Journal of Engg. Research Vol. 7 No. (2) June 2019 pp. 333-351

Experimental Investigation of Thermal Performance of Engine Coolant Oil and Water in Helical Coil Heat Exchanger

Asif Afzal*, Mohammed Samee A. D.** and Abdul Razak R. K.*

*Department of Mechanical Engineering, P. A. College of Engineering (Affiliated to Visvesvaraya Technological University), Mangaluru, India
**Department of Mechanical Engineering N. K. Orchid College of Engineering, Solapur, Maharashtra, India
*Corresponding Author: asif.afzal86@gmail.com

ABSTRACT

A comparative thermal analysis of water and engine coolant oil in a helical coil tube and shell heat exchanger is performed. The experimental study is carried out in parallel and counter flow conditions with laminar flow of the fluids. Various factors like heat transfer coefficient, friction factor, pressure drop, and pumping power for different fluid flow rates of 0.25 lpm (litre per minute), 0.5 lpm, and 0.75 lpm along tube side and shell side are compared. The other common factors of the heat exchanger along tube and shell side like overall heat transfer coefficient, NTU (Number of Transfer Units), LMTD (Log Mean Temperature Difference), effectiveness, and average heat transfer coefficient are also analysed for variation in flow rates. The variation of overall heat transfer coefficient is also compared with different non-dimensional numbers such as He (Helical Number), De (Dean Number), LMTD, and NTU. The maximum enhancement % of various heat transfer characteristics comparative to water in parallel flow condition is provided. For coolant oil in counter flow condition, the average heat transfer is enhanced by 63.3%, convective heat transfer coefficient by 42.7%, and overall heat transfer coefficient by 98.9% compared to parallel flow of water. It is also observed that counter flow of water provides more enhanced heat transfer (18.7%) than parallel flow of coolant oil. Finally it is concluded that in helical tube and shell type of heat exchanger the counter flow with coolant oil as a coolant is more effective.

Keywords: Counter flow; Engine coolant oil; helical coil tube; heat transfer; parallel flow.

Nomenclature			
Symbol	**Notation**	**Symbol**	**Notation**
A	Surface area of coiled tube, m^2	r	Curvature radius, m
p	Coil pitch, m	D_h	Hydraulic diameter, m
D	Shell diameter, m	De	Dean number
Re	Reynolds number	d	Coiled tube diameter, m
He	Helical number	v	Fluid average velocity m/s
K	Thermal conductivity, W/m K	Nu	Nusselt number
Uo	Overall heat transfer coefficient, W/m^2 K	h	Convective heat transfer coefficient, W/m^2 K
ρ	Density kg/m^3	μ	Dynamic Viscosity kg/ms
Pr	Prandtl Number	L	Length of helical coil tube in m

l	Length of shell in m	u	Fluid flow velocity m/s
P	Pressure N/m^2	Q	Heat transfer in W.
ε	Effectiveness of heat exchanger	m	Mass flow rate kg/s
NTU	Number of transfer units	LMTD	Log mean temperature difference
C_{min}	Minimum specific heat capacity (J/kg K)		
subscripts: i-inner o-outer, f- fluid or coolant, t- tube side, s- shell side			

INTRODUCTION

For efficient transfer of heat, compact and curved types of tubes are employed in present situations. One among them is helically coiled tube which is used as a heat transfer enhancer. Many researchers have focused on analysis of heat transfer and characteristics of fluid flow in heat exchangers (HE) using helical tubes. On the other hand, among the fluids used to enhance the heat transfer characteristics a lot of study is conducted on preparation, characterization, functionalization, and performance analysis of nanofluids (Huminic and Huminic 2011). The presence of nanoparticles in conventional fluids increases the ability of the fluids to transfer heat, which is interesting and required in important fields. Nanoparticles of metals that are chemically stable like silver, zinc, copper, carbon allotropes such as Multi Walled Carbon Nano Tubes (MWCNT), diamond, and other oxides like CuO, ZnO, TiO_2, Al_2O_3, SiO_2, etc. are suspended in the base fluid to prepare the nanofluid by using single- or two-step method with or without surfactant. The most noteworthy property of presence of these nanoparticles in the fluids is its ability to greatly enhance the heat transfer coefficient and thermal conductivity of the base fluid (Huminic and Huminic 2016).

Literature review is presented regarding research works carried using different nanofluids in different HE focusing mainly on helically coiled tube HE. 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 (Heris, Etemad, and Esfahany 2006). 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 (W. Y. Lai, Phelan, and Prasher 2006). 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 vol. % nanoparticles (Jung, Oh, and Kwak 2009). In other work, Heris et al. conducted an experiment by maintaining constant wall temperature boundary condition with 0.2 to 2.5 vol. % of nanoparticles for Re varying between 700 and 2050. They again found that Nu increases with the use of nanofluids as compared to water (Heris, Esfahany, and Etemad 2007). Suresh et al. worked on CuO nanoparticles of 15.3 nm. 0.1%, 0.2%, and 0.3% vol fractions were considered for analysis for Re in the range 2500-6000 adopting constant heat flux (Suresh, Chandrasekar, and Sekhar 2011). Pakdaman and Behabadi analysed the performance of MWCNT nanofluid in a helically coiled heat exchanger kept vertically. 0.1%, 0.2%, and 0.4% Vol. fractions were considered for the analysis (Pakdaman and Akhavan-Behabadi 2012; Fakoor-Pakdaman and Akhavan-Behabadi 2013). MWCNT suspended in oil was used by Behabadi and Pakdaman to investigate heat transfer enhancement in helically coiled HE. The nanofluid gave improved heat transfer coefficient relative to the base fluid (Akhavan-Behabadi and Pakdaman 2012). Helically coiled tubes held in vertical and horizontal positions were investigated using CuO nanofluid with 0.1% and 0.2% vol. to compare pressure drop and heat transfer characteristics by Kannadasan et al. They found no change in performance held in both positions (Kannadasan, Ramanathan, and Suresh 2012). For the same tube with constant heat flux, CuO and oil were used as fluid by Hashemi and Akhavan-Behabadi. 0.5%, 1%, and 2% vol. fractions of the nanoparticle were used and thermal performance was compared with that of straight tube. Helical coil showed improved performance than straight tube (Hashemi and Akhavan-Behabadi 2012).

Heris et al. utilized CuO nanoparticles (60 nm) in a base fluid of water/EG (Ethylene Glycol) 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 54ºC. For 0.8 vol% of nanofluid Nu is enhanced up to 55%. As the flow rate increased Nu improved along with the volume concentration of the nanofluid and radiator inlet temperature (Heris, Shokrgozar, and Poorpharhang 2014). Ebrahimi et al. studied the outcome of mixing SiO_2 nanoparticle 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 (Ebrahimi et al. 2014). ZnO nanoparticles were used by Zyla and Cholewa considering glycol as the base fluid. They reported about thermal performance enhancements along with % vol. (Żyła and Cholewa 2014). The temperature and % vol. effect on the kinematic viscosity on SiC- ethylene glycol based nanofluid were studied by Li et al. They mentioned that viscosity increased along with % vol. but viscosity decreased with temperature (Li et al. 2015). Ali et al. analyzed the performance of aluminium car radiator utilizing water based ZnO nanofluids. A heat transfer improvement of up to 46% was obtained by utilizing 0.2% vol. nanofluid. They concluded that enhancement in heat transfer in nanofluids highly depends on the volumetric concentration of the respective nanoparticles (Ali et al. 2015). Li et al. investigated thermal performance of engine coolant based SiC nanofluids. They found the thermal performance enhancement by 53% for 0.5% vol. fraction at a temperature of 50ºC (Li, Zou, and Qi 2016). Recently Alimoradi and Veysi experimentally investigated the effect of different geometrical parameters on heat transfer and entropy generation in helical coiled tube and shell type of heat exchanger. With the help of this study they have determined the optimal and critical values of these parameters so as to maximize the performance of heat exchanger (Alimoradi and Veysi 2017). Alimoradi has proposed an equation to determine the heat transfer rates of inner and outer side of the coil or the heat exchanger efficiency as functions of geometrical as well as operational parameters of the heat exchanger (Alimoradi 2017). Several others who worked on different heat exchangers include Asif Afzal, AD, and RK 2017; Kumar, Afzal, and Ramis 2017; Asif Afzal et al. 2017; A. Afzal, Samee, and Razak 2018; A. Afzal et al. 2018; Asif Afzal et al. 2018.

From the above literature review it is clear that most of the studies related to helical coil tube and shell type of HE are pertinent to nanofluid as a coolant in which the heat transfer enhancement is reported but the problem with nanofluid coolant is settling of nanoparticles, which may further choke up the flow of fluid. Hence to overcome the problems of nanofluid, in the present investigation we have used two most commonly used coolants, i.e. water and engine coolant oil and also, in helical coiled tube and shell HE, thermal performance analysis using engine coolant oil is not conducted. Engine coolant has more thermal conductivity than water. Hence, this is the motivation for the current research work. Thus the prime objective of present experimental study is to check the thermal performance of helical tube and shell type of heat exchanger under parallel and counter flow environment and to provide a comparative statement for these two coolants and to find out the best coolant with best flow condition. The flow is laminar and forced convection condition. The engine coolant oil considered is Cool Guard, which is available in many automobile service centres.

EXPERIMENTAL SETUP

The heat exchanger employed for the investigation of thermal performance of water and engine coolant oil is shell and helical coil tube type heat exchanger kept in horizontal position. The schematic figure of the helical tube and shell type heat exchanger is shown in Fig. 1. The overview of the entire experimental set up is shown in Fig. 2. The details of physical dimensions of helical coil and shell used in this study are mentioned in Table. 1. The shell and helical coil tube HE are well instrumented and are intact. The shell material is carefully insulated with asbestos in order to avoid any heat transfer. An electric heater is fixed to the hot reservoir that can supply heat to the fluid to the required temperature. The temperature attained by the fluid in the hot reservoir can be altered by changing the supply voltage to the electric heater. A pump supplies the hot fluid along tube side through the rotameter and ball valve to measure and regulate the fluid flow. The rotameter can measure the fluid flow rate up to an accuracy of 0.2 lpm and the same type of rotameter and ball valve is fixed to another pump to supply fluid flow along shell side. The inlet /outlet, hot / cold fluid temperature are measured using k-type thermocouples coupled with digital monitor as shown in Fig. 2 to show temperature readings. These thermocouples are inserted at an opening of the inlet and outlet pipes having a small opening such that there is no leakage of heat and fluid. The observed data was recorded in MS excel file 2007 for further calculations. For each flow rate of 0.25, 0.5, and 0.75 lpm, three trials were taken carefully and data was recorded after steady state is reached. In this investigation, water and Cool Guard engine coolant oil (here onwards 'coolant') are considered as hot and cold fluids along tube and shell side. RO (Reverse Osmosis) treated water is easily obtained and the coolant oil can be purchased from any automobile service centre. The density of coolant oil is 988 kg/m^3 and specific heat capacity is 5300 kJ/kg-K, which is greater than specific heat capacity of RO (Reverse Osmosis) treated water (4187 kJ/kg-K). Viscosity of coolant oil is 6.81×10^{-7} kg/ms at 35°C, which is greater than the viscosity of water.

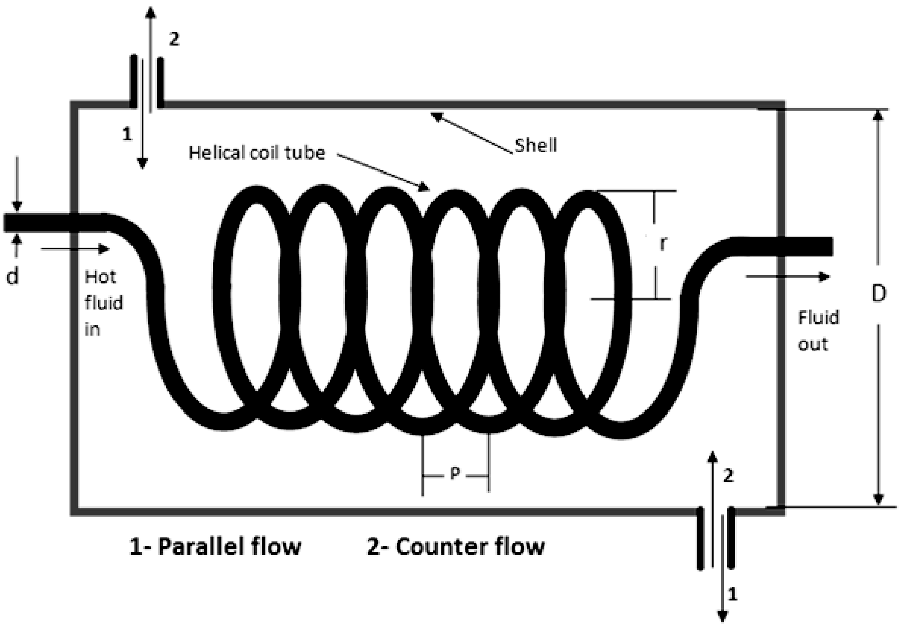

Fig. 1. Helical coil tube and shell type of heat exchanger.

Table 1. Dimensions and material for tube and shell used in the helical heat exchanger.

Helical coil tube						Shell	
d_i	d_o	Material	p	Length	R	D	Length
0.0083 m	0.0098 m	copper	0.024 m	3.65 m	0.0225 m	0.075 m	0.45 m

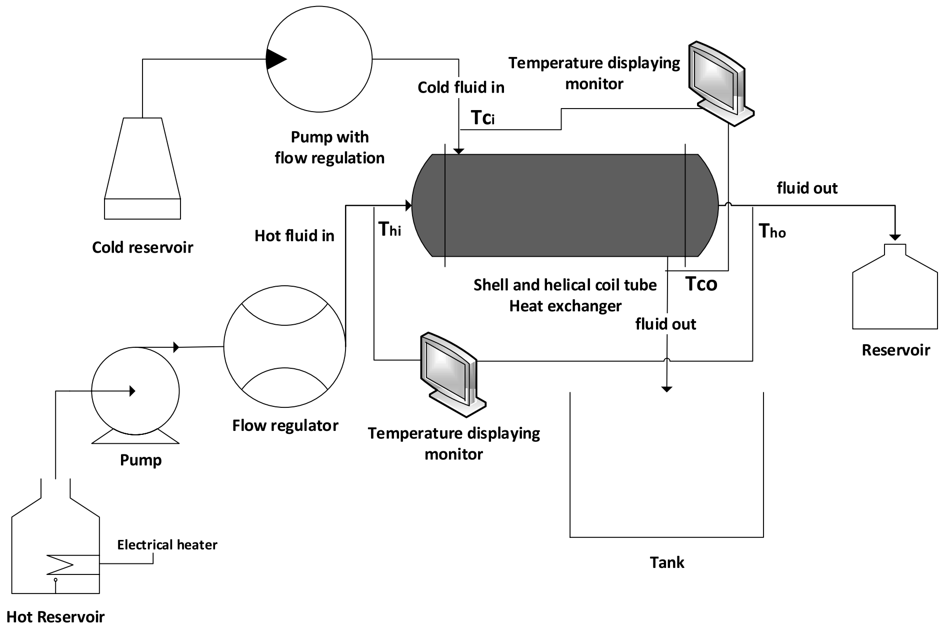

Fig. 2. Schematic overview of experimental setup of helical coil heat exchanger.

Correlations Used

Equations 1-15 are used to calculate different thermal performance parameters. In Fig. 1, d_i is the inside diameter of the helical tube, r is the radius of curvature of the helical tube, D is the inner diameter of the shell, and p is the pitch of the helical coil. The value of curvature ratio (δ) is calculated using the simple relation, $\delta = {}^{d}/_{2r}$ and the relation $\gamma = {}^{p}/_{2\pi r}$ is used to calculate the non-dimensional pitch (γ). The other important parameters like Re, Nu, De, He are calculated using equations and correlations mentioned as follows. Parameters like Re, h, Ɛ, NTU, ΔT_{lmtd}, Q, U_o, f, ΔP and P were calculated using equations mentioned (Rajput 2015; Cengel and Ghajar 2014). Parameters like Nu, He, De and D_h were estimated using equations 2 and 5-7 (Salimpour 2009).

$$Re_{f,t} = {}^{\rho_{f,t} d_i v_{f,t}}/_{\mu_{f,t}} \quad (1)$$

$$D_h = {}^{(D^2 - 2\pi r {d_o}^2 \gamma^{-1})}/_{(D^2 - 2\pi r d_o \gamma^{-1})} \quad (2)$$

$$Re_{f,s} = {}^{\rho_{f,s} D_h v_{f,s}}/_{\mu_{f,s}} \quad (3)$$

$$De = Re_{f,t} ({}^{d_i}/_{2r})^{0.5} \quad (4)$$

$$He = {}^{De}/_{(1+\gamma^2)^{0.5}} \quad (5)$$

$$Nu_{f,t} = 0.152 De^{0.431} Pr^{1.06} \gamma^{-0.277} \quad (6)$$

$$Nu_{f,s} = 19.64 {Re_{fs}}^{0.531} Pr^{0.129} \gamma^{0.938} \quad (7)$$

$$h_{f,t} = {Nu_{f,t}k}/{d_i} \tag{8}$$

$$h_{f,s} = {Nu_{f,s}k}/{D_h} \tag{9}$$

$$\mathcal{E} = {Q}/{Q_{max}} \tag{10}$$

$$NTU = {UA}/{C_{min}} \tag{11}$$

$$\Delta T_{lmtd} = {(\Delta T_2 - \Delta T_1)}/{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)} \tag{12}$$

Where, $\Delta T_2 = T_{h,o} - T_{c,i}$, $\Delta T_1 = T_{h,i} - T_{c,o}$

$$Q_{f,t} = m_{f,t}C_{p,t}\left(T_{h,i} - T_{h,o}\right) \tag{13}$$

$$Q_{f,s} = m_{f,s}C_{p,s}\left(T_{c,o} - T_{c,i}\right) \tag{14}$$

$$\frac{1}{U_o} = \frac{A_o}{A_i h_{f,t}} + \frac{A_o ln({d_o}/{d_i})}{2\pi kl} + \frac{1}{h_{f,s}} \tag{15}$$

$$f = {64}/{R_e} \tag{16}$$

$$\Delta P = f\rho\left({L}/{D}\right)\left({u^2}/{2}\right) \tag{17}$$

$$P = \Delta P f \dot{v} \tag{18}$$

The method suggested in Schultz and Cole (1979) was adopted to perform uncertainty analysis in all the trials as it is of prime importance in experimental analysis. The experimental error in calculating various thermal performance parameters was found to be ±5% as expected and is depicted in Table 2. The variable (δ) represents uncertainty of the computed variable, say Q, NTU etc., which depends upon the independent variable like T, m etc. Using equations (19-21) the uncertainties of dependent variable parameters were estimated for heat transfer (Q), Number of Transfer Units (NTU), Logarithmic mean temperature difference (ΔT_{lmtd}) and effectiveness of heat exchanger ($\mathcal{E}$) (Srinivas and Venu Vinod 2016; Sohel et al. 2014; Shahrul et al. 2016; Azmi et al. 2014). During the experimentation it was found that the type of flow (parallel or counter) did not had much effect on the uncertainties in dependent variables but it was considerable for change in flow rates.

$$\frac{\delta Q}{Q} = \left\{\left(\frac{\delta m}{m}\right)^2 + \left(\frac{\delta T}{T}\right)^2\right\}^{0.5} \tag{19}$$

$$\frac{\delta NTU}{NTU} = \left\{\left(\frac{\delta A}{A}\right)^2 + \left(\frac{\delta C_{min}}{C_{min}}\right)^2\right\}^{0.5} \tag{20}$$

$$\frac{\delta(\Delta T_{lmtd})}{\Delta T_{lmtd}} = \left\{\left(\frac{\delta\left(T_{c,o} - T_{c,i}\right)}{\left(T_{c,o} - T_{c,i}\right)}\right)^2 + \left(\frac{\delta\left(T_{h,i} - T_{c,0}\right)}{\left(T_{h,i} - T_{c,0}\right)}\right)^2 + \left(\frac{\delta\left(T_{h,o} - T_{c,i}\right)}{\left(T_{h,o} - T_{c,i}\right)}\right)^2\right\}^{0.5} \tag{21}$$

Table 2. Uncertainties for different parameters.

Parameter	**Uncertainty**
Q (W)	±3
NTU	±0.5
Ɛ	±0.4
LMTD	±2
D_h (mm)	±4
Flow rate (lpm)	±0.08

RESULTS AND DISCUSSIONS

The thermal performance analysis of water and coolant oil in helical coil tube and shell HE is presented in this section. The fluids were passed through tube side and shell side of the HE for different flow rates of 0.25 lpm, 0.5 lpm, and 0.75 lpm. The flow generated is laminar with forced convection in the HE and for each flow rate three trails were conducted. Analysis of both the fluids considered is performed along tube and shell side.

Effect of variation in flow rate on tube side

The variations of convective heat transfer coefficient, friction factor, pressure drop, and pumping power for different flow rates of 0.25, 0.5, and 0.75 lpm are shown in fig 3 to fig 6, respectively. The convective heat transfer coefficient increases with change in the flow rate as shown in fig. 3. Coolant along tube side in counter flow condition shows highest heat transfer coefficient relative to other fluid flow conditions. Friction factor, pressure drop, and pumping power for the coolant vary along with flow rate. Friction factor reduces more for water because of its lower viscosity compared to coolant oil, whereas pressure drop and pumping power required keeps on increasing along with flow rate. The same is required more for coolant oil than water because of change in viscosity. Nu almost varies linearly with Re as shown in Fig. 7 for both fluids in parallel and counter flow, which shows that the flow is laminar. Nu is more for coolant in counter flow, as it has more heat transfer coefficient ability than water. In all the cases mentioned above, there is fluid flow along tube side while considering parallel and counter flow along shell side.

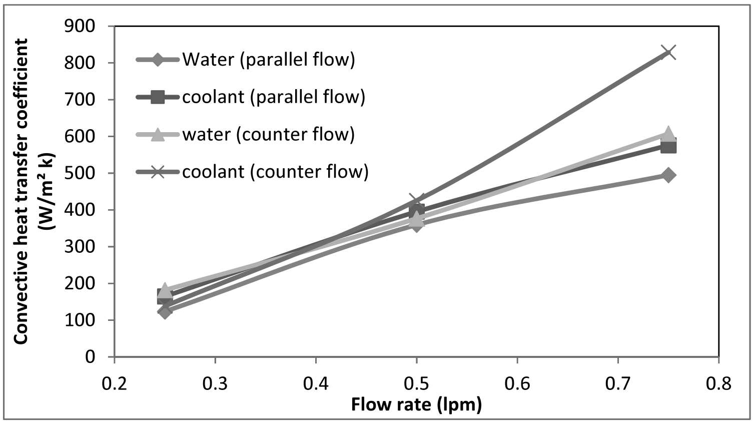

Fig. 3. Convective heat transfer coefficient vs flow rate along tube side.

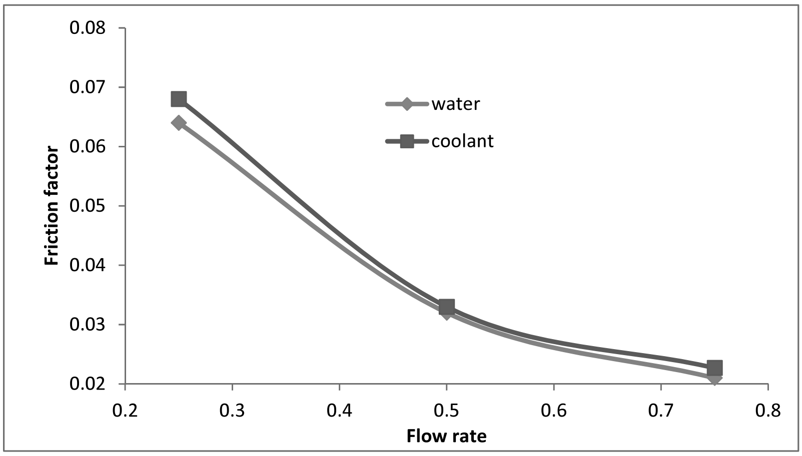

Fig. 4. Friction factor vs flow rate along tube side flow.

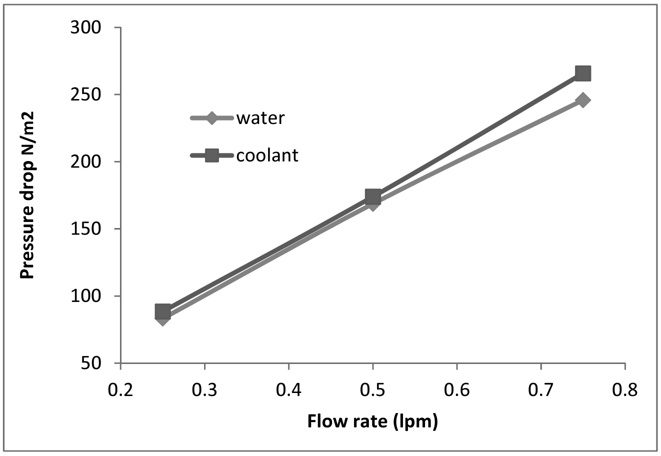

Fig. 5. Pressure drop vs flow rate along tube side flow.

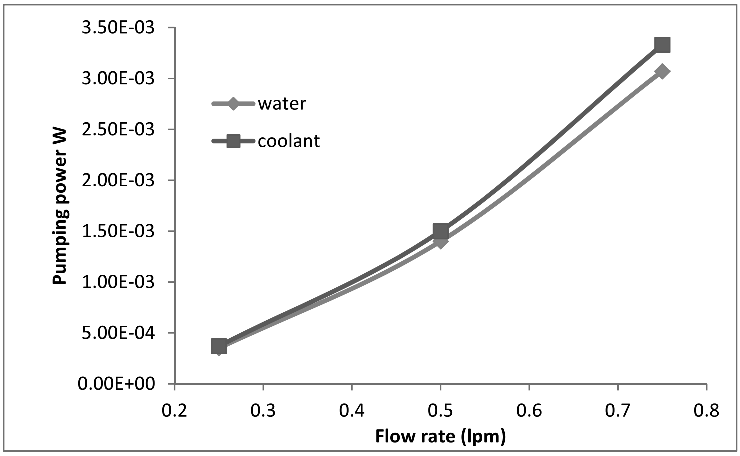

Fig. 6. Pumping power vs flow rate along tube side flow.

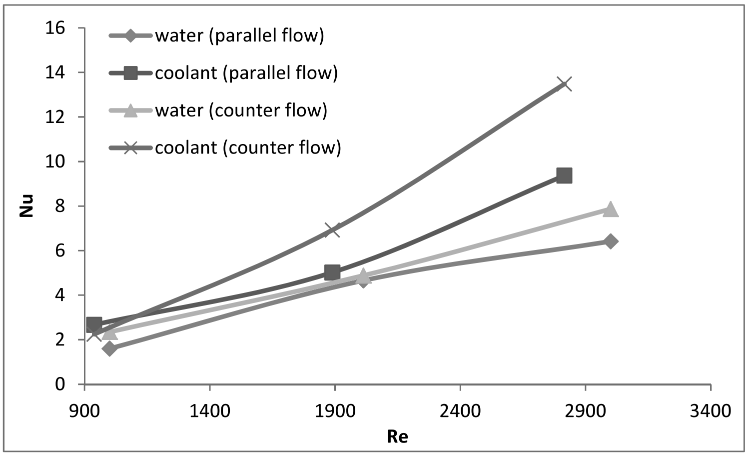

Fig. 7. Nusselt number vs Reynolds number along tube side flow.

Effect of changing flow rate on shell side

The variations of convective heat transfer coefficient, friction factor, pressure drop, and pumping power for different flow rates of 0.25, 0.5, and 0.75 lpm are shown in fig. 8 to fig. 12, respectively. The convective heat transfer coefficient increases with change in the flow rate as shown in Fig. 8. Coolant along shell side in counter flow condition shows highest heat transfer coefficient relative to other fluid flow conditions. Friction factor, pressure drop, and pumping power for the coolant vary along with flow rate. Friction factor reduces more for water because of its lower viscosity compared to coolant oil, whereas pressure drop and pumping power required keep on increasing along with flow rate. The same is required more for coolant oil than water because of its increased viscosity. Nu almost varies linearly with Re as shown in Fig. 7 for both fluids in parallel and counter flow, which shows that the flow is laminar. Nu is more for coolant in counter flow, as it has more heat transfer coefficient ability than water. All the cases mentioned above are for fluid flow along shell side by considering parallel and counter flow conditions.

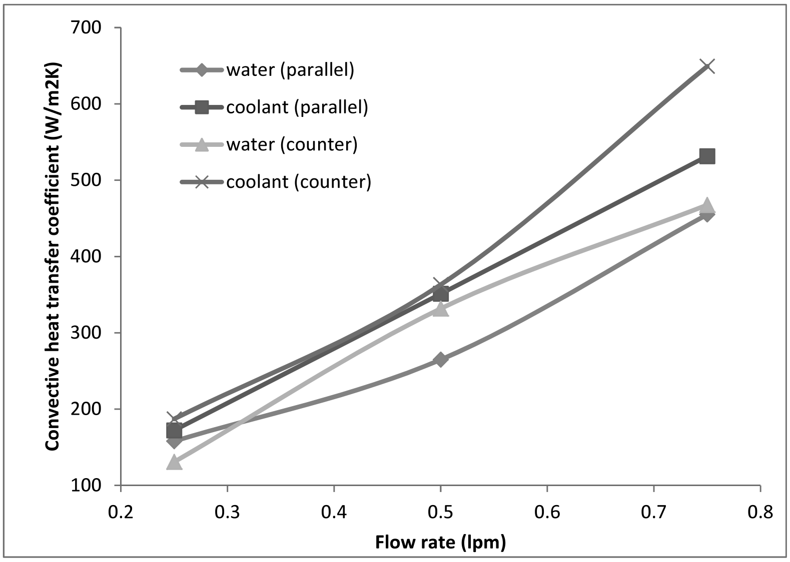

Fig. 8. Convective heat transfer coefficient vs flow rate along shell side.

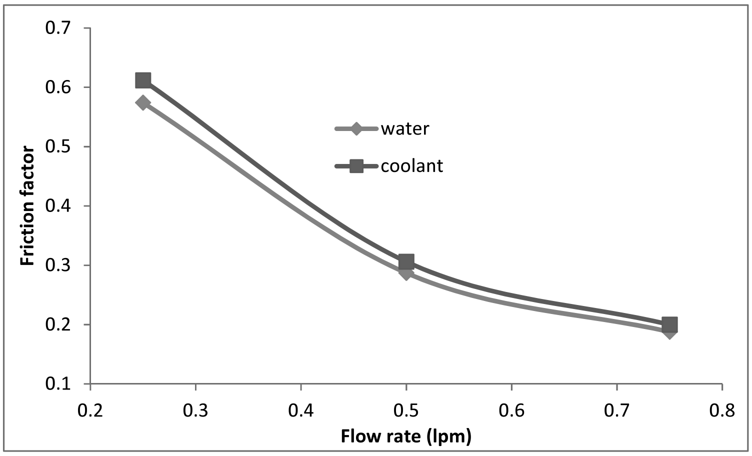

Fig. 9. Friction factor vs flow rate along shell side flow.

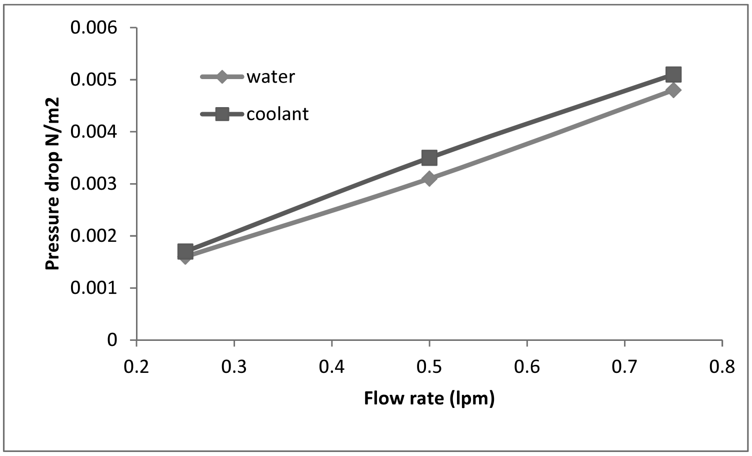

Fig. 10. Pressure drop vs flow rate along shell side flow.

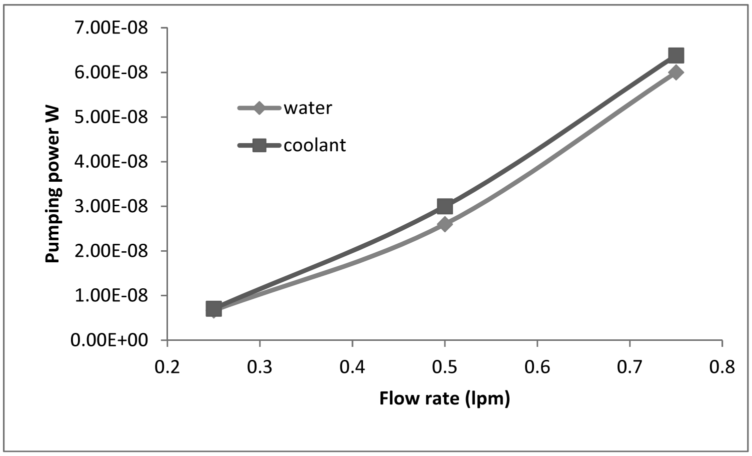

Fig. 11. Pumping power vs flow rate along shell side flow.

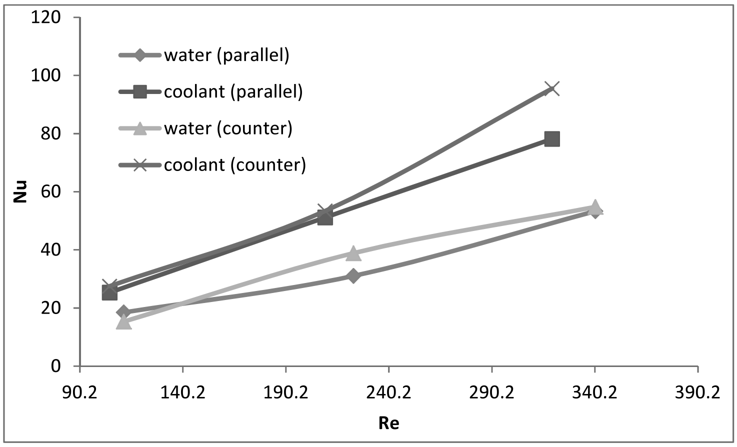

Fig. 12. Nusselt number vs Reynolds number along tube side flow.

Effect of changing flow rate on other thermal parameters of the Heat Exchanger

The variation of important thermal parameters with different flow rate and non-dimensional numbers is compared in this section. Average heat transfer is more for coolant oil in counter flow of fluid at 0.75 lpm compared to other fluid flow conditions as this can be seen in Fig. 13. The overall heat transfer coefficient also increases almost linearly with flow rate, whereas for counter flow of fluid at 0.75 lpm it quite rapidly increases because of the increase in Re as shown in Fig 14. Figures 15 and 16 show variation of He and De along with flow rate, which is linearly increasing and is more for water compared to coolant. The effectiveness of counter flow of coolant is highest comparatively and is maximum for flow rate of 0.75 lpm. LMTD also increases along with the increase in flow rate, which is due to the increase in Re and Nu as shown in Fig. 17. Similarly, overall heat transfer coefficient continuously increases with LMTD, NTU, and De as shown in Figures 18, 19, and 20 respectively. Figure 21 shows increase in effectiveness of the fluids with increase in flow rate. In all the above cases mentioned, counter flow of coolant oil gives improved performance than the remaining fluid flows. The reason behind this is that the heat transfer coefficient for counter flow of coolant is more than other fluid flows. Finally Fig. 22 shows the heat transfer characteristic enhancement % comparative to water. In all the cases (Q, h and Uo) counter flow of coolant outperforms the other fluid flow situations. We can see that Q is 16.5% more for coolant in parallel flow, 18.7% more for water in counter flow, and 63.3% more for coolant in counter flow. Similarly, the other factors h and Uo are also increasing in the order coolant (parallel flow) than water (counter flow) and then highest for coolant (counter flow). One thing to note here in all the cases discussed is that, instead of adopting coolant in parallel flow, water in counter flow can be adopted as alternative as its performance is better in all comparisons.

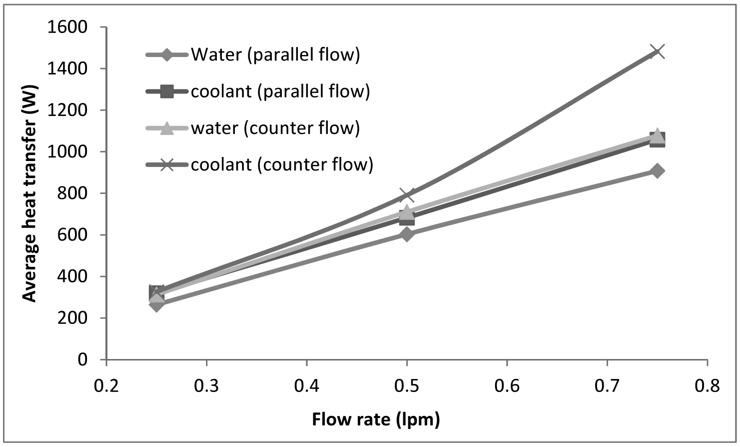

Fig. 13. Average heat transfer vs flow rate.

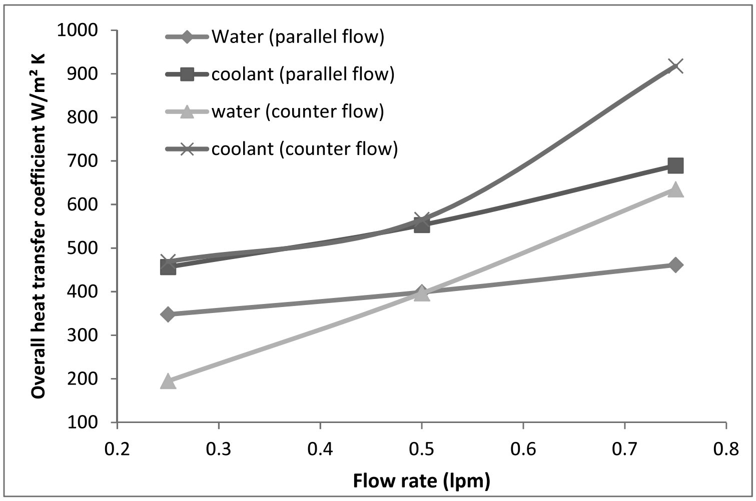

Fig. 14. Overall heat transfer coefficient vs flow rate.

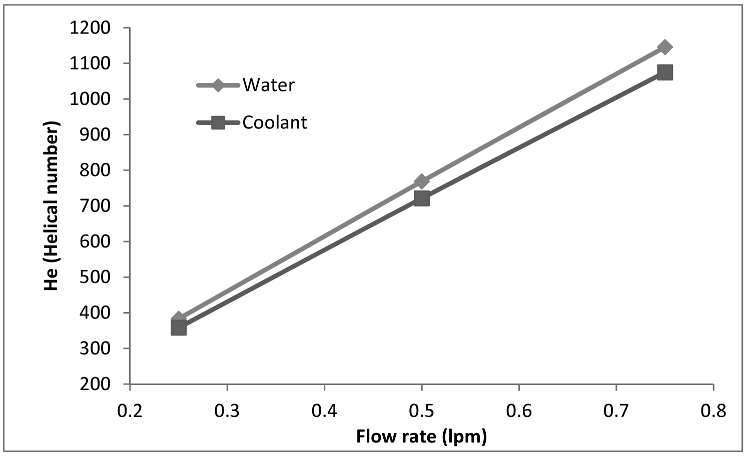

Fig. 15. Helical number vs flow rate.

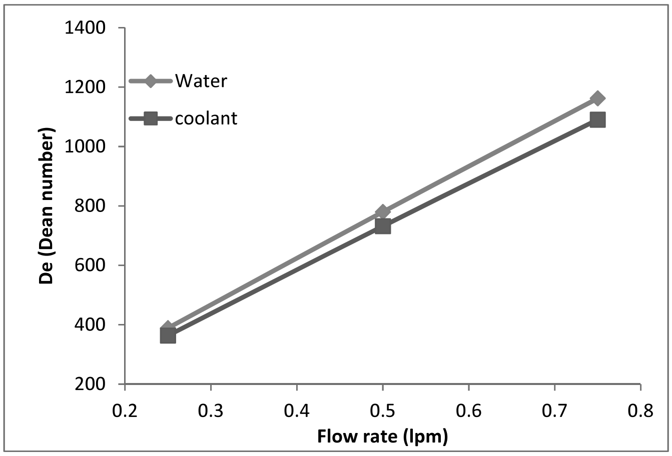

Fig. 16. Dean number vs flow rate.

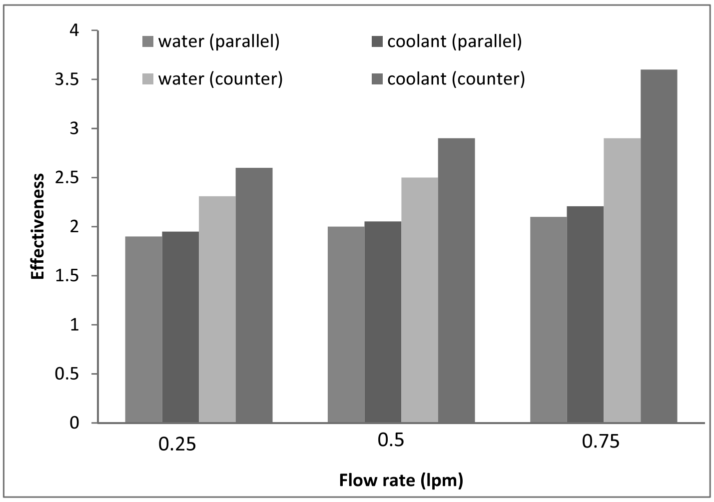

Fig. 17. Variation of effectiveness of the heat exchanger vs flow rate.

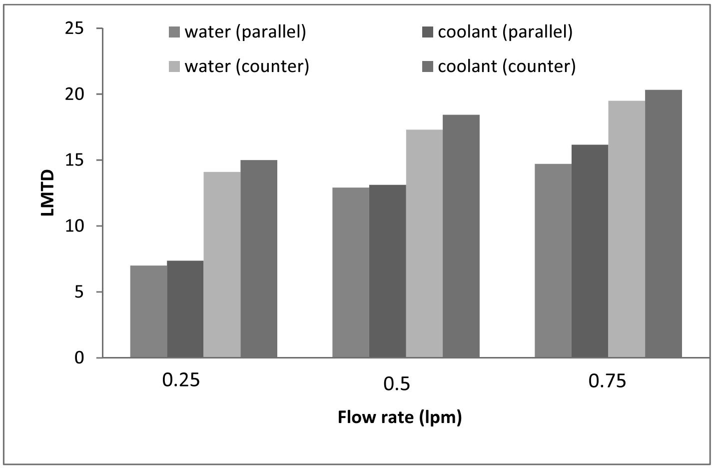

Fig. 18. LMTD vs flow rate of the heat exchanger for water and coolant oil.

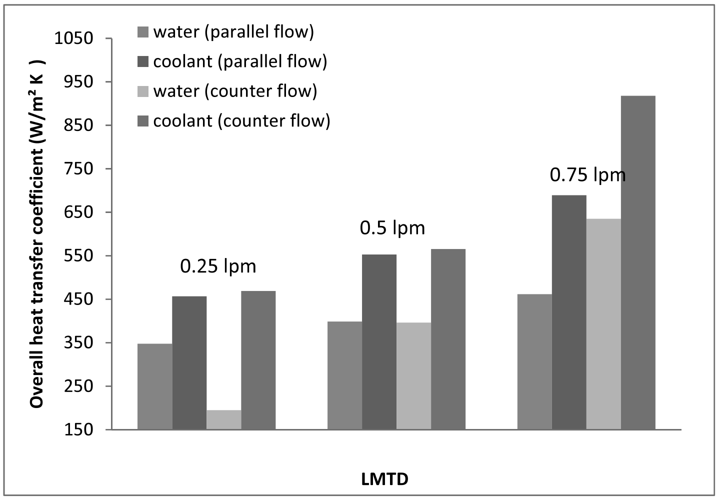

Fig. 19. Overall heat transfer coefficient vs LMTD.

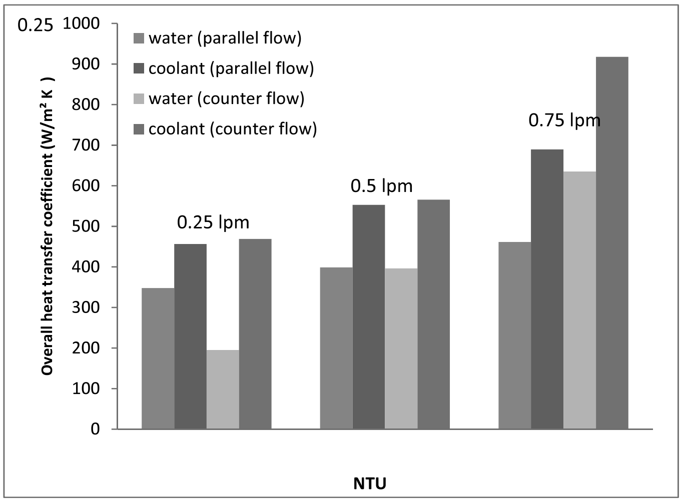

Fig. 20. Overall heat transfer coefficient vs NTU.

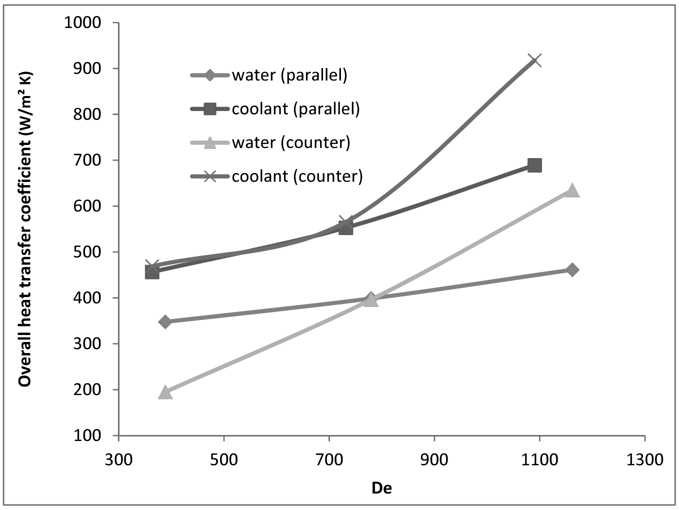

Fig. 21. Overall heat transfer coefficient vs Dean number.

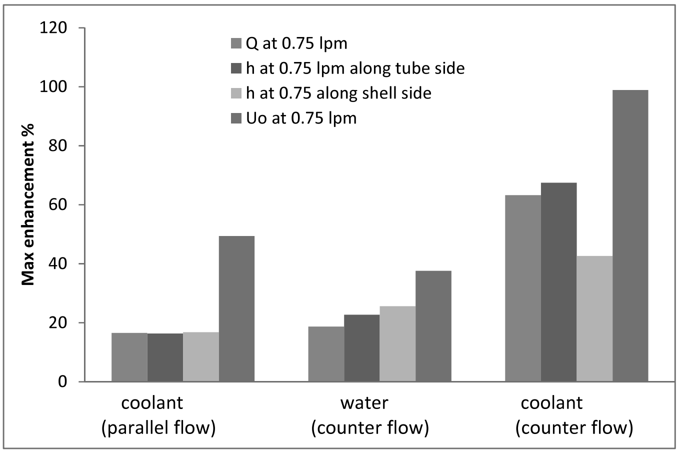

Fig. 22. Maximum heat transfer enhancement % for different flows compared to water in parallel flow.

Comparative study with previous studies

In Table 3 a comparison between previous experimental studies and present experimental study conducted is provided stating different details like nanofluid used, flow rate, and concentration of nanoparticle. The enhancement obtained in this study can be understood as follows. In this study the diameter of the helically coiled tube used was very small and conductivity of tubes was very high as the material used was copper. Hence the enhancement was far higher compared to the previous investigations.

Table 3. Comparison between present study and previous studies.

Nanofluid	Flow rates	Nanoparticle concentration	Results	Results of present study	Reference
Al_2O_3, CuO and TiO_2. Water is base fluid	0.5 to 5 lpm	0.3 to 2 weight percentage (% wt)	Heat transfer rate increased by 32.7% for CuO-water nanofluid compared to base fluid.	Up to 67% heat transfer enhancement is obtained for counter flow of engine coolant oil compared to water	(Srinivas and Venu Vinod 2016)
Al_2O_3, CuO and ZnO. Water is base fluid	3 to 6 lpm	1 to 4% volume concentration (% VC)	7.14% enhancement in heat transfer coefficient compared to other nanofluids	42.7% heat transfer enhancement is obtained for counter flow of engine coolant oil compared to water	(Khairul et al. 2013)
Al_2O_3, CuO SiO_2 and ZnO. Water, engine oil and ethylene glycol are base fluids.	0.01 to 0.06 kg/s	1 to 4 %VC	Up to 5% enhancement in Nu was obtained for 4 %VC of CuO-water compared to water	More than 50% enhancement in Nu is obtained for counter flow of engine coolant oil compared to water	(Narrein and Mohammed 2013)

CONCLUSION

An experimental thermal analysis of water and engine coolant oil in a helical coil tube and shell heat exchanger is studied. The investigation is carried out in parallel and counter flow conditions for both fluids with laminar flow of the fluids. Comparative analysis is made for different thermal performance characters for different fluid flow rates of 0.25 lpm (liter per minute), 0.5 lpm, and 0.75 lpm along tube side and shell side. The following important conclusions are drawn from the present work:

- Irrespective of flow rate, engine coolant oil gives highest heat transfer coefficient under counter flow condition compared to other fluids considered in the present study.
- Engine coolant oil requires more pumping work compared to other fluids irrespective of flow rate and flow conditions.
- An enhancement rate of 22.8% in heat transfer is observed in parallel flow condition for engine coolant oil compared to water flow, while for counter flow the rate of heat transfer enhancement is increased up to 67% for engine coolant oil compared to water flow.
- The overall heat transfer coefficient is highest for counter flow condition of engine coolant oil.
- It is found from the present comparative analysis that the counter flow of coolant oil performs better than the other three fluid flow conditions in all aspects. But at the same time coolant oil requires more pumping power compared to water due to more pressure drop and friction factor. However, water with counter flow can be an alternative to parallel flow of coolant oil as it gives more heat transfer enhancement. The same study needs to be carried out for coils with different pitches, different nanofluids with coolant oil as base fluid.

REFERENCES

Afzal, A., A.D.M. Samee, & R.K.A. Razak. 2018. "Comparative Thermal Performance Analysis of Water, Engine Coolant Oil and MWCNT-W Nanofluid in a Radiator." *Modelling, Measurement and Control B* 87 (1): 1–6.

Afzal, A., A.D.M. Samee, R.K.A. Razak, & M.K. Ramis. 2018. "Heat Transfer Characteristics of MWCNT Nanofluid in Rectangular Mini Channels." *International Journal of Heat and Technology* **36**(1): 222–28. https://doi.org/https://doi.org/10.18280/ijht.360130.

Afzal, Asif, Mohammed Samee AD, & Abdul Razak RK. 2017. "Experimental Thermal Investigation of CuO-W Nanofluid in Circular Minichannel." *Modelling, Measurement and Control B* **86**(2): 335–44.

Afzal, Asif, Ibrahim Nawfal, I. M. Mahbubul, & Sunil Siddalingappa Kumbar. 2018. "An Overview on the Effect of Ultrasonication Duration on Different Properties of Nanofluids." *Journal of Thermal Analysis and Calorimetry*. Springer Netherlands. https://doi.org/https://doi.org/10.1007/s10973-018-7144-8.

Afzal, Asif, Mohammed Samee A. D, Abdul Javad, Ahamed Shafvan S, Ajinas P V, & Ahammedul Kabeer K. M. 2017. "Heat Transfer Analysis of Plain and Dimpled Tubes with Different Spacings." *Heat Transfer—Asian Research*, 1–13. https://doi.org/http://dx.doi.org/10.1002/htj.21318.

Akhavan-Behabadi, MA, & MF Pakdaman. 2012. "Experimental Investigation on the Convective Heat Transfer of Nanofluid Flow inside Vertical Helically Coiled Tubes under Uniform Wall Temperature Condition." *International Communications in Heat and Mass Transfer* 39 (4): 556–64. http://www.sciencedirect.com/science/article/pii/S0735193312000358.

Ali, HM, H Ali, H Liaquat, HTB Maqsood, & MA Nadir. 2015. "Experimental Investigation of Convective Heat Transfer Augmentation for Car Radiator Using ZnO–water Nanofluids." *Energy* **84**: 317–24. http://www.sciencedirect.com/science/article/pii/S0360544215002807.

Alimoradi, Ashkan. 2017. "Investigation of Exergy Efficiency in Shell and Helically Coiled Tube Heat Exchangers." *Case Studies in Thermal Engineering* 9. Elsevier Ltd: 100–107. https://doi.org/10.1016/j.csite.2016.12.005.

Alimoradi, Ashkan, & Farzad Veysi. 2017. "Optimal and Critical Values of Geometrical Parameters of Shell and Helically Coiled Tube Heat Exchangers." *Case Studies in Thermal Engineering* 10. Elsevier Ltd: 73–78. https://doi.org/http://doi.org/10.1016/j.csite.2017.03.003.

Azmi, W. H., K. V. Sharma, P. K. Sarma, Rizalman Mamat, & Shahrani Anuar. 2014. "Comparison of Convective Heat Transfer Coefficient and Friction Factor of TiO2 Nanofluid Flow in a Tube with Twisted Tape Inserts." *International Journal of Thermal Sciences* **81**(1): 84–93. https://doi.org/10.1016/j.ijthermalsci.2014.03.002.

Cengel, Yunus A., & Afshin J. Ghajar. 2014. *Heat and Mass Transfer: Fundamentals and Applications*. Tata McGraw-Hill Education.

Ebrahimi, M, M Farhadi, K Sedighi, & S Akbarzade. 2014. "Experimental Investigation of Force Convection Heat Transfer in a Car Radiator Filled with SiO 2–water Nanofluid." *IJE TRANSACTIONS B: Applications* **27**(2): 330–40. http://www.sid.ir/En/VEWSSID/J_pdf/856201402B17.pdf.

Fakoor-Pakdaman, M, & MA Akhavan-Behabadi. 2013. "An Empirical Study on the Pressure Drop Characteristics of Nanofluid Flow inside Helically Coiled Tubes." *International Journal of Thermal Sciences* 65: 206–13. http://www.sciencedirect.com/science/article/pii/S1290072912002876.

Hashemi, SM, & MA Akhavan-Behabadi. 2012. "An Empirical Study on Heat Transfer and Pressure Drop Characteristics of CuO–base Oil Nanofluid Flow in a Horizontal Helically Coiled Tube under Constant Heat Flux." *International Communications In*. http://www.sciencedirect.com/science/article/pii/S0735193311002041.

Heris, SZ, MN Esfahany, & SG Etemad. 2007. "Experimental Investigation of Convective Heat Transfer of Al 2 O 3/Water Nanofluid in Circular Tube." *International Journal of Heat and Mass Transfer* **28**(2): 203–10. http://www.sciencedirect.com/science/article/pii/S0142727X06001007.

Heris, SZ, SG Etemad, & MN Esfahany. 2006. "Experimental Investigation of Oxide Nanofluids Laminar Flow Convective Heat Transfer." *International Communications in Heat and Mass Transfer* **33**(4): 529–35. http://www.sciencedirect.com/science/article/pii/S0735193306000194.

Heris, SZ, M Shokrgozar, & S Poorpharhang. 2014. "Experimental Study of Heat Transfer of a Car Radiator with CuO/Ethylene Glycol-Water as a Coolant." *Journal of Dispersion* **35**(5): 677–84. http://www.tandfonline.com/doi/abs/10.1080/01932691.2013.805301.

Huminic, Gabriela, & Angel Huminic. 2011. "Heat Transfer Characteristics in Double Tube Helical Heat Exchangers Using Nanofluids." *International Journal of Heat and Mass Transfer* **54**(19–20). Elsevier Ltd: 4280–87. https://doi.org/10.1016/j.ijheatmasstransfer.2011.05.017.

Huminic Gabriela, Huminic Angel Transilvania. 2016. "Heat Transfer and Flow Characteristics of Conventional Fluids and Nanofluids in Curved Tubes: A Review." *Renewable and Sustainable Energy Reviews* **58**: 1327–47. https://doi.org/10.1016/j.rser.2015.12.230.

Jung, JY, HS Oh, & HY Kwak. 2009. "Forced Convective Heat Transfer of Nanofluids in Microchannels." *International Journal of Heat and Mass* **52**: 466–72. http://www.sciencedirect.com/science/article/pii/S0017931008003530.

Kannadasan, N., K. Ramanathan, & S. Suresh. 2012. "Comparison of Heat Transfer and Pressure Drop in Horizontal and Vertical Helically Coiled Heat Exchanger with CuO/Water Based Nano Fluids." *Experimental Thermal and Fluid Science* 42. Elsevier Inc.: 64–70. https://doi.org/10.1016/j.expthermflusci.2012.03.031.

Khairul, M. A., R. Saidur, M. M. Rahman, M. A. Alim, A. Hossain, & Z. Abdin. 2013. "Heat Transfer and Thermodynamic Analyses of a Helically Coiled Heat Exchanger Using Different Types of Nanofluids." *International Journal of Heat and Mass Transfer* 67. Elsevier Ltd: 398–403. https://doi.org/10.1016/j.ijheatmasstransfer.2013.08.030.

Kumar, Mohan, Asif Afzal, & M K Ramis. 2017. "Investigation of Physicochemical and Tribological Properties of TiO2 Nano-Lubricant Oil of Different Concentrations." *TRIBOLOGIA - Finnish Journal of Tribology* **35**(3): 6–15.

Li, X, C Zou, & A Qi. 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* **77**: 159–64. http://www.sciencedirect.com/science/article/pii/S0735193316302299.

Li, X, C Zou, T Wang, & X Lei. 2015. "Rheological Behavior of Ethylene Glycol-Based SiC Nanofluids." *International Journal of Heat and Mass Transfer* 84: 925–30. http://www.sciencedirect.com/science/article/pii/S0017931015001222.

Narrein, K., & H. A. Mohammed. 2013. "Influence of Nanofluids and Rotation on Helically Coiled Tube Heat Exchanger Performance." *Thermochimica Acta* 564 (July): 13–23. https://doi.org/10.1016/j.tca.2013.04.004.

Pakdaman, MF, & MA Akhavan-Behabadi. 2012. "An Experimental Investigation on Thermo-Physical Properties and Overall Performance of MWCNT/Heat Transfer Oil Nanofluid Flow inside Vertical Helically Coiled Tubes." *Experimental Thermal and Fluid Science* **40**: 103–11. http://www.sciencedirect.com/science/article/pii/S0894177712000507.

Rajput, R. K. 2015. *Heat and Mass Transfer*. S. Chand Limited.

Salimpour, M. R. 2009. "Heat Transfer Coefficients of Shell and Coiled Tube Heat Exchangers." *Experimental Thermal and Fluid Science* **33**(2): 203–7. https://doi.org/10.1016/j.expthermflusci.2008.07.015.

Schultz, R. R., & R Cole. 1979. "Uncertainty Analysis in Boiling Nucleation." *AIChE Symposium Series* **75**(189): 32–38. https://scholar.google.co.in/scholar?hl=en&q=R.R.+Schultz%252C+R.+Cole%252C+Uncertainty+analysis+in+boiling+nucleation%252C+AICHE+Symp.+Ser.+189+%252875%2529+%25281979%2529+32–38.&btnG=.

Shahrul, I. M., I. M. Mahbubul, R. Saidur, & M. F M Sabri. 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. Elsevier Ltd: 547–58. https://doi.org/10.1016/j.ijheatmasstransfer.2016.02.016.

Sohel, M. R., S. S. Khaleduzzaman, R. Saidur, A. Hepbasli, M. F M Sabri, & I. M. Mahbubul. 2014. "An Experimental Investigation of Heat Transfer Enhancement of a Minichannel Heat Sink Using Al2O3-H2O Nanofluid." *International Journal of Heat and Mass Transfer* 74 (July): 164–72. https://doi.org/10.1016/j.ijheatmasstransfer.2014.03.010.

Srinivas, T., & A. Venu Vinod. 2016. "Heat Transfer Intensification in a Shell and Helical Coil Heat Exchanger Using Water-Based Nanofluids." *Chemical Engineering and Processing: Process Intensification* 102. Elsevier B.V.: 1–8. https://doi.org/10.1016/j.cep.2016.01.005.

Suresh, S, M Chandrasekar, & SC Sekhar. 2011. "Experimental Studies on Heat Transfer and Friction Factor Characteristics of CuO/Water Nanofluid under Turbulent Flow in a Helically Dimpled Tube." *Experimental Thermal and Fluid* **48**(4): 683–94. http://www.sciencedirect.com/science/article/pii/S0894177710002463.

W. Y. Lai, B. Duculescu, P. E. Phelan, & R. S. Prasher. 2006. "Convective Heat Transfer with Nanofluids in a Single 1.02-Mm Tube." In *ASME 2006 International Mechanical Engineering Congress and Exposition*, 337–42. Chicago, Illinois, USA. https://doi.org/10.1115/IMECE2006-14132.

Żyła, G, & M Cholewa. 2014. "On Unexpected Behavior of Viscosity of Diethylene Glycol-Based MgAl 2 O 4 Nanofluids." *RSC Advances* 4 (50): 26057–62. http://pubs.rsc.org/en/content/articlehtml/2014/ra/c4ra03143a.

Submitted: 28/09/2016
Revised: 25/04/2017
Accepted: 15/02/2018

دراسة عملية عن الأداء الحراري لتبريد المحرك بالزيت وماء التبريد في مُبادل حراري حلزوني الأنبوب

***آصف أفضال، **محمد سامع و*عبد الرزاق أر كي**

*قسم الهندسة الميكانيكية، كلية الهندسة بي ايه (التابعة لجامعة فيسفيسفارايا التكنولوجية)، مانجالورو، الهند

**قسم الهندسة الميكانيكية، كلية ناغش كاراجاجي اوركيد للهندسة والتكنولوجيا، سولابور، ماهاراشترا، الهند

الخلاصة

تم إجراء تحليل حراري مُقارن لماء التبريد وزيت تبريد المحرك في مبادل حراري ذو أنبوب ملتف حلزوني . تم تنفيذ الدراسة العملية في حالة السريان الانسيابي المتوازى والمتعاكس للموائع. تمت مقارنة عوامل مختلفة مثل معامل انتقال الحرارة، ومعامل الاحتكاك، والهبوط السريع في الضغط وقوة الضخ عند تدفق الموائع بمعدلات مختلفة، مثل: 0.25 لتر في الدقيقة و 0.5 لتر في الدقيقة و 0.75 لتر في الدقيقة على طول جانب الأنبوب والجدار كما تم تحليل العوامل المشتركة الأخرى للمبادل الحراري على طول جانب الأنبوب والجدار، مثل: المعامل الإجمالي لانتقال الحرارة، وعدد وحدات النقل (NTU)، والمتوسط اللوغارتمي لفرق درجات الحرارة (LMTD)، وفعالية ومتوسط معامل انتقال الحرارة للتباين في معدلات التدفق. تم كذلك مقارنة اختلاف المعامل الإجمالي لانتقال الحرارة مع أرقام لا بعدية مختلفة، مثل: الرقم الحلزوني (Helical Number) ورقم دين (Dean Number) و LMTD و NTU. وتم توفير أقصي نسبة محسنة لخصائص نقل الحرارة المختلفة مقارنة بالمياه في حالة السريان المتوازي. بالنسبة لزيت المبرد في حالة السريان المتعاكس، فقد تحسن معدل نقل الحرارة بنسبة 63.3%، ومعامل انتقال الحرارة بالحمل بنسبة 42.7% والمعامل الإجمالي لنقل الحرارة بنسبة 98.9% مقارنة بالسريان المتوازي للماء. ولاحظنا أيضاً أن السريان المتعاكس للماء يوفر انتقال الحرارة بنسبة تحسن (18.7%) أكثر من السريان الانسيابي لزيت المبرد. وأخيراً، نستنتج أن السريان المتعاكس بزيت التبريد يعمل بفعالية أكثر في مبادل حراري ذو أنبوب حلزوني