EFFECTS OF NANOFLUIDS ON HEAT TRANSFER CHARACTERISTICS IN SHELL AND TUBE HEAT EXCHANGER

by

Sakthivel PERUMAL[a*], Vijayan VENKATRAMAN[b], Rajkumar SIVANRAJU[c], Addisalem MEKONNEN[c], Sathish THANIKODI[d], and Ramesh CHINNAPPAN[e]

[a]Department of Mechanical Engineering, Sri Krishna College of Technology, Coimbatore, Tamilnadu, India
[b]Department of Mechanical Engineering, K. Ramakrishnan College of Technology (Autonomous), Tiruchirappalli, Tamilnadu, India
[c]Department of Mechanical Engineering, Faculty of Manufacturing, Institute of Technology, Hawassa University, Hawassa, Ethiopia
[d]Department of Mechanical Engineering, Saveetha School of Engineering, SIMATS, Chennai, Tamilnadu, India
[e]Department of Mechanical Engineering, M. Kumarasamy College of Engineering, Karur, Tamilnadu, India

Original scientific paper
https://doi.org/10.2298/TSCI200426076P

Nowadays ensure the performance of heat exchanger is one of the toughest roles in industries. In this work focused on improve the performance of shell and tube heat exchangers by reducing the pressure drop as well as raising the overall heat transfer. This work considered as a different nanoparticles such as Al_2O_3, SiO_2, TiO_2, and ZrO_2 to form a nanofluids. This nanofluids possesses high thermal conductivity by using of this increase the heat transfer rate in shell and tube heat exchanger. The selected nanofluids are compared to base fluid based on the thermophysical properties as well as heat transfer characteristics. All the heat transfer characteristics are improved by applying of nanofluids particularly higher results are obtained with using of TiO_2 and Al_2O_3 compared to SiO_2 and ZrO_2. Mixing of nanoparticles increased in terms of volume percentage it will be increases the all heat transfer characteristics as well as performance of the heat exchanger.

Key words: Al_2O_3, thermal conductivity, nanofluids, heat exchanger, Prandtl number, TiO_2

Introduction

The main purpose of heat exchangers are used to transfers the heat inbetween two working medium such as gas or fluids [1, 2]. Heat exchangers are classified based on the geometrical shape and properties of flow medium. Better adaptability nature shell and tube heat exchangers are widely used in industrial applications and also low cost in production. The

*Corresponding author, e-mail: skt4design@gmail.com

baffle plates are changes the thermophysical properties of the fluid medium also changes the flow direction [3, 4]. Baffles are built the rigid structure of the bundle of tubes inside the shell. In higher performance of working the failures of the tubes are prevented by the baffles and also observe the vibrations at the time of flow [5]. The fluid-flow in the shell and tube heat exchangers is categorized by longitudinal flow, transverse flow and helical flow in nature. Transverse flow with segmental baffles heat exchangers are fabricated in less cost and vastly used, it has some disadvantages huge amount of pressure loss, minimum heat transfer efficiency, *etc*. Replacing of segmental baffles by helical baffles improve the heat transfer efficiency and offer little amount of flow restrictions [6]. Numbers of tubes are considered as bundle of tubes also termed as tube stacks, based on the usage it can be varied. The failures of the tubes are replaced in simple manner and bundle can be subdivided in two categories namely: fixed tube sheet and U-type sheet [7]. Normally the fixed sheets are in straight form and both ends are supported by tube plates in rigid connections. In U-tube heat exchanger the bended U-shape tubes are connected by a single tube plate. The tubes are arranged in either square pattern or triangular pattern [8]. Modelling of shekel and tube heat exchangers were also done for predicting the heat transfer rate by using methodologies such as artificial neural network, teaching learning optimization, and support vector machine [9, 10].

In normal the cleaning process are made complicated in inside of the tubes to overcome this difficulties fixed tube sheet heat exchangers are used, Both ends of the heads are removed simply and cleaned well thoroughly outside of the tubes are cleaned by chemical cleaning process. In this research, it is planned for analyzing the heat transfer characteristics of all nanofluids used in the shell and tube heat exchangers effectively.

Experimental work

In this research study the shell and tube heat exchangers are considered to evaluate the heat transfer behavior effectively, the fluid inlet and outlet, baffle arrangements and the flow directions are illustrated in the fig. 1.

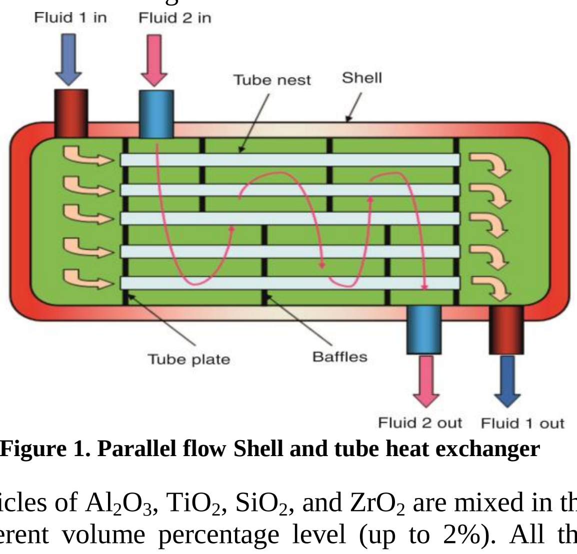

Figure 1. Parallel flow Shell and tube heat exchanger

The nanoparticles of Al_2O_3, TiO_2, SiO_2, and ZrO_2 are mixed in the base fluid such as distilled water in different volume percentage level (up to 2%). All the nanoparticles are mixed in proper ratio with produced effective heat transfer medium. The two forms of fluid circulated into the shell and tube. It increases the heat transfer rate as well as improves the overall heat transfer coefficient.

Results and discussion

Heat transfer feature of thermal conductivity, heat transfer coefficient, heat transfer rate, and Prandtl number of the fluid characteristics were estimated while at the time of circulated fluid in the shell and tube heat exchanger. The tab. 1 presented the heat transfer coefficient results with usage of different percentage level of nanoparticles in the fluid.

Table 1. Summary of heat transfer coefficient

Nanoparticles mixing [vol.%]	Heat transfer coefficient [$Wm^{-1}K^{-1}$]			
	Al_2O_3	SiO_2	TiO_2	ZrO_2
0.5	1365.12	1145.73	1498.77	1296.77
1	2458.61	2346.91	2555.13	2598.36
1.5	3365.57	3185.47	3465.99	3200.77
2	4025.31	3625.23	4253.22	3710.21

Heat transfer coefficient

Increasing of nanoparticles mixing in the base fluid to increase the heat transfer coefficient it can be noticed in the tab. 1. Among four nanoparticles mixing level, the 2% of TiO_2 presented in the fluid registered a higher value of heat transfer coefficient (4253.22 W/mK) followed by Al_2O_3 (4025.31 W/mK), ZrO_2 (3710.21W/mK), and SiO_2 (3625.23 (W/mK). Figure 2 shows that the interaction between nanoparticles mixing (vol.%) and heat transfer coefficient. The graph provided heat transfer coefficient improved by increasing of nanoparticle mixing in terms of volume fraction. Variation of heat transfer coefficient was achieved in applying of all nanofluids, finally the TiO_2 nanofluid has offered maximum heat transfer coefficient. The lower level of heat transfer coefficient was obtained by using of SiO_2 nanofluid it induced the lowest heat transfer coefficient.

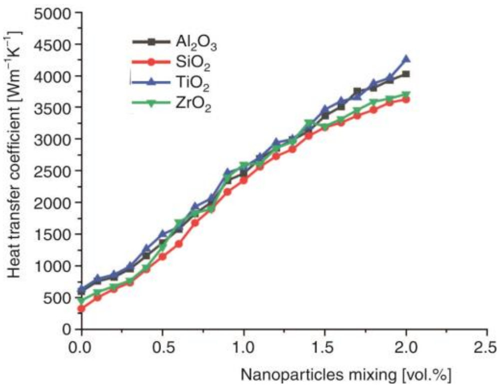

Figure 2. Graph between nanoparticles mixing (vol.%) and heat transfer coefficient
(*for colour image see journal web site*)

Heat transfer rate

Higher heat transfer rate was registered by the TiO_2 nanofluid such as 29.3 W was presented in the tab. 2, further Al_2O_3 nanofluid offered 19 W of heat transfer rate followed by SiO_2 nanofluid of 16.7 W, and the ZrO_2 of 15.47 W. Figure 3 illustrated that the relationsbetween nanoparticles mixing (vol.%) and heat transfer rate. From the graph, the heat transfer rate was concluded in the aspect of increasing nanoparticles. Based on the higher density and higher specific heat, TiO_2 and Al_2O_3 offered higher heat transfer rate at the sam e SiO_2 and ZrO_2 offered minimum heat transfer rate.

Table 2. Summary of heat transfer rate

Nanoparticles mixing [vol.%]	Heat transfer rate [W]			
	Al_2O_3	SiO_2	TiO_2	ZrO_2
0.5	3	3	7	3
1	6.8	5.8	13.45	5
1.5	12.4	10	20.36	9.4
2	19	16.7	29.43	15.47

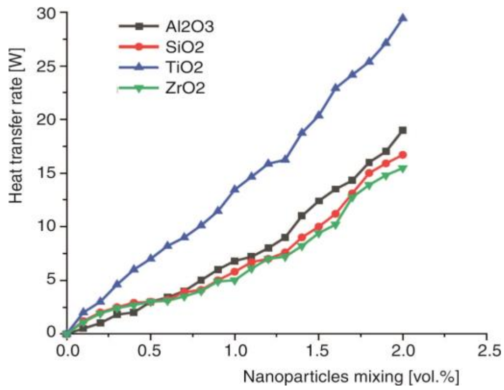

Figure 3. Graph between nanoparticles mixing (vol.%) and heat transfer rate
(*for colour image see journal web site*)

Thermal conductivity

Table 3 presented summary of thermal conductivity of different nanofluids, the tab. 3 point out that the TiO_2 nanofluid offered higher thermal conductivity such as 0.0383 W/mK. Minimum level of thermal conductivity was obtained through using of ZrO_2 nanofluids such as 0.0343 W/mK. Figure 4 demonstrates that the major deviation of thermal conductivity was obtained between TiO_2 and Al_2O_3 to SiO_2 and ZrO_2,. Finally the TiO_2 offered maximum thermal conductivity with increasing of nanoparticles.

Table 3. Summary of thermal conductivity

Nanoparticles mixing [vol.%]	Thermal conductivity [$Wm^{-1}K^{-1}$]			
	Al_2O_3	SiO_2	TiO_2	ZrO_2
0.5	0.0356	0.0297	0.0356	0.0301
1	0.0363	0.0321	0.0367	0.0316
1.5	0.0369	0.0335	0.0375	0.0328
2	0.0375	0.0348	0.0383	0.0343

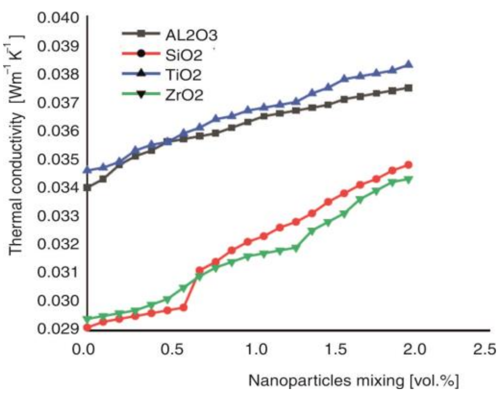

Figure 4. Graph between nanoparticles mixing (vol.%) and thermal conductivity
(*for colour image see journal web site*)

Overall heat transfer coefficient

Table 4 illustrated the overall heat transfer coefficient of the all four nanofluids effectively; TiO_2 nanofluid offered superior overall heat transfer coefficient value such as 301.12 W/m^{2}K. Compared to other nanofluids, SiO_2 nanofluid offered minimum level of overall heat transfer coefficient like as 259.13 W/m^{2}K. From three nanofluids Al_2O_3, SiO_2, and ZrO_2 are offered minimum level of overall heat transfer coefficient compared to TiO_2 as shown in fig. 5.

Table 4. Summary of overall heat transfer coefficient

Nanoparticles mixing [vol.%]	Overall heat transfer coefficient [Wm^{-2}K^{-1}]			
	Al_2O_3	SiO_2	TiO_2	ZrO_2
0.5	236.15	231.58	238.75	229.74
1	246.57	242.86	254.17	240.87
1.5	259.64	252.34	263.47	250.34
2	265.31	259.13	301.12	260.18

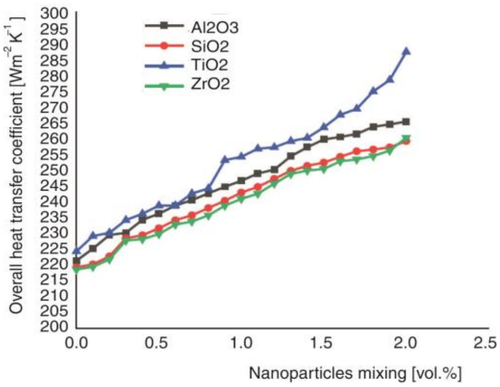

Figure 5. Graph between nanoparticles mixing (vol.%) and overall heat transfer coefficient
(*for colour image see journal web site*)

Prandtl number

The tab. 5 presented the summary of Prandtl number. The maximum Prandtl number of 0.0379 was achieved by using of Al_2O_3 nanoparticles, contrary the minimum Prandtl number 0.0335 was offered by TiO_2 nanoparticles. Figure 6 illustrates that the increasing of nanoparticles mixing decrease the Prandtl number. The TiO_2 nanofluid produced minimum Prandtl number.

Table 5. Summary of Prandtl Number

Nanoparticles mixing [vol.%]	Prandtl Number			
	Al_2O_3	SiO_2	TiO_2	ZrO_2
0.5	0.0459	0.0446	0.0389	0.0441
1	0.0407	0.0417	0.037	0.0414
1.5	0.0394	0.0395	0.0355	0.0393
2	0.0379	0.0375	0.0335	0.0366

Conclusions

The heat transfer characteristics of shell and tube heat exchanger with influencing of different nanofluids are investigated in clear manner. The nanoparticles were mixed well in the base fluid at maximum 2% of volume level. The results of these investigations were concluded as follows.

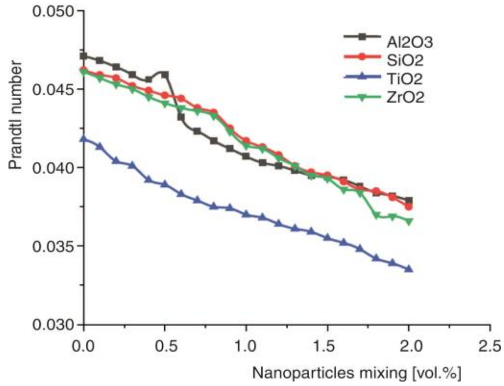

Figure 6. Graph between nanoparticles mixing (vol.%) and Prandtl number
(*for colour image see journal web site*)

- From in all four nanofluids TiO_2 nanofluid registered a higher value of heat transfer coefficient as 4253.22 W/mK, followed by Al_2O_3 4025.31 W/mK, ZrO_2 3710.21 W/mK, and SiO_2 3625.23 W/mK. The TiO_2 nanofluid has offered maximum heat transfer coefficient. Lower level of heat transfer coefficient was obtained by using of SiO_2 nanofluid.
- Higher heat transfer rate was recorded by the using of TiO_2 nanofluid such as 29.3 W, followed by Al_2O_3 19 W, SiO_2 16.7 W, and the ZrO_2 of 15.47 W. Higher density and higher specific heat of TiO_2 and Al_2O_3 produced higher heat transfer rate at the same time SiO_2 and ZrO_2 offered minimum heat transfer rate.
- The TiO_2 nanofluid offered higher thermal conductivity such as 0.0383 W/mK. Lower level of thermal conductivity was obtained through using of ZrO_2 nanofluid such as 0.0343 W/mK. The TiO_2 nanofluids offered excellent overall heat transfer coefficient value such as 301.12 W/m^{2}K. The SiO_2 nanofluid offered minimum level of overall heat transfer coefficient like as 259.13 W/m^{2}K
- The maximum Prandtl number of 0.0379 was reached by using of Al_2O_3 nanoparticles, contrary the lower Prandtl number 0.0335 was offered by TiO_2 nano particles.

Reference

[1] Keklikcioglu, O., Ozceyhan, V., Experimental Investigation on Heat Transfer Enhancement of a Tube with Coiled-Wire Inserts Installed with a Separation from the Tube Wall, *International Communications in Heat and Mass Transfer*, *78* (2016), Nov., pp. 88-94
[2] Kamyar, A., *et al*., Application of Computational Fluid Dynamics (CFD) for Nanofluids, *International Journal of Heat and Mass Transfer, 55* (2012), 15-16, pp. 4104-4115
[3] Sakthivel, P., *et al*., Experimental Heat Transfer Analysis on Heat Pipe Using SiO_2 and TiO_2 Nano Fluid, *Journal of Applied Fluid Mechanics*, *11* (2018), Special Issue, pp. 91-101
[4] Leong, K. Y., *et al*., Modeling of Shell and Tube Heat Recovery Exchanger Operated with Nanofluid Based Coolants, *International Journal of Heat and Mass Transfer*, *55* (2012), 4, pp. 808-816
[5] Sivasubramanian, A. P., *et al*., Heat Transfer and Friction Factor Characteristics of Pipe-in-Pipe Heat Exchanger fitted with Variant Plain Tape Insert, *Thermal Science, 24* (2020), 1B, pp. 623-633
[6] Palanisamy, K., Mukesh Kumar, P. C., Heat Transfer Enhancement and Pressure Drop Analysis of a Cone Helical Coiled Tube Heat Exchanger Using MWCNT/Water Nanofluid, *Journal of Applied Fluid Mechanics, 10* (2017), Special Issue, pp. 7-13
[7] Huminic, G., Huminic, A., Application of Nanofluids in Heat Exchangers: A Review, *Renewable and Sustainable Energy Reviews, 16* (2012), 8, pp. 5625-5638
[8] Thanikodi, S., *et al*., Teaching Learning Optimization and Neural Network for the Effective Prediction of Heat Transfer Rates in Tube Heat Exchangers, *Thermal Science, 24* (2020), 1B, pp. 575-581

[9] Muthukrishnan, S., *et al*., Support Vector Machine for Modelling and Simulation of Heat Exchangers, *Thermal Science, 24* (2020), 1B, pp. 499-503
[10] Thanikodi, S., *et al*., Teaching Learning Optimization and Neural Network for the Effective Prediction of Heat Transfer Rates in Tube Heat Exchangers, *Thermal Science, 24* (2020), 1B, pp. 575-581

Paper submitted: April 26, 2020
Paper revised: July 2, 2020
Paper accepted: December 5, 2020