

Research Article

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Experimental investigations on heat transfer enhancement in a double pipe heat exchanger using hybrid nanofluids

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Abstract: Heat exchanger (HE) is an instrument that facilitates the operation of HE between two fluids that are at various temperatures. Double-pipe HEs are used in many organizations because of their low installation, design, maintenance costs, flexibility, and their suitability for high pressure applications. Heat transfer (HT) augmentation techniques (passive, active or compound techniques) are used in heat exchangers to reduce the HT surface area, to increase HT capacity and to reduce pumping power. Passive augmentation techniques are much cheaper and do not involve any external power input. They aim to improve the effective surface area, the residence time of the HT fluid and its thermal conductivity by the usage of nanofluids. Nanofluids are used for cooling applications in organizations, transportation, nuclear reactors, electrical and electronic devices and for biomedical applications. Hybrid nanofluids have higher thermal conductivity, low PD and frictional losses and pumping power as compared to the mono nanofluids. In this present work, experiments are conducted in a double pipe HE using TiO_2 and SiC -water nanofluids by varying the volume concentration and cold fluid mass flow rate ranging from 17.5 to 34.5 lpm by making constant hot fluid mass flow rate. Further, experiments are conducted using TiO_2 - SiC /water hybrid nanofluids. Influence of nano and hybrid nanofluids on the overall HTC and friction factor are experimentally investigated. From the experiments, TiO_2 - SiC /water hybrid nanofluid with nanoparticle ratio TiO_2 : SiC = 1:2 is found to be optimum as the heat transfer enhancement is more with less improvement in friction

factor. The overall heat transfer, and friction factor enhancement is 22.92 %, and 11.20 % higher respectively when compared with base fluid for TiO_2 : SiC = 1:2.

Keywords: heat exchanger; hybrid nanofluids; heat transfer enhancement; over all heat transfer coefficient; friction factor

1 Introduction

Throughout the world shortage of energy and fossil fuels, optimization and consumption of energy are very important nowadays (Gugulothu et al. 2017). Energy utilization is one of the most effective technologies to minimizing the energy losses in heat exchangers to enhance the thermal efficiency of heat exchangers. Because, heat exchangers have many industrial applications due to their compact size, robustness, and high heat transfer rate, so development of heat exchangers is one of the most important challenges (Gugulothu, Sanke, and Gupta 2019; Khan et al. 2021). In terms of thermal performance and fluid flow characteristics recent pioneers achieved higher values by development of heat exchangers (Gugulothu et al. 2023a). Heat exchanger is a device which can transfer heat energy between two fluids at various temperatures (Ahmed et al. 2021a). Passive heat transfer techniques are one of the most suitable methods to enhance the heat transfer in heat exchangers (Kurnia et al. 2022). In recent years many efforts have been devoted studies on forced and free convection, as well as convection heat transfer in heat exchanger processes, few of them are listed in this research paper (Kimura et al. 1983).

Abbasian Arani et al. (2012) achieved to investigate the impact of TiO_2 -water nanofluid on HT characteristics and PD in a double tube HE with volume concentrations fluctuate from 0.002 % to 0.02 % under turbulent flow regime ($8000 < \text{Re} < 51,000$). They concluded that Nu and thermal performance factor of the TiO_2 -water nanofluid enhances with Re and vol. concentration due to the increase in thermal conductivity, mixing effects of nanoparticles near the wall and Brownian motion of nanoparticles. Hussein (2017)

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experimentally attempted the thermal achievement of AlN-ethylene glycol nanofluid in a double pipe HE for volume concentrations fluctuate from 1 to 4 % under laminar flow conditions ($500 < Re < 1750$). Their results show that with an improvement in volume concentration, friction factor and Nu increased significantly. At the highest volume concentration, the friction factor enhanced by 12.5 % and the Nu enhanced by 35 %.

Sajadi et al. (2011) experimentally explore the turbulent HT behavior of TiO_2 -water nanofluid in a circular pipe for vol. concentrations ranging from 0.05 to 0.25 %. The convective HTC enhanced by 22 % at 0.25 % volume concentration due to enhanced thermal conductivity and chaotic movement of nanoparticles which accelerated the energy exchange process in the fluid. The maximum improvement in pressure drop was about 25 % at a volume concentration 0.25 %. Han, He, and Asif (2017) carried out an exploratory study with Al_2O_3 -water nanofluid in the double pipe HE for volume concentrations 0.25 % and 0.5 % at inlet temperature's 40 °C and 50 °C under turbulent flow conditions ($20,000 < Re < 60,000$). The maximum improvement of the HTC at 40 °C was 19.6 % and at 50 °C was 29 %.

Madhesh et al. (2014) studied on HT and rheological properties of Cu- TiO_2 /water hybrid nanofluids flowing throughout the tubular HE for volume concentrations fluctuate from 0.1 to 1 %. Singh (2009) made investigations on the thermal conductivity and mechanical effects of SiC-water nanofluids from 1 % to 7 % volume concentrations for HT appliances. With addition of nanoparticles thermal conductivity and viscosity increased, maximum thermal conductivity improvement was 28 % at 7 % volume concentration and this enhancement was attributed to variety of mechanisms including clustering, agglomeration, micro convection & Brownian motion. Hamid (2017) explore the thermal conductivity of TiO_2 - SiO_2 hybrid nanoparticles distribute in EG/water for vol. concentrations fluctuate from 0.5 to 3 %, and at the temperatures 30 °C, 50 °C, 70 °C. They concluded that thermal conductivity of nanofluid improved with concentration due to collision between nanoparticles and it increased with temperature because of Brownian motion, as Brownian motion is a strong function of temperature.

Mushtaq Ismael Hasan, Salman, and Thajeel (2018) made an innovative study on the thermal accomplishment of double pipe HE using Al_2O_3 , and TiO_2 -water nanofluids for parallel and counter flow arrangements. They proved that the HTR improved with an enhancement in vol. concentrations from 0.05 to 0.3 % due to the increment of thermophysical properties of nanofluids, which also accelerated the thermal accomplishment of the HE. Also, counter flow arrangement provided best performance when validated

with parallel flow arrangement for both the nanofluids. Pankaj Pandey et al. (2017) explored the HTR in shell and tube HE by using Al_2O_3 -SiC based hybrid nanofluid for 0.1 %, 0.2 %, and 0.3 % vol. concentrations. Experimentally they concluded that, Al_2O_3 -SiC based hybrid nanofluid enhanced the HTC by 5 % and increased with the increase in volume concentration and Re. Arsan et al. (2018) experimentally investigated the thermal performance of shell and tube HE using magnesium-aluminum/water hybrid nanofluids for the vol. concentrations 5 %, 10 %, 15 %, 20 %, and 25 %. They concluded that HTR enhanced with the flow rate due to occurrence of atomization in molecules and with volume concentration it enhanced due to increase in thermal conductivity and decrease in thermal resistance. Bobbo et al. (2012) experimentally studied on the HT capability of SiC-ethylene glycol nanofluid for the volume concentrations 0.1 %, 1 %, and 5 %. They observed that thermal conductivity enhancement was more than proportional to the enhancement of nanoparticle concentration and increment in dynamic viscosity is small at low nanoparticle concentrations upto 1 %.

Sneha Ponnada et al. (2019) experimentally investigated the SiC-distilled water in a circular tube for the vol. concentrations 0.04–0.1 % under turbulent flow conditions. They concluded that the enhancement of HTR ranged from 3.38 % to 36.74 % and the enhancement of friction factor ranged from 2.1 % to 13.5 % with the enhancement of particle loading. Suresh et al. (2012) experimentally studied the HT and PD characteristics using Al_2O_3 -Cu/water hybrid nanofluids through a circular tube at 0.1 % volume concentration for various mass flow rates. They concluded that the enhancement in Nu for Al_2O_3 -Cu/water hybrid nanofluids were 10.94 % and for Al_2O_3 /water was 6.09 %. Tareq Salameh et al. (2018) studied on HT enhancement in a concentric tube HE using TiO_2 , and CuO-water nanofluids for the vol. concentrations of 0.05 and 0.2 %. They concluded that the improvement of the HTC for CuO-water nanofluid was 62 % compared to base fluid and CuO-water nanofluid maintained higher HTC values than TiO_2 -water nanofluid for both volume concentrations. The HT enhancement ratio for CuO-water nanofluid was 1.4 and for TiO_2 -water nanofluid, it was 1.25 for 0.2 % volume concentration.

Yang et al. (2005) experimentally studied the HT performance of graphite –synthetic oil nanofluids in a horizontal tube HE under laminar flow conditions at 2 wt% and 2.5 wt% nanoparticle loading. They concluded that nanofluids enhanced the heat transfer coefficient by enhancing the thermal conductivity of overall system and the movement of particles in stream lines. Kristiawan et al. (2019) numerically investigated to enhance the heat transfer using microfin structure and nanofluids (TiO_2 /water) by varying

various nanoparticle concentrations ranging from 0.005 to 0.1. They found that the maximum performance evaluation criteria 1.2 at Reynolds number 380 in the presence of 0.01 % volume concentration, at same volume concentration heat transfer also enhanced. They concluded that the excellent performance and economic point of view, the combine techniques are recommended. Kristiawan et al. (2020) experimentally investigated further using microfin structure and TiO_2 /water with various volume concentrations ranging from 0.05 to 0.3 vol.% concentrations to study the thermal performance, friction factor and developed a correlation. They observed that the pressure drop 73 %, 77 %, and 80 % higher than the plain tube.

Purnama et al. (2015) experimentally studied the properties of high purity cobalt ferrite nanoparticles by carrying annealing time period during the synthetic process. Successfully they demonstrated the magnetic properties of cobalt ferrite nanoparticles which depend on their relative particle sizes. Vijaya Kumar Reddy et al. (2017) experimentally investigated to enhance the heat transfer coefficient using hot and cold working fluids as well as ZnO, MgO, and CuO nanofluids for various volume concentrations ranging from 0.05 to 0.1 %. They found that the enhanced overall heat transfer coefficient in the presence of CuO nanofluid than the MgO, and ZnO, this enhancement is 62 % higher than the base fluid.

From the pioneers study, it is observed that application of nanofluid in HT enhances the heat transfer performance and various nanofluids (Al_2O_3 -water, CuO-water, TiO_2 -water, MgO-water, Al_2O_3 -Ag/water, Fe_3O_4 -water etc...) are used under different conditions to improve the performance of HE. But the work done with hybrid nanoparticles TiO_2 & SiC with base fluid as water is limited. Hence in this work, experimental test conducted in a double pipe HE with TiO_2 -

water, SiC-water, TiO_2 -SiC/water hybrid nanofluids. Extensive experiments have been carried out in a double pipe HE to discover the influence of nanofluids on heat transfer performance for various vol. concentrations. Because traditional working fluids possess lower heat transfer capacity. So nanofluids come up with a solution to the improvement of thermal conductivity (Ahmed et al. 2022b).

2 Experimental work

Schematic Diagram of Double Pipe HE is shown in Figure 1. The experimental setup given in Figure 2 embodies a heat exchanger, hot fluid tank, cold fluid tank, pumps for hot and cold fluids, U-tube manometer, thermocouples, and a Geyser. Hot fluid from the geyser flows through the inner pipe, while the cold fluid flows through the annular space between two pipes in opposite directions to obtain a counter-flow regime. The hot and cold fluid flow rate are regulated by means of the valves available on the respective pipes. Fluids after passing through the HE returned to the respective tanks and re-circulated by using the pumps. Thermocouples are used to measure the temperature at hot fluid inlet & outlet and cold fluid inlet & outlet. A U-tube manometer is usefulness to quantify the PD over the test section and all temperatures are indicated by a digital temperature indicator. A mechanical stirrer and digital analytical balance are used for the preparation of nanofluids.

Experiments conducted with constant hot fluid flow rate of 14.5 lpm and for various cold fluid flow rates of 17.5, 21, 25, 29.5 and 34.5 lpm. Four types of working fluids Water, TiO_2 /water, SiC/water and TiO_2 -SiC/water are used in the double pipe HE for experimentation. Length of the HE is 2.1 m. The inner and outer diameters of the inside pipe are 37.64 mm and 56.66 mm respectively. Inner diameter of the outer pipe is 74.74 mm. Hot fluid from the geyser flows in the inner pipe and cold fluid from the supply tank flows along the annular space between the inner and outer pipe. Power is supplied at 220 V and capacity of the geyser used is 20 L with 2 KW. Two centrifugal pumps with 1HP motor are utilized to circulate hot fluid and cold fluid along the inner pipe and annulus region of the HE respectively.

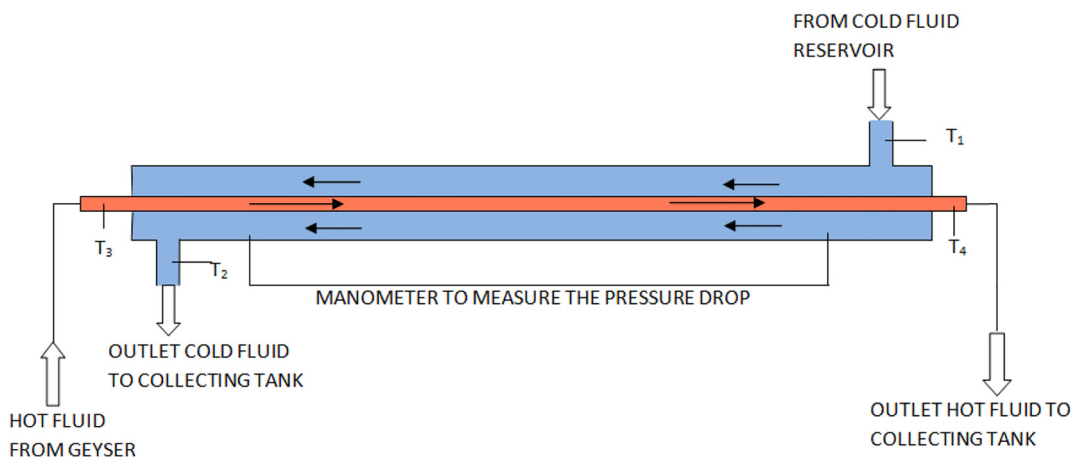


Figure 1: Schematic diagram of double pipe HE.



Figure 2: Experimental setup of double pipe HE.

Figure 3 shows the geyser which can supply hot water. Figure 4 indicates the mechanical stirrer with electric motor that drives the metal rod with blades which is immersed in the nanoparticles and water mixture. Maximum operating speed of stirrer is 1550 RPM and motor wattage is 45 W. Figure 5 depicts the digital analytical balance, that is utilized to quantify the mass of nanoparticles. The accuracy of instrument is 0.001 g with the capacity of 220 g.

Digital temperature indicator: Temperature indicator process signals from thermocouple and display them on the screen. The temperature to be displayed is controlled by selector switch.



Figure 3: Geyser.



Figure 4: Mechanical stirrer.



Figure 5: Digital analytical balance.

3 Preparation of nanofluids

Two step method is adopted for the preparation of nanofluids. Initially mass of nanoparticles (TiO_2 and SiC) is measured with digital analytical balance. Then, measured amount of nanoparticles is added to the base fluid i.e. water. Further, surfactant SDBS 0.1 % of nanoparticle concentration is added for uniform dispersion and stability improvement. Samples are stirred by mechanical agitator to ensure that the nanoparticles are properly mixed with the base fluid water. Figure 6 shows the various types of nanofluids at different volume concentrations.

Experiments are conducted with TiO_2 /water and SiC/water nanofluids with vol. concentrations fluctuate from 0.01 to 0.09 %. Later, similar experiments are conducted with TiO_2 -SiC/water hybrid nanofluids with nanoparticles ratio TiO_2 :SiC = 1:1, TiO_2 :SiC = 1:2, TiO_2 :SiC = 2:1 for 0.09 % volume concentration.



Figure 6: Nanofluid samples with different percentage volume concentrations.

4 Data reduction

Overall HTC is (Jena, Patro, and Shankar Behera 2013)

$$U = \frac{1}{\frac{1}{h_i} + \frac{r_i}{k_{ip}} \ln\left(\frac{r_{o,ip}}{r_{i,ip}}\right) + \frac{1}{h_o} \frac{r_{i,ip}}{r_{o,ip}}} \quad (1)$$

where, The heat transfer coefficient (Soma et al. 2014) $h = \frac{kNu}{d}$

The Nusselt number (Soma et al. 2014) $Nu = 0.023 Re^{0.8} Pr^{0.33}$

Friction factor is (Ahmed et al. 2022a; Krishna Nitturi et al. 2023)

$$f = \frac{2\Delta P}{\rho_c V_c^2} \frac{D_h}{L} \quad (2)$$

$$\text{Pressure drop is } \Delta P = \rho g (\Delta h) \frac{N}{m^2} \quad (3)$$

Blasius correlation is (Gugulothu et al. 2023b; Wijayanta et al. 2020)

$$f = \frac{0.316}{Re^{0.25}} \quad (4)$$

where Reynolds number (Somanchi et al. 2014; Yaningsih et al. 2018) $Re = \frac{\rho v d_i}{\mu}$

Colebrook's correlation (Mellal et al. 2017)

$$f = \frac{1}{(0.782 \ln(Re) - 1.51)^2} \quad (5)$$

Deviation is 1.65 %, 0.29 %, 1.40 %, and 10.97 % for hot fluid, and 0.50 %, 0.15 %, 0.47 %, and 9.71 % in density, specific heat, thermal conductivity, and dynamic viscosity for cold fluid when compared with (Kaleru, Venkatesh, and Kumar 2022a; Kaleru, Venkatesh, and Kumar 2022b) base fluid properties equation.

The density of nanofluid (Ahmed et al. 2021b; Gugulothu and Sanke 2022)

$$\rho_{nf} = (1 - \phi)\rho_{bf} + \phi\rho_p \quad (6)$$

The specific heat of a nanofluid (Ahmed et al. 2021b; Gugulothu et al. 2022)

$$(C_p)_{nf} = \frac{(1 - \phi)(\rho C_p)_f + \phi(\rho C_p)_{np}}{\rho_{nf}} \quad (7)$$

The thermal conductivity of nanofluid is (Gugulothu and Sanke 2022)

$$k_{nf} = \frac{k_{np} + (m - 1)k_f - (m - 1)(k_f - k_{np})\phi}{k_{np} + (m - 1)k_f + (k_f - k_{np})\phi} \quad (8)$$

where $m = 3$ for spherical shaped nanoparticles.

Viscosity of nanofluid is (Gugulothu et al. 2022)

$$\mu_{nf} = \frac{\mu_f}{(1 - \phi)^{2.5}} \quad (9)$$

Results obtained from the experimentation were compared with correlations given by Vajjha (Gugulothu 2023) and Xuan and Li (Gugulothu 2023) for the validation. The correlations used for the comparison are.

Xuan and Li correlation (Gugulothu 2023)

$$Nu_{\text{theory}} = 0.0059(1 + 7.6286\phi^{0.6886}Pe^{0.001})Re^{0.9238}Pr^{0.4} \quad (10)$$

where Peclet number, $Pe = \frac{\rho_{nf} V_{nf} D_h}{k_{nf}}$

Vajjha correlation (Vajjha et al. 2010a) for friction factor

$$f = \left(\frac{\rho_{nf}}{\rho_{bf}}\right)^{0.797} \left(\frac{\mu_{nf}}{\mu_{bf}}\right)^{0.108} \quad (11)$$

where, f is taken from equation (4)

Pongjet Pomvonge equation (Gugulothu 2023a)

$$Nu_c = 0.0327Re_c^{0.755}Pr_c^{0.4} \quad (12)$$

Nusselt number is calculated by Promvonge et al. (Gugulothu 2023)

$$Nu_c = 0.0135Re_c^{0.85}Pr_c^{0.4} \quad (13)$$

5 Validation

As shown in the Figure 7, experimental values of overall HTC were compared to the values obtained from theoretically for base fluid/water. Figure 8 shows the comparison between

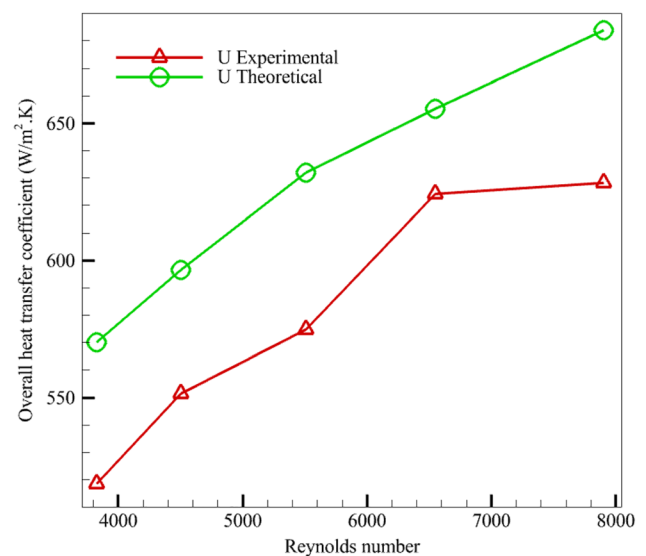


Figure 7: Comparison of experimental and theoretical values of overall heat transfer coefficient.

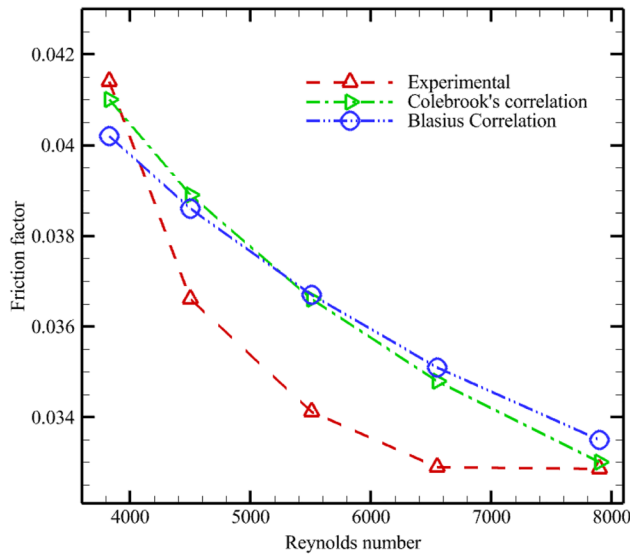


Figure 8: Comparison of experimental data with correlations of friction factor.

experimental and empirical correlation of friction factor for water. The investigational values are well in acceptance with the empirical values obtained from correlation. Throughout the range of Re, it is noticed that the experimental overall HTC and friction factor fell within the $\pm 10\%$ accuracy fluctuate of empirical and experimental values. Author found well agreement i.e. 2.01 % minimum and 7.56 % maximum than Blasius correlation, and 0.97 % minimum and 7.27 % maximum deviation for Colebrook's correlation when compared with experimental values.

6 Uncertainty analysis

Reynolds number (Kristiawan et al. 2020)

$$\left(\frac{\delta Re}{Re}\right)^2 = \left(\frac{\delta V}{V}\right)^2 + \left(\frac{\delta \rho}{\rho}\right)^2 + \left(\frac{\delta D}{D}\right)^2 + \left(\frac{\delta \mu}{\mu}\right)^2 \quad (14)$$

Nusselt number (Kristiawan et al. 2020)

$$\left(\frac{\delta Nu}{Nu}\right)^2 = \left(\frac{\delta h}{h}\right)^2 + \left(\frac{\delta d}{d}\right)^2 + \left(\frac{\delta k}{k}\right)^2 \quad (15)$$

Friction factor (Kristiawan et al. 2020)

$$\left(\frac{\delta f}{f}\right)^2 = \left(\frac{\delta \Delta P}{P}\right)^2 + \left(\frac{\delta \rho}{\rho}\right)^2 + \left(\frac{\delta v}{v}\right)^2 \quad (16)$$

The experimental uncertainty is computing using equations (14)–(16) in terms of Reynolds number, Nusselt number, and friction factor. The maximum uncertainty of Reynolds number, Nusselt number, and friction factor is

5.43 %, 7.19 %, and 6.03 % respectively, which shows good agreement within the limit i.e. $< 10\%$.

7 Results and discussion

Previously Vijaya Kumar Reddy et al. (2015) worked on this same experimental setup to study the enhancement of heat transfer using nanofluids (MgO, ZnO, and CuO) at various volume fractions in a double pipe made of steel inner and outer diameters are 0.625 and 0.815 inch with the length 1 m and found good agreement in validation. In the present work is carried out using $\text{TiO}_2/\text{water}$, and SiC/water nanofluids, and further studied using hybrid nanofluids at various ratios.

Figure 9 represents variation of overall HTC for TiO_2 -Water nanofluid in the Re ranging from 3600 to 8100. It noticed that overall HTC enhances with enhancement in Re and with enhancement in percentage volume concentration. For all volume concentrations of nanofluids and Reynolds number, overall HTC of TiO_2 -water nanofluid is more in contrast to the water. For 0.01 %, 0.03 %, 0.05 %, 0.07 %, and 0.09 % TiO_2 -water nanofluids, maximum enhancement of overall HTC is 0.35 %, 10.72 %, 16.55 %, 17.32 % and 20.94 % respectively.

For TiO_2 -Water nanofluid, maximum improvement of overall HTC in contrast to water is 20.94 %, which is obtained at higher Re and at 0.09 % volume concentration. This can be due to increased thermal conductivity because of dispersed nanoparticles. Also, Brownian motion of the particles could be one of the mechanisms influencing enhanced HTC.

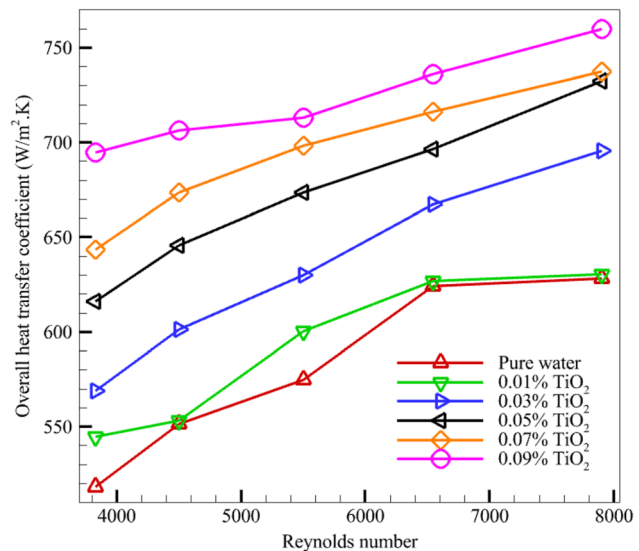


Figure 9: Overall HTC with Re for TiO_2 -water nanofluids.

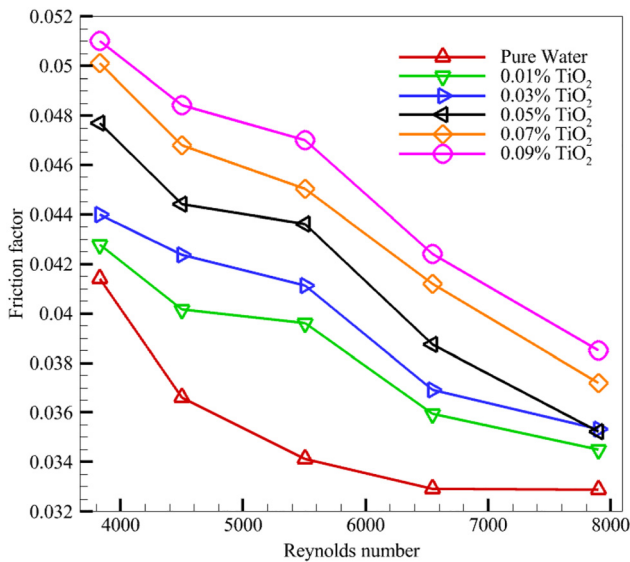


Figure 10: Friction factor with Re for TiO_2 -water nanofluid.

Figure 10 represents the friction factor for TiO_2 -water nanofluid in the Re ranging from 3600 to 8100. It is observed that the friction factor decreases with enhancement in Re and enhances with enhancement in percentage volume concentration. For 0.01 %, 0.03 %, 0.05 %, 0.07 %, and 0.09 % TiO_2 -water nanofluid, increase in friction factor is 5 %, 7.5 %, 7.21 %, 13.21 %, and 17.16 % respectively.

Figure 11 represents variation of overall HTC for SiC-water nanofluid in the Reynolds range (3600–8100). It is noticed that overall HTC of SiC-water nanofluids increases with Re and with increase in percentage volume concentration. For all volume concentrations of SiC-water

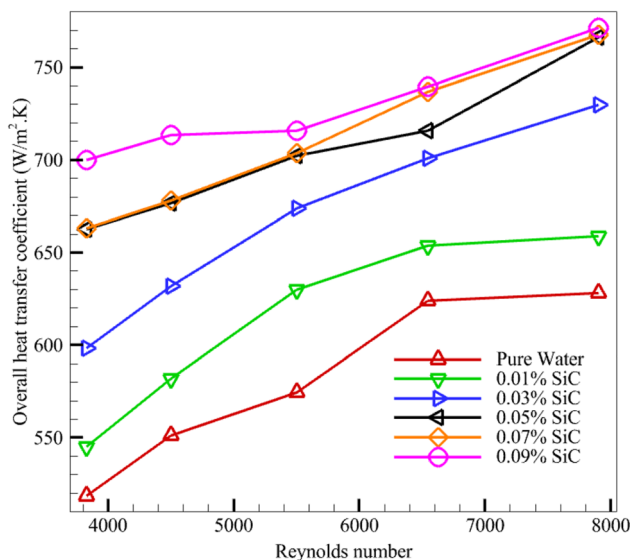


Figure 11: Variation of overall HTC with Re for SiC-water nanofluids.

nanofluids and Re, overall HTC of SiC-Water nanofluid is higher in contrast to the water. For 0.01 %, 0.03 %, 0.05 %, 0.07 %, and 0.09 % SiC-Water nanofluids, maximum improvement in overall HTC is 4.84 %, 16.12 %, 21.93 %, 22.2 %, and 22.7 % respectively. This may be because of improvement in thermal conductivity because of dispersed nanoparticles and brownian motion of the particles.

Figure 12 represents friction factor for SiC-water nanofluid in the Reynolds range (3600–8100). From the experimental results; it is observed that friction factor decreases with improvement in Re and improvement with improvement in percentage vol. concentration. For 0.01 %, 0.03 %, 0.05 %, 0.07 %, and 0.09 % SiC-water nanofluids, increase in friction factor is 1.95 %, 4.2 %, 6.21 %, 12.6 %, and 15.033 % respectively.

Figure 13 represents variation of overall HTC for hybrid nanofluids with nanoparticles ratio $\text{TiO}_2:\text{SiC} = 1:1$, $\text{TiO}_2:\text{SiC} = 1:2$, $\text{TiO}_2:\text{SiC} = 2:1$ in the Reynolds range (3600–8100). From the experiment, it is noticed that overall HTC increases with Re. For all values of Reynolds number, overall HTC of TiO_2 -SiC/water Hybrid nanofluid with $\text{TiO}_2:\text{SiC} = 1:2$ ratio is higher in contrast to the water and the maximum enhancement in overall HTC is 23.8 %. This may be due to their synergistic thermal effects and better overall hydro-thermal characteristics compared to other fluids. The physical properties of the nanofluids are higher than the base water is the major reason for this enhancement.

Figure 14 represents variation of friction factor for hybrid nanofluids in the Reynolds range 3600–8100. From the experimental results, it is noticed that friction factor decreases with improvement in Re. For hybrid nanofluid

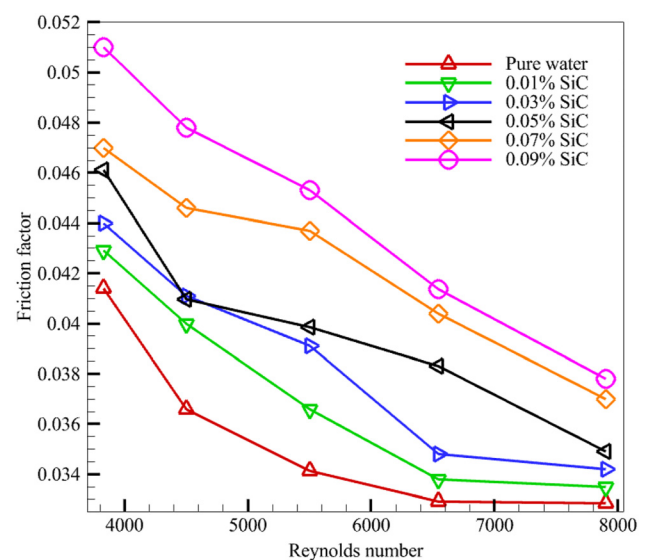


Figure 12: Friction factor with Re for SiC-water nanofluid.

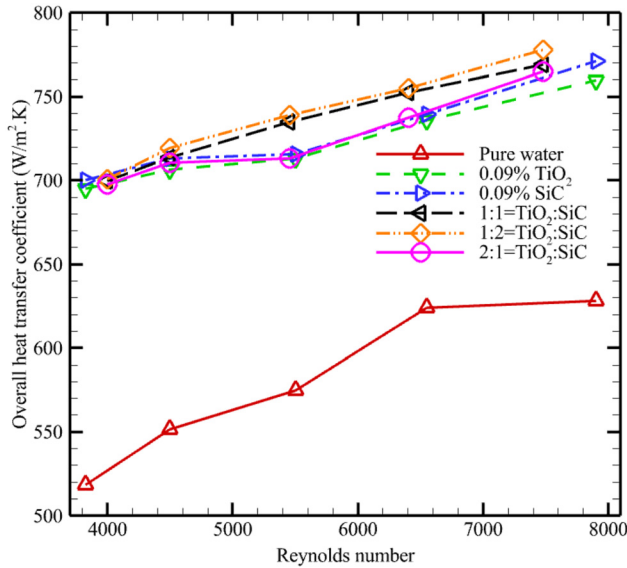


Figure 13: Overall HTC with Re for hybrid nanofluids.

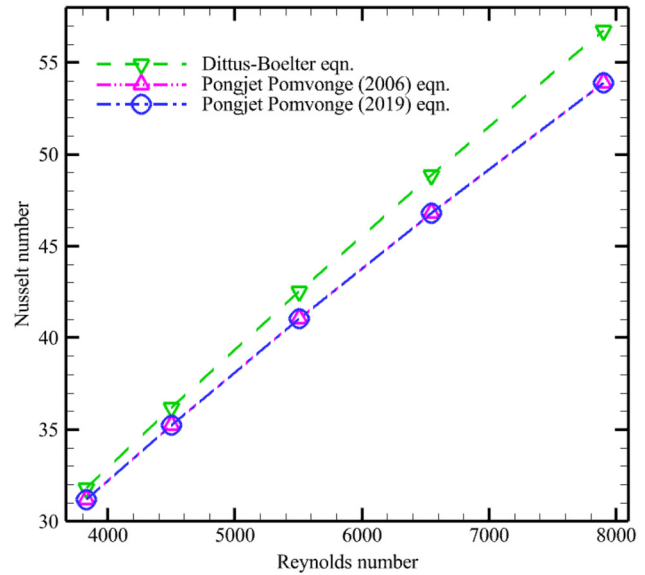


Figure 15: Nusselt number versus Reynolds number.

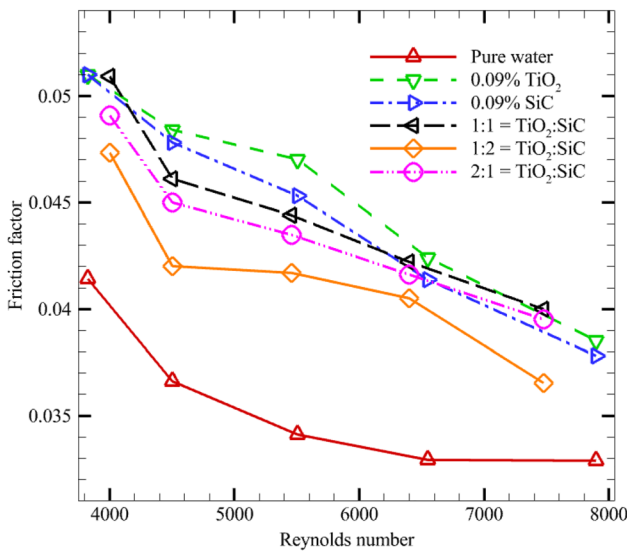


Figure 14: Friction factor with Re for hybrid nanofluids.

with $\text{TiO}_2:\text{SiC} = 1:1$ ratio, maximum enhancement of overall HTC is 22.41 % and respective increase in friction factor is 21.72 %. Maximum improvement of overall HTC is 21.77 % for $\text{TiO}_2:\text{SiC} = 2:1$ ratio Hybrid nanofluid and respective increase in friction factor is 20.2 %. For hybrid nanofluid with $\text{TiO}_2:\text{SiC} = 1:2$ ratio, maximum increment of overall HTC is 23.8 % and enhancement in friction factor is 11.2 %.

Figure 15 illustrates the Nusselt number variation with Reynolds number for various correlations, Nusselt number rises with the rising of Reynolds number. This Nusselt number is computed with the help of equations (12) and (13).

The minimum and maximum error between the Dittus-Boelter equation and Pongjet Pomvonge (2006 and 2019) equation are 1.92 and 5.06 at lower and higher Reynolds number respectively.

8 Conclusions

The HT characteristics using TiO_2 -water nanofluids, SiC-water nanofluids and hybrid nanofluids with nanoparticles ratio of $\text{TiO}_2:\text{SiC} = 1:1$, $\text{TiO}_2:\text{SiC} = 1:2$, $\text{TiO}_2:\text{SiC} = 2:1$ are experimentally investigated in a double pipe HE. The conclusions drawn from the experimental investigations are.

- Experimental values of overall HTC using water as working fluid have shown 9.8 % maximum deviation with the correlations available in literature. Whereas, experimental values of friction factor have shown 7.56 % maximum deviation.
- Overall HTC improved with improvement in the mass flow rate of TiO_2 -water and SiC-water nanofluids. Maximum improvement of overall HTC is 20.94 % for TiO_2 -water nanofluid and 22.7 % for SiC-water nanofluid compared to water.
- Friction factor decreased with enhancement in the mass flow rate and increases with enhancement of volume concentration of TiO_2 -water and SiC-water nanofluids. This is happen due to enhancement of dynamic viscosity enhancement. Maximum increase in friction factor for TiO_2 -water nanofluid and SiC-water nanofluids are 17.16 %, and 15.03 % respectively.

- Overall HTC increased with enhancement in percentage vol. concentration of TiO_2 -water and SiC-water nanofluids. This may be due to the improvement in the effective thermal conductivity of nanofluids.
- Overall HTC improved with enhancement in the mass flow rate of hybrid nanofluid. Highest HTC increment is 23.8 % was noticed for hybrid nanofluid with TiO_2 :SiC = 1:2 ratio followed by 22.7 % enhancement for SiC-water nanofluid with 0.09 % concentration followed by 20.94 % enhancement for TiO_2 -water nanofluid with 0.09 % concentration.
- Friction factor decreased with improvement in the mass flow rate of hybrid nanofluid. Maximum increase in the friction factor for hybrid nanofluid with TiO_2 :SiC = 1:2 ratio, TiO_2 :SiC = 1:1 ratio and with TiO_2 :SiC = 2:1 ratio are 11.2 %, 21.72 % and 20.2 % respectively.
- Within the selected range of flow (Reynolds number varying from 3600 to 8100), hybrid nanofluid with TiO_2 :SiC = 1:2 ratio is found to be optimum as the heat transfer enhancement is more with less improvement in the friction factor.

Research ethics: Not applicable.

Author contributions: The authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Competing interests: All authors state no conflict of interest.

Research funding: None declared.

Data availability: Not applicable.

Nomenclature

HE	heat exchanger
Re	Reynolds number
Nu	nusselt number
HTC	heat transfer coefficient
HTR	heat transfer rate
vol.	volume
PD	pressure drop
HT	heat transfer

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