and 0.75 lpm. For 0.25, 0.5 and 0.75 lpm flow rate, variation in friction factor, heat transfer coefficient, Nu (Nusselt number), pressure drop and pumping power of these coolants is compared. Among the coolants considered MWCNT-W nanofluid comparatively gives maximum heat transfer enhancement due to its high heat carrying capacity. However MWCNT-W nanofluid consumes more pumping power than the other two coolants due its increased viscosity and pressure drop.

1. INTRODUCTION

Nanofluids are the fluids which contain particles whose size varies between 1 to 100 nanometers that are dispersed in fluids, generally known as base fluids. Nanofluids have been proved as a better candidate for heat transfer in various applications like thermal processing of elements, energy storage, electronics cooling, fuel cells, heat exchangers, engine cooling etc [1]. In the car radiator, the hot fluid from the engine is pumped through the radiator tubes, while the air is drawn by forced convection and heat exchange takes place between the hot engine fluid and air. If nanofluids are passed in these tubes, then there is a possibility of increased heat transfer, because of increased thermal conductivity of these nanofluids. The amount of coolant required in the tubes will also be less because of excellent thermal conductivity properties of nanofluids. Hence reduction in pumping power is possible [2].

Many research works are published which provide thermal performance characteristics of various nanofluids used in heat exchangers and radiators. Ali et al., analyzed the performance of car with aluminium radiator utilizing water based ZnO nanofluids. A heat transfer improvement of up to 46% was obtained by utilizing 0.2% volume concentration (%VC) of nanofluid. They concluded that enhancement in heat transfer by nanofluid highly depends on the volumetric concentration of the respective nanoparticles [3]. The effectiveness of a radiator was investigated by Hussein et al., by suspending TiO₂ and SiO₂ nanoparticles in water which acts as a base fluid having 22 nm and 50 nm size particles. A highest Nusselt number (Nu) was recorded up to 17.85 and 16.4 for SiO₂-W and TiO₂-W respectively. Their experiment showed that Nu highly depends on the flow rate and volume concentration of

nanoparticles [4]. Heris et al., utilized CuO nanoparticles (60nm) in a base fluid of water/EG mixture to scrutinize the performance of a radiator. The experiment involved different flow rates i.e., 4-8 lit/min, with 0.05-0.8 vol% of volumetric concentration of nanofluids and inlet temperatures such as 35, 44 and 54°C. For 0.8 %VC of nanofluid Nu enhanced up to 55%. As the flow rate increased Nu improved along with the volume concentration of the nanofluid and radiator inlet temperature [5]. Ebrahimi et al., studied the outcome of mixing SiO₂nanoparticle to water i.e., the base fluid and also the coefficients of forced convection, effect of Reynolds number (Re), nanoparticle volume fraction and fluid inlet temperature were analyzed in a radiator. The engine performance enhanced as well as fuel consumption reduced by increasing heat transfer performance utilizing nanofluid as working fluid. [6].

Pak and Cho conducted an experimental study on water based alumina nanofluids (Al₂O₃-water) with 1 to 3 %VC. They find that an increment in Nu with increasing in volume concentration and Re of the nanofluids [7]. Heris et al., conducted an experiment by maintaining constant wall temperature boundary condition and found an enhancement in heat transfer rate using water based alumina nanofluids [8]. In other work, Heris et al., conducted an experiment by maintaining constant wall temperature boundary condition with 0.2 to 2.5 %VC of nanoparticles for Re varying between 700 and 2050. They again found that Nu increases with the use of nanofluids as compared to water [9]. Lai et al., studied the flow behavior of water based alumina nanofluids in a test tube, subjected to constant wall heat flux boundary condition and for a low Re. They found an increment in the heat transfer along with Re [10]. Jung et al., conducted an experiment in

rectangular micro-channel under laminar flow conditions using water based alumina nanofluids (Al_2O_3 - water). They found that the heat transfer coefficient increases by more than 32% for 1.8 %VC nanoparticles [11].

On the other hand, Carbon based nanofluids have shown a great potential in heat transfer ability along with increase in %VC and temperature [12]. The temperature and %VC effect on the kinematic viscosity on SiC- ethylene glycol based nanofluid was studied by Li et al. They mentioned that viscosity increased along with %VC but viscosity decreased with temperature [13]. ZnO nanoparticles were used by Zyla et al., considering glycol as the base fluid. They reported about thermal performance enhancements along with %VC [14]. Li et al., investigated thermal performance of engine coolant based SiC nanofluids. They found the thermal performance enhancement by 53% for 0.5%VCat a temperature of 50°C [15].

Many more such similar works have been reported considering Al_2O_3 , ZnO, CuO, Carbon nanotubes, SiO_2 etc., as the nanoparticles suspended in glycol/ water as the base fluid [16-19]. Many researchers have focused mainly on the aforementioned nanoparticles and compared with their various %VC. But very limited work is available on the comparative thermal performance study of car engine coolant and any other nanofluid. Therefore this research work focuses on comparative study on thermal performance of different fluids like water (as a base fluid), engine coolant oil and Multi Walled Carbon Nano Tube nanofluid with water (MWCNT-W) as base fluid.

2. EXPERIMENTAL METHOD

2.1 Experimental setup

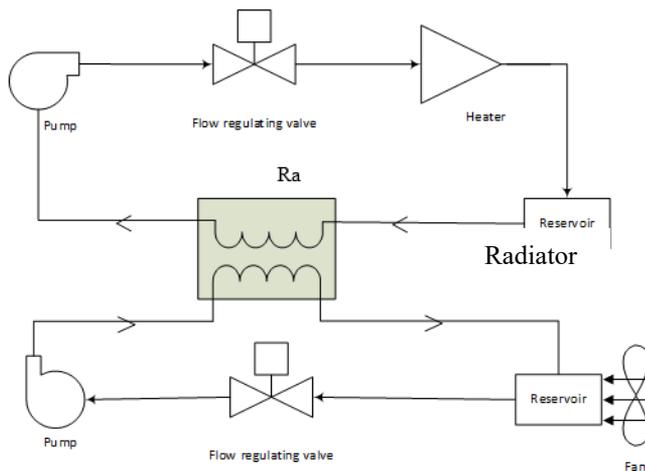


Figure 1. Schematic diagram of the radiator

The flow diagram of the experimental set up used for the present experimental study is as shown in Figure 1. It consists of a reservoir, a heater, a pump, a flow meter, a forced draft fan and a car radiator. An electrical heater is used for heating the fluid. This hot fluid from the reservoir flows through the radiator tubes ($d=3mm$ and $D=9mm$) by a pump with constant flow rate. The radiator consists of 34 vertical aluminium tubes making a total length of 7000mm. The distance between the tube rows were filled with thin perpendicular aluminium fins. A flow meter is used to control and operate the flow rate with the precision of 0.1lpm. The upper surface of the radiator is equipped with copper K-type thermocouple at equal intervals.

T-type of thermocouple is attached at the inlet and outlet of fluid flow. The flow pipe from the reservoir is attached with the inlet thermocouple and the exit pipe from the heat exchanger is equipped with the outlet thermocouple. Pressure drop is measured with the help of manometer. The heated coolant is made to pass s through the counter flow heat exchangers to maintain the inlet temperature value of the coolant constant, once the coolant achieves the required inlet temperature it is made to flow in reservoir. This reservoir tank contains the working fluid which gets mixed and cooled to desired inlet temperature. For cooling the liquid, an axial forced flow fan was installed close at the axis line of the radiator and consequently air and fluid have indirect cross flow contact.

2.2 Materials and Methods for nanofluid preparation

MWCNT-W nanofluids were prepared by one step method using water as base fluid. Engine coolant oil was also purchased from the market and it was used for experiment. The MWCNT nano particles required was estimated using Equation 1 to get 0.01%VC of nano fluid.

$$\phi = \frac{\frac{m_n}{\rho_n}}{\frac{m_n}{\rho_n} + \frac{m_f}{\rho_f}} \quad (1)$$

The procedure followed for preparation of nanofluid is similar to work from Sharul et al. [20], Estelle et al. [21] and Oliveira et al. [22]. In the present study MWCNT nanoparticle were purchased from Sigma Aldrich Chemicals Limited, India with purity upto 99% and having average particle size less than 20nm. Water was used as a base fluid for the study. The MWCNT-W nanofluid of 0.01%VC were prepared by dispersing MWCNT nanoparticles in water. The solution was sonicated continuously for 1 hour using a bath sonicator (power sonicator, POWERSONIC 405 purchased from South Korea) to disperse the nanoparticle uniformly. Following this, the nanofluids were stirred continuously to obtain uniform dispersion of nanoparticles in base fluid.

2.3 Measurement of thermo physical properties

To measure the thermophysical properties of MWCNT-W nanofluid the following Equations 2-5 were used. Density, dynamic viscosity, specific heat capacity and thermal conductivity required to calculate the various thermal performance parameters of MWCNT-W nanofluid these equations were used [23-31].

$$\rho_{nf} = (1 + \phi)\rho_f + \phi\rho_p \quad (2)$$

$$\mu_{nf} = \frac{\mu_f}{(1-\phi)^{2.5}} \quad (3)$$

$$(\rho C_p)_{nf} = (1 - \phi)(\rho C_p)_f + \phi(\rho C_p)_p \quad (4)$$

$$k_{nf} = \left(\frac{k_p + (n-1)k_f - (n-1)\phi(k_f - k_p)}{k_p + (n-1)k_f + \phi(k_f - k_p)} \right) k_f \quad (5)$$

The density of MWCNT nanoparticles is 1800 Kg/m³, thermal conductivity is 7620 W/mK and specific heat capacity is 7200 J/KgK and dynamic viscosity equal to 0.557 Ns/m². The engine coolant oil properties are 991Kg/m³, 0.41 W/mK, 3630 J/Kg K and 6.81x10⁻³Ns/m² respectively.

2.4 Conduction of experiment

This work is based on forced convection and the flow is laminar. Four trials were performed for each flow rate of 0.25lpm, 0.5 imp and 0.75lpm considering water, engine coolant oil and MWCNT-W nanofluid. Steady state for the fluid will be achieved for each flow rate and each fluid. Each trial takes at least 15 minutes to complete. In addition to this, the pump used for this experimental setup having five to six liters of capacity, needed bulk sonication of the MWCNT-W nanofluids, which took more than an hour after each trial. The readings of the experiment were taken with lot of effort and care in order to avoid any miscalculation. To avoid any kind of clogging in the tubes, after each trial of coolant oil and MWCNT-W nanofluid, water was used to circulate to remove any stains of these fluids in the tubes at high velocity.

2.5 Relations used to calculate various thermal parameters

The below mentioned Equations 6-14, were employed to calculate the thermal performance of the radiator. Actual heat transfer (q), convective heat transfer coefficient (h), Reynolds number (Re), Prandtl number (Pr), Nusselt number (Nu), Friction factor (f), Pressure drop (ΔP): Pumping power (P) are given by:

$$q = m_f C_p (T_{c,o} - T_{c,i}) \quad (6)$$

$$h = N_u k / D_h \quad (7)$$

$$Re = \rho D_h u / \mu \quad (8)$$

$$Pr = \mu C_p / k \quad (9)$$

$$Nu = 4.364 + 0.0722 (Re D_h Pr (D/L)) \quad (10)$$

$$f = 64 / Re \quad (11)$$

$$\Delta P = f \rho (L/D) (u^2 / 2) \quad (12)$$

$$P = \Delta P f \dot{v} \quad (13)$$

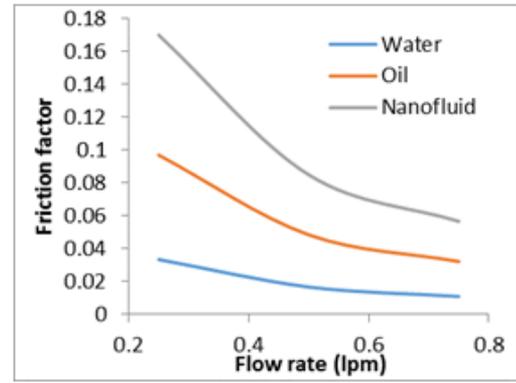
Here, the hydraulic diameter (D_h) is given by equation:

$$D_h = \frac{4((\pi/4)d^2 + (D-d)d)}{(\pi d + 2(D-d))}$$

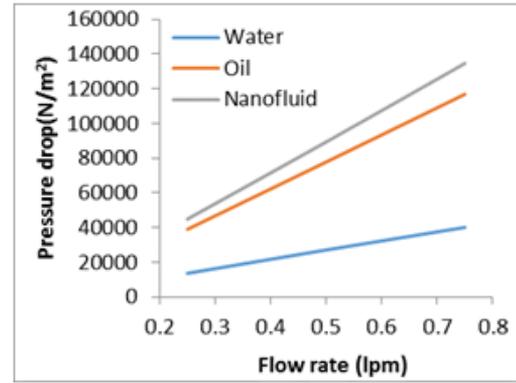
3. RESULTS AND DISCUSSIONS

Various thermal performance parameters were calculated based on relations mentioned in Equation 6-14. The readings were obtained by using different fluids in the radiator and temperature was recorded for different fixed flow rates of 0.25 litre per minute (lpm), 0.5lpm and 0.75lpm. The first readings were obtained for water, then for engine coolant oil (Flow Guard) and later for MWCNT-W nanofluid. In following subsection, we discuss about the results obtained for comparative analysis.

3.1 Flow rate vs various heat transfer parameters

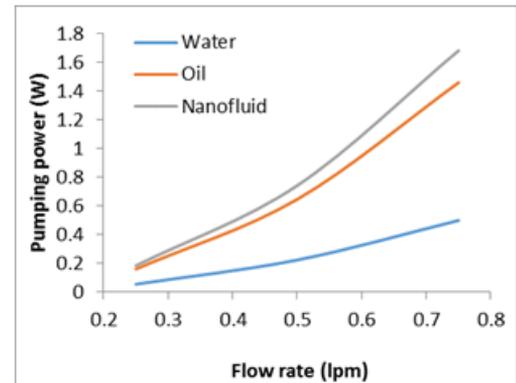


(a)

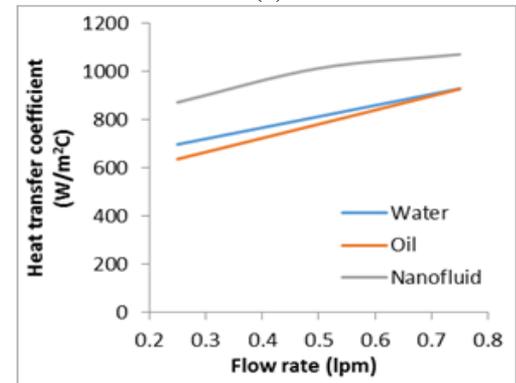


(b)

Figure 2. Flow rate vs (a) friction factor and (b) pressure drop for different fluids



(a)



(b)

Figure 3. Flow rate vs (a) pumping power and (b) heat transfer coefficient for different fluids

The variation of friction factor with change in flow rate is shown in Fig. 4. Friction factor keeps on reducing with increase in flow rate. But, pressure drop, pumping power, heat transfer coefficient and Nu increase along with increased flow rate, it can be seen from Fig. 2(b), 3(a), 3(b) and 4 respectively. Due to increased flow rate the friction reduces because, the increased flow velocity has more kinetic energy with it and hence easier to overcome the flow friction. On the other hand, with increase in flow rate, pressure drop also increases due to increase in friction losses. Pumping power keeps on increasing along with flow as with increase in flow rate the pump work required to overcome the pressure drop is more. Similarly heat transfer coefficient increases with flow rate as more quantity of fluid is made to flow in short interval of time. There exists a limiting value of flow rate (0.51pm) beyond which the Nusselt number remains constant.

3.2 Heat transfer enhancement using nanofluid

Convective heat transfer coefficient enhancement (%) and actual heat transfer (%) obtained by using the MWCNT-W nanofluid relative to water is shown in Fig. 5 (a and b). About 25% of heat transfer enhancement in both the cases is obtained for MWCNT-W nanofluid. However, for engine coolant oil 8.7% reduction in heat transfer is seen. As the MWCNT-W nanofluid has more specific heat, thermal conductivity, compared to water and engine coolant oil, hence enhancement in heat transfer is observed. Whereas the Pr (41.629) and viscosity of oil is more compared to water (Pr=9.645), hence reduction in heat transfer is seen for coolant oil. Due to high Prandtl number of engine coolant oil the velocity boundary layer thickness dominates over thermal boundary layer thickness which may tends to decrease the heat transfer rate.

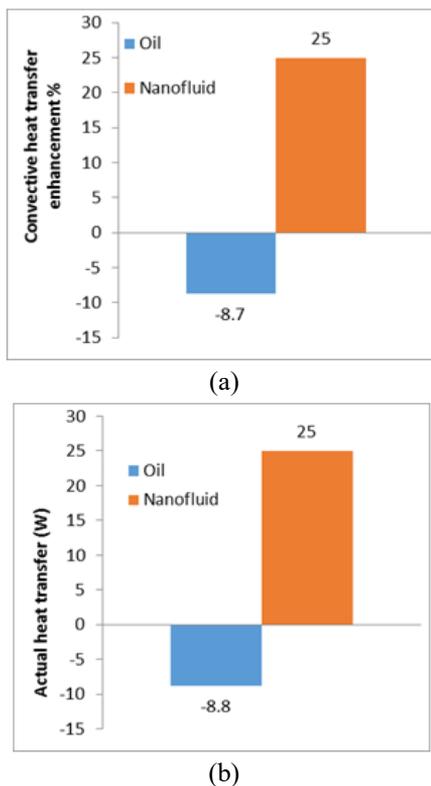


Figure 5. (a) Convective heat transfer enhancement (%) using nanofluid and coolant oil relative to water. (b) Actual heat transfer enhancement (%) using nanofluid and coolant oil relative to water

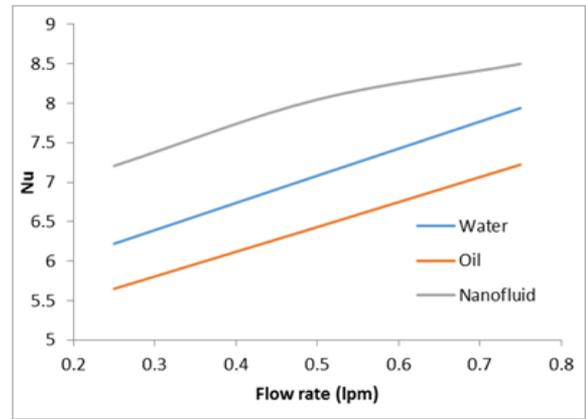


Figure 4. Flow rate vs Nu for different fluids

4. CONCLUSION

Comparative analysis of thermal characteristics of water, engine coolant oil and MWCNT-W nanofluid is studied in this work. 0.01% vol. fraction of MWCNT-W nanofluid is prepared by single step process. The radiator type of heat exchanger with unmixed cross flow condition is selected for present investigation. Analysis was done for different flow rates of 0.51pm, 0.51pm and 0.751pm and for different fluid velocity of 0.589 m/s, 1.176 m/s and 1.786 m/s. The following conclusions are drawn from the experimental analysis:

- Heat transfer rate and convective heat transfer coefficient are increased by 25% for MWCNT-W nanofluid as compared to other coolants considered in present study. Whereas for engine coolant oil the heat transfer rate and convective heat transfer coefficient reduces by 9%.
- Friction factor reduces along with increase in flow rate/ fluid velocity for all the coolants used. MWCNT-W has more friction factor due to immersion of nanoparticles.
- Pressure drop and ultimately pumping power required is more for MWCNT-W nanofluid than water and engine coolant oil. Again, this is related to the friction factor of the MWCNT-W nanofluid which is higher.
- MWCNT-W nanofluid tends to increase the Nusselt number compare to water and engine coolant oil.

MWCNT-W nanofluid proved to be more efficient heat transfer fluid than water and engine coolant oil due to increased heat carrying capacity, but with more pumping work. In future, different concentrations of MWCNT-W nanofluid with water and engine coolant oil as the base fluid can be used for the same study. The same experiment can be conducted in parallel and counter flow heat exchanger, spiral and helical heat exchanger and mini and micro channels.

REFERENCES

- [1] Sohel MR, Khaleduzzaman SS, Saidur R, Hepbasli A, Sabri MFM, Mahbulul IM. (2014). An experimental investigation of heat transfer enhancement of a minichannel heat sink using $Al_2O_3-H_2O$ nanofluid. *Int. J. Heat Mass Transfer* 74: 164–172.
- [2] Sheikholeslami M, Gorji-Bandpy M, Ganji DD. (2016). Effect of discontinuous helical turbulators on heat transfer characteristics of double pipe water to air heat exchanger. *Energy Conversion and Management* 118:

- 75–87.
- [3] Ali M, Ali H, Liaquat H, Maqsood HTB, Nadir MA. (2015). Experimental investigation of convective heat transfer augmentation for car radiator using ZnO–water nanofluids. *Energy* 84: 317-324.
- [4] Hussein AM, Bakar RA, Kadirgama K, Sharma KV. (2014). Heat transfer augmentation of a car radiator using nanofluids. *Heat and Mass Transfer* 50(11): 1553-1561.
- [5] Heris SZ, Shokrgozar M, Poorparhang S, Shanbedi M, Noie SH. (2014). Experimental study of heat transfer of a car radiator with CuO/ethylene glycol-water as a coolant. *Journal of Dispersion Science and Technology* 35(5): 677-684.
- [6] Ebrahimi M, Farhadi M, Sedighi K, Akbarzade S. (2014). Experimental investigation of force convection heat transfer in a car radiator filled with SiO₂–water nanofluid. *IJE Trans B: Appl* 27(2): 333-340.
- [7] Pak BC, Cho IY, (1998). Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. *Experimental Heat Transfer* 11: 151-170.
- [8] Heris SZ, Etemad SG, Nasr Esfahany M (2006). Experimental investigation of oxide nanofluids laminar flow convective heat transfer, *International Communications in Heat and Mass Transfer* 33(4): 529-535.
- [9] Heris SZ, Nasr Esfahany M, Etemad SG. (2007). Experimental investigation of convective heat transfer of Al₂O₃/water nanofluid in circular tube. *International Journal of Heat and Fluid Flow* 28 (2): 203-210.
- [10] Lai WY, Duculescu B, Phelan PE, Prasher RS. (2006). Convective heat transfer with nanofluids in a single 1.02-mm tube. *Proceedings of ASME International Mechanical Engineering Congress and Exposition (IMECE 2006)*.
- [11] Jung JY, Oh HS, Kwak HY. (2006). Forced convective heat transfer of nanofluids in microchannels. *Proceeding of ASME International Mechanical Engineering Congress and Exposition (IMECE 2006)*.
- [12] Halelfadl S, Maré T, Estellé P. (2014). Efficiency of carbon nanotubes water based nanofluids as coolants. *Exp. Thermal Fluid Sci.* 53: 104-110.
- [13] Li X, Zou C, Wang T, Lei X. (2015). Rheological behavior of ethylene glycol-based SiC nanofluids. *Int. J. Heat Mass Transf.* 84: 925-930.
- [14] Zyla G, Cholewa M. (2014). On unexpected behavior of viscosity of diethylene glycol-based MgAl₂O₄ nanofluids. *RSC Adv.* 4: 26057.
- [15] Li XK, Zoua CJ, Qi AH. (2016). Experimental study on the thermo-physical properties of car engine coolant (water/ethylene glycol mixture type) based SiC nanofluids. *International Communications in Heat and Mass Transfer* 77: 159-164.
- [16] Kole M, Dey TK. (2010). Viscosity of alumina nanoparticles dispersed in car engine coolant *Exp. Thermal Fluid Sci.* 34(6): 677-683.
- [17] Agarwal R, Verma K, Agrawal NK, Duchaniya RK, Singh R. (2016). Synthesis, characterization, thermal conductivity and sensitivity of CuO nanofluids. *Appl. Therm. Eng.* 102: 1024–1036.
- [18] Elias MM, Mahbulul IM, Saidur R, Sohel MR, Shahrul IM, Khaleduzzaman SS, Sadeghipour S. (2014). Experimental investigation on the thermo-physical properties of Al₂O₃ nanoparticles suspended in car radiator coolant. *Int. Commun. Heat Mass Transfer* 54: 48–53.
- [19] Nikkam N, Saleemi M, Haghghi EB, Ghanbarpour M, Khodabandeh R, Muhammed M, Palm B, Toprak MS. (2014). Fabrication, characterization and thermophysical property evaluation of water/ethylene glycol based SiC nanofluids for heat transfer applications. *Nano-Micro Lett.* 6: 178–189.
- [20] Shahrul IM, Mahbulul IM, Saidur R, Sabri MFM. (2016). Experimental investigation on Al₂O₃–W, SiO₂–W and ZnO–W nanofluids and their application in a shell and tube heat exchanger. *International Journal of Heat and Mass Transfer* 97: 547–558.
- [21] Estellé P, Halelfadl S. (2015). Thermal conductivity of CNT water based nanofluids: Experimental trends and models overview. *Journal of Thermal Engineering* 1(2): 381-390.
- [22] Oliveira GA, Contreras EMC, Filho EPB. (2016). Experimental study on the heat transfer of MWCNT/water nanofluid flowing in a car radiator. *Applied Thermal Engineering* <http://dx.doi.org/10.1016/j.applthermaleng.2016.05.086>
- [23] Crosse OK, Hamilton RL. (1962). Thermal conductivity of heterogeneous two-component systems. *Ind. Eng. Chem. Fundam.* 1(3): 187-191.
- [24] Adil A, Gupta S, Ghosh P. (2014). Numerical prediction of heat transfer characteristics of nanofluids in a minichannel flow. *J. Energy* 2014(6): 1-7.
- [25] Hamilton RL, Crosse OK. (1962). Thermal conductivity of heterogeneous two-component systems. *Ind. Eng. Chem. Fundam.* 1(3): 187-191.
- [26] Ismail M, Fotowat S, Fartaj A. (2016). Transient response of minichannel heat exchanger using Al₂O₃-EG/W nanofluid.” *SAE Tech. Pap.* 2016.
- [27] Kumar M, Afzal A, Ramis MK. (2017). Investigation of physicochemical and tribological properties of TiO₂ nano-lubricant oil of different concentrations. *TRIBOLOGIA - Finnish Journal of Tribology* 35(3): 6-15.
- [28] Afzal A, Samee MAD, Razak ARK. (2017). Experimental thermal investigation of cuo-w nanofluid in circular minichannel. *AMSE JOURNALS-AMSE IIETA publication-2017-Series: Modelling B* 86(2): 335-344.
- [29] Afzal A, Samee ADM, Javad A, Shafvan SA, PVA, Kabeer KMA. (2017). Heat transfer analysis of plain and dimpled tubes with different spacings. *Heat Trans Asian Res.* 1-13. <https://doi.org/10.1002/htj.21318>
- [30] Afzal A, Samee ADM, Razak RKA, Ramis MK. (2018). Heat transfer characteristics of MWCNT nanofluid in rectangular mini channels. *International Journal Heat and Technology* 36: 222-8. <https://doi.org/10.18280/ijht.360130>
- [31] Afzal A, Nawfal I, Mahbulul IM, Kumbar SS. (2018). An overview on the effect of ultrasonication duration on different properties of nanofluids. *J Therm Anal Calorim* 2018. <https://doi.org/10.1007/s10973-018-7144-8>

NOMENCLATURE

D	Outer diameter of tube (m)
d	Inner diameter of tube (m)
L	Length of the tubes (m)

C_p	Specific heat capacity (kJ/Kg K)	f	Heat transfer coefficient (W/m ² K)
$A = \pi DLn$	Area (M ²)	h	Hydraulic diameter (m)
m_f	Mass flow rate (Kg/s)	D_h	Actual heat transfer (W)
ϕ	Volume concentration of nanofluids	q	
T	Temperature (°C)		
c	Massin kg	Subscripts	
k	Thermal conductivity	p	Nanoparticle
ρ	Density (kg/m ³)	f	Base fluid
\dot{v}	Volume flow rate	nf	Nanofluid
μ	Dynamic viscosity (Ns/m ²)	c	Cold fluid
Nu	Nusselt number	h	Hot fluid
Re	Reynolds number	o	Outlet
Pr	Prandtl number	i	Inlet
P	Pumping power (W)		
ΔP	Pressure drop (N/m ²)		
	Friction factor		