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Thermal Enhancement of Ribbed Double Pipe Heat Exchangers Using Titanate Nanofluids for Advanced Heat Transfer Systems

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ABSTRACT

This study investigates the improvement of thermal performance in smooth and ribbed double-pipe heat exchangers using titanium-based nanofluids. Titanate nanoparticles and nanotubes were synthesized and dispersed in water through a two-step method to ensure stable nanofluid mixtures. Experimental trials were conducted at varying concentrations and flow rates to evaluate temperature difference, heat transfer rate, coefficient, and efficiency. Results indicate a consistent performance increase in ribbed configurations, with titanium nanotubes outperforming their nanoparticle counterparts. This enhancement occurs because the ribbed geometry promotes turbulence while the nanotube's morphology increases thermal conductivity and energy interaction with the fluid. The combination of structural design and nanofluid science enhances energy efficiency in heat exchanger systems. These findings support the development of more effective thermal systems through the integration of nanotechnology and mechanical design, aligning with advancements in science and engineering education.

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1. INTRODUCTION

The ongoing demand for high-performance thermal management in various industrial sectors has accelerated research into advanced heat exchanger designs and advanced working fluids. Among the different types of heat exchangers, the ribbed double pipe heat exchanger (RDPHE) has garnered significant attention due to its high thermal performance, compact design, and flexibility across different power and industrial applications. The ribbed tube heat exchanger consists of pipes with longitudinal ribs or fins, which can either be integral to the tube material or added externally to increase the surface area for heat transfer and induce turbulence, which promotes more efficient heat exchange between the fluids. Ribbed or internally enhanced double-pipe heat exchangers have proven particularly effective in terms of performance due to their ability to intensify fluid turbulence and disrupt the thermal boundary layer, resulting in significantly higher heat transfer rates compared to smooth tube exchangers.

Over the years, numerous studies have been conducted to explore the efficiency of heat exchangers under various operational conditions (Nandiyanto *et al*., 2022a; Nandiyanto *et al*., 2021; Nandiyanto *et al*., 2022b; Ragadhita & Nandiyanto, 2024; Nugraha Nandiyanto, 2021; Ragadhita & Nandiyanto, 2024). Early research works relating to RDPHE focused on the fundamental aspects of heat transfer mechanisms in ribbed pipes. For example, several researchers developed a comprehensive empirical model for predicting heat transfer coefficients in ribbed tubes, highlighting the role of rib geometry and flow conditions in enhancing thermal performance. Their results indicated that ribbed surfaces can considerably increase heat transfer rates compared to a smooth pipe heat exchanger (SDPHE).

Subsequently, the influence of rib configuration, including rib height, spacing, and orientation, on the heat transfer and pressure drop characteristics has been studied inclusively. For example, several researchers (Ahmed *et al*., 2022) examined the effect of rib height and pitch on both heat transfer enhancement and friction factor. They concluded that higher rib heights improved heat transfer and led to increased pressure losses, thereby affecting the overall performance of the system. Similarly, several researchers conducted a comparative study on the effects of different rib geometries and demonstrated that a larger rib pitch often resulted in improved heat transfer rates but also contributed to higher operational costs due to increased energy consumption for pumping the fluid through the exchanger due to high pressure drop. Several researchers (Zheng *et al*., 2015) demonstrated the successful application of ribbed tube heat exchangers in engine cooling systems, reporting considerable reductions in size and weight compared to traditional smooth-tube designs, while maintaining or improving heat transfer capabilities.

Recent advancements have also considered the hybrid systems combining ribbed pipes with other heat transfer augmentation methods, such as twisted tapes or nanofluids. For example, integrating ribbed pipes with nanofluid has been shown to significantly improve heat transfer performance by enhancing thermal conductivity and the fluid’s heat capacity compared to conventional designs. These hybrid approaches continue to be a promising area of research, particularly in applications that demand both high heat transfer and energy efficiency. Several studies have demonstrated that combining nanofluids with ribbed geometries yields a synergistic effect, resulting in substantial enhancements in the Nusselt number and overall heat exchanger effectiveness. The improved thermal conductivity from nanoparticles and the increased turbulence from ribs lead to a more uniform temperature distribution and reduced thermal resistance. Several researchers (Tiwari *et al*., 2003) demonstrated that the use of water-based nanofluids containing aluminium oxide (Al_2O_3)

nanoparticles in a tube heat exchanger resulted in a significant increase in thermal conductivity, which subsequently enhanced the overall heat transfer coefficient. Correspondingly, (Prajapati, *et al*., 2015) reviewed various studies and concluded that nanofluids in ribbed tube configurations could significantly improve heat transfer rates, particularly in forced convection scenarios.

The impact of different types of nanoparticles on the thermal performance of ribbed tube heat exchangers has also been explored. Several researchers (Murshed & De Castro, 2014) investigated the thermal performance of multi-walled carbon nanotube (MWCNT) nanofluids, and superior heat transfer performance was achieved when compared to conventional Al_2O_3 nanofluids. Other researchers studied the heat transfer characteristics of CuO nanofluids and concluded that such fluids could significantly improve heat transfer in ribbed pipe heat exchangers, especially at high flow rates. Furthermore, the thermal performance of a ribbed tube using hybrid MXene + Al_2O_3 nanofluid has been studied experimentally by several researchers (Saeed & Qasim, 2023). This experimental work explored the use of a hybrid nanofluid consisting of MXene and Al_2O_3 nanoparticles in a ribbed double-pipe heat exchanger. The results indicated that the hybrid nanofluid achieved a remarkable increase in the Nusselt number and the heat transfer coefficient, especially at higher Reynolds numbers. The study found that combining the unique thermal properties of MXene and Al_2O_3 with the ribbed geometry provided up to a 27% improvement in heat transfer performance compared to conventional fluids, with only a moderate penalty in pressure drop. A numerical study has been conducted to analyse the turbulent flow and heat transfer of Al_2O_3/water nanofluid in RDPHE using the CFD modelling. Results showed that ribs performed better, and increasing the volume fraction of Al_2O_3 nanoparticles led to higher heat transfer rates. The highest improvement in thermal performance was recorded at 0.1% nanoparticle concentration, resulting in up to 36% enhancement in the Nusselt number over the baseline.

The effect of CNT nanofluids in corrugated double-pipe heat exchangers (2021) was evaluated through the use of carbon nanotube (CNT) nanofluids in corrugated double-pipe heat exchangers, which is functionally equivalent to ribbed designs. The study found that CNT/water nanofluids led to up to a 24% improvement in heat transfer compared to water, with optimal performance at 0.1% CNT concentration. Finally, a comprehensive review of nanofluids in enhanced heat exchangers. Summarized the latest advances in using nanofluids in internally enhanced (ribbed, corrugated, or finned) double-pipe heat exchangers. It concluded that the majority of studies reported 15–35% increases in heat transfer rates using TiO_2, Al_2O_3, and hybrid nanofluids in conjunction with internal surface enhancements. It emphasized the importance of both nanoparticle selection and rib design for maximizing system performance, as well as the need for further research on stability and long-term operation.

On the other hand, the effect of using TiO_2/water nanofluids with delta-wing twisted tape inserts inside a double-pipe heat exchanger was investigated to optimize both the thermal and hydraulic performances through multi-objective algorithms (Eiamsa-ard & Promvonge, 2021). The experimental results demonstrated that the addition of TiO_2 nanoparticles further enhanced the heat transfer rate. The highest Nusselt number enhancement was observed at a nanoparticle volume fraction of 0.1%, with the overall thermal performance factor increasing by 18% compared to water without nanofluid. A recent literature review provided a comprehensive summary of nanofluid applications in various heat exchanger configurations, with particular attention to ribbed and internally enhanced double-pipe designs. The review highlights that the combination of TiO_2 and Al_2O_3 nanofluids with ribbed pipe consistently results in 20–30% improvements in heat transfer rates. The influence of

TiO_2/water nanofluid on the thermal performance of a copper double-pipe heat exchanger operating with this nanofluid has been investigated using different nanoparticle concentrations, and results revealed that adding 0.3% volume TiO_2 led to a 23% increase in heat transfer efficiency, while higher concentrations resulted in diminishing returns and increased pressure drops.

The promising results obtained with TiO_2 and other nanomaterials in ribbed double-pipe heat exchangers pave the way for using more advanced nanostructures such as titanium nanotubes (TiNTs), which may offer even greater improvements due to their unique morphology and thermal properties. The present study aims to comprehensively explore the improvement in thermal performance of double-pipe heat exchangers through the use of titanium dioxide nanoparticles (TiNPs) and titanium nanotubes (TiNTs) working as nanofluids in double-pipe heat exchangers by contemplating ribbed tubes and nanofluids.

This study aims to evaluate the enhancement of thermal performance in ribbed double-pipe heat exchangers using titanate-based nanofluids, specifically titanium dioxide nanoparticles (TiNPs) and titanium nanotubes (TiNTs). An experimental approach was employed by constructing two heat exchanger configurations—smooth and ribbed—operated with nanofluids synthesized via a two-step method and tested across various concentrations and flow rates. The novelty of this work lies in the combined application of surface engineering and nanotechnology, where TiNTs, due to their higher thermal conductivity and tubular structure, intensify turbulence and heat transfer. This integrated strategy offers an innovative solution for developing more efficient heat exchanger systems based on applied science and technology.

2. METHODS

The experimental work involves the synthesis and characterization of two types of nanomaterials (TiNPs and TiNTs), as well as measuring and investigating the thermal and hydraulic variables of two configurations of heat exchangers: smooth and ribbed double-pipe heat exchangers. The TiNTs were synthesized by alkaline hydrothermal reaction at atmospheric pressure. The samples were analysed and characterized using advanced methods like Fourier transform infrared spectroscopy, scanning electron microscopy, transmission electron microscopy, and X-ray diffraction analysis, which confirmed that the TiNPs were in the anatase form with an average diameter of 40.39 nm, and that the titanate nanotubes (TiNTs) had a crystalline structure with an average diameter of 27.30 nm. The detailed synthesis process and the characterization results were presented in previous works (Al-Hajjaj *et al*., 2011). The experimental setup equipped with suitable measuring instruments was designed and constructed specially for the present study.

2.1 Experimental Setup

The experimental setup consists of two double-pipe heat exchangers. The first one is equipped with a SDPHE, while the second is equipped with an RDPHE, as shown in **Figure 1** schematically and photographically**.** In both configurations, the heat exchange section is a horizontal counter-current flow heat exchanger with two flow loops, a heating unit, a cooling unit, and temperature and flow rate measurement equipment. In this configuration, one loop transmits hot water through the inner pipe, while the second loop transmits cooling nanofluid moving counter-currently across the annular gap.

Figure 1. Schematic diagram (a) and photograph image (b) of the experimental setup.

The inner pipes of SDPHE and RDPHE were built of 1.2 m long copper pipe with an inner diameter of 20 mm and an outside diameter of 22 mm (see **Figure 2**), while the annular segments are composed of smooth copper pipe with an inner diameter of 48 mm and an outer diameter of 51 mm. Each flow loop featured a pump, flow meter, reservoir, and control valves. Eight digital thermometers were placed at various positions along the heat exchangers to measure the inlet and exit temperatures of the cold and hot fluids.

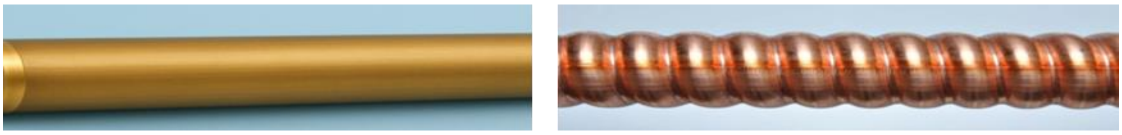

Figure 2. Inner pipes of the experimental DPHE setup: (a) smooth pipe, (b) circumferentially ribbed pipe.

The flow loops of this setup consist of heating and cooling loops. The heating loop consisted of a 60-liter constant-temperature bath filled with hot water. This bath includes built-in heaters and pumps for a hot water recirculating system. The nanofluid chilling system comprises two thermally insulated plastic tanks. The first tank was used to store heated nanofluid. The second tank is the chilling tank, which is used to cool the nanofluid to the desired temperature. This tank consists of a 5-liter tightly closed cylindrical thermos with a 5 m length of 1/4-inch-diameter helical brass pipe connected to a cooling facility via a 1/6 hp fridge compressor. This design allows for a consistent flow of a cooling medium, which effectively removes heat from warm nanofluids.

2.2 Titanate/Water Nanofluids; Preparation and Properties

The nanofluids utilized in the experimental work were prepared using the two-step process. This process involves dispersing TiNPs and TiNTs powders individually into distilled water at various volume concentrations, i.e., 0.05%, 0.1%, 0.15%, and 0.2 wt%. Each nanofluid was homogenized for 30 minutes with an electrical overhead stirrer to guarantee consistent particle mixing and distribution. Oleic acid was utilized as a surfactant in distilled water to increase the nanofluids' dispersion and stability. **Table 1** lists the thermophysical properties of the nanomaterials and base fluid (water).

Table 1. Thermophysical properties of nano materials and base fluid.

Material	Density (kg/m³)	Thermal conductivity (kW/m. K)	Heat Capacity (kJ/kg. K)
TiNPs	4230	1.20	0.710
TiNTs	4510	1.65	0.8520
Water	1000	0.607	4.183

The thermophysical properties of TiNPs and TiNTs nanofluids are determined based on the fraction of titanate nanoparticles and nanotubes in the base fluid (water) using the following set of equations (see equations (1), (2), (3), and (4)) (Olabi *et al*., 2021):

Density: $\rho_{nf} = (1 - \emptyset_v)\, \rho_{bf} + \emptyset_v\, \rho_{np}$ (1)

Specific heat capacity: $= \frac{\emptyset_V\, \rho_{np}\, C_{P_{np}} + (1 - \emptyset_V)\, \rho_{bf}\, C_{P_{bf}}}{\rho_{nf}}$ (2)

Thermal conductivity: $K_{nf} = K_{bf} \cdot \left(\frac{K_{np} + 2K_{bf} + 2(K_{np} - K_{bf})\, \emptyset_V}{K_{np} + 2K_{bf} - (K_{np} - K_{bf})\, \emptyset_V} \right)$ (3)

Viscosity: $\mu_{nf} = (1 + 2.5\, \emptyset_v)\, \mu_{bf}$ (4)

where ρ_{nf} is the density of nano-fluid (kg/m³). $\emptyset_v$ is the concentration of nanoparticles, K_{nf} is the thermal conductivity of nanofluids (W/m.K). μ_{nf} is the viscosity of nanofluids (kg/m.s), and for all thermos-physical properties, the subscripts *np* and *b* refer to nanoparticle and base fluid, respectively.

2.3 Governing Equations and Calculations

The thermal performance calculations for the hot fluid temperature difference (*ΔTh*), the average heat transfer rate (*Qavg*), the overall heat transfer coefficient (*Ui*), and the thermal efficiency of the hot side (*η*) are shown below. In addition, the evaluation of the correlation parameters of a DPHE having a cross-section diagram is presented in **Figure 3**.

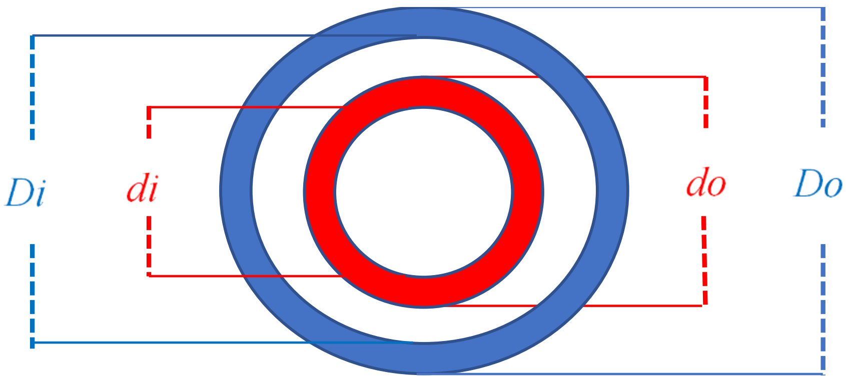

Figure 3. The double-pipe heat exchanger piping scheme. The blue and red colors refer to cold and hot fluids, respectively.

2.3.1 Hot fluid temperature difference

The temperature difference of the hot fluid stream (ΔTh) is calculated using Equation (5):

$$\Delta T_h = T_i - T_o \quad (5)$$

where T_i is the inlet temperature (°C), and T_o is the outlet temperature (°C)

2.3.2 Average heat transfer rate

The average heat transfer rate (Qavg) from hot stream (inner tube) into cold stream (outer tube) can be calculated from equation (6):

$$Q_{avg.} = [(mCp\Delta T)_h + (mCp\Delta T)_c]/2 \quad (6)$$

where *Qavg* is the average heat transfer rate (W), *m* is the mass flow rate (kg/s), *Cp* is the heat capacity (kJ/kg.°C), and *ΔT* is the temperature difference (°C).

2.3.3 Overall heat transfer coefficient

The overall convective heat transfer coefficients for inner stream and outer stream can be determined based on Equation (7) with a correction factor (*F*) equal to unity:

$$U = \frac{Q}{A\Delta T_m} \quad (7)$$

where *U* is the overall convective heat transfer coefficient (W/m². k), *A* refers is the heat transfer area (m²), and *ΔTm* is the Logarithmic mean temperature difference for the counter flow arrangement and given by equation (8):

$$\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \quad (8)$$

ΔT_1 and ΔT_2 in Equation (8) can be determined from Equations (9) and (10), respectively.

$$\Delta T_1 = (T_{h1} - T_{c2}) \quad (9)$$

$$\Delta T_2 = (T_{h2} - T_{c1}) \quad (10)$$

where T_{h1} is the inlet temperature of the hot fluid (°C), T_{h2} is the outlet temperature of the hot fluid (°C), T_{c1} is the inlet temperature of the cold fluid (°C), and T_{c2} is the outlet temperature of the cold fluid (°C).

2.3.4 Overall heat transfer coefficient

The thermal efficiency of the hot side is defined as the ratio of the temperature difference on the heat side to the maximum temperature difference between the heat and cold sides in an ideal heat exchanger. In an ideal heat exchanger, the maximum temperature difference is the difference between the entrance temperatures of the hot fluid and the inlet temperature of the cold fluid, as indicated in Equation (11):

$$\eta = \frac{(T_{h1} - T_{h2})}{(T_{h1} - T_{c1})} \quad (11)$$

2.3.5 Enhancement percentage

The improvement percentage can be calculated as an enhancement percentage (E%) in the hot fluid temperature difference, overall heat transfer coefficients, heat transfer rates, and thermal efficiency according to Equation (12) (Majeed & Abd, 2021):

$$\%\,E = \frac{Value\ of\ nanofluid - Value\ of\ base\ fluid}{Value\ of\ base\ fluid} * 100 \quad (12)$$

3. RESULTS AND DISCUSSION

This section discusses and analyses the performance of two types of double pipe heat exchangers: SDPHE and RDPHE, which use TiNPs and TiNTs nano fluids at two hot fluid flow rates (1 and 8 L/min). Performance analysis of both types of heat exchangers focuses on four thermal performance metrics: hot fluid temperature differential (ΔTh), total heat transfer coefficient (Uo), heat transfer rate ($Qavg$), and thermal efficiency (η).

3.1 Hot Fluid Temperature Difference (ΔTh)

Figure 4 compares the hot fluid temperature difference (ΔTh) using TiNPs and TiNTs nano fluids in SDPHE and RDPHE at hot fluid flow rates of 1 L/min (see **Figure 4(a)**) and 8 L/min (see **Figure 4(b)**). At the highest nano fluid flowrate (8 L/min), RDPHE shows superior performance: for TiNTs, ΔTh reaches 8.3°C at 1 L/min and 6.5°C at 8 L/min, while for TiNPs it reaches 7.7°C and 6.0°C, respectively. In comparison, SDPHE values are as low as 6.6°C (TiNTs) and 6.1°C (TiNPs) at 1 L/min, and 4.2°C (TiNTs) and 3.8°C (TiNPs) at 8 L/min. This reflects a performance improvement of about 54.76% for TiNTs and 53.84% for TiNPs with the ribbed design due to the superior thermal performance of TiNTs and the efficiency of the ribbed design in promoting.

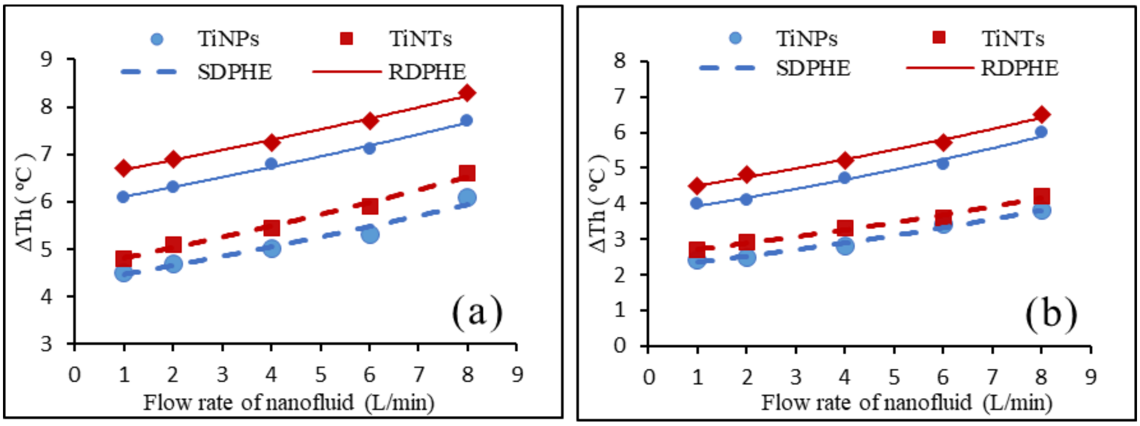

Figure 4. Comparison between hot fluid temperature difference in SDPHE and RDPHE at two hot fluid flow rates: (a) 1 and (b) 8 L/min.

3.2 Overall Heat Transfer Coefficient (U)

A comparison of the overall heat transfer coefficient (U) for TiNPs and TiNTs nano fluids in SDPHE and RDPHE is shown in **Figure 5.** At the highest nano fluid flow rate (8 L/min), RDPHE consistently shows enhanced performance than that of SDPHE. For TiNTs, Uo in RDPHE reaches about 319.5 W/m^2.K at 1 L/min and 2142.6 W/m^2.K at 8 L/min, compared to 239.3 and 1312.1 W/m^2.K in SDPHE, with an improvement of around 33.51 and 63.3%, respectively. For TiNPs, RDPHE achieves 275.7 W/m^2.K at 1 L/min and 1797.6 W/m^2·K at 8 L/min, versus 214.3 and 1129.7 W/m^2.K in SDPHE gains of roughly 28.65 and 59.12%. These results indicate that the ribbed shape of the inner pipe promotes boundary layer disruption, resulting in better convective heat transfer.

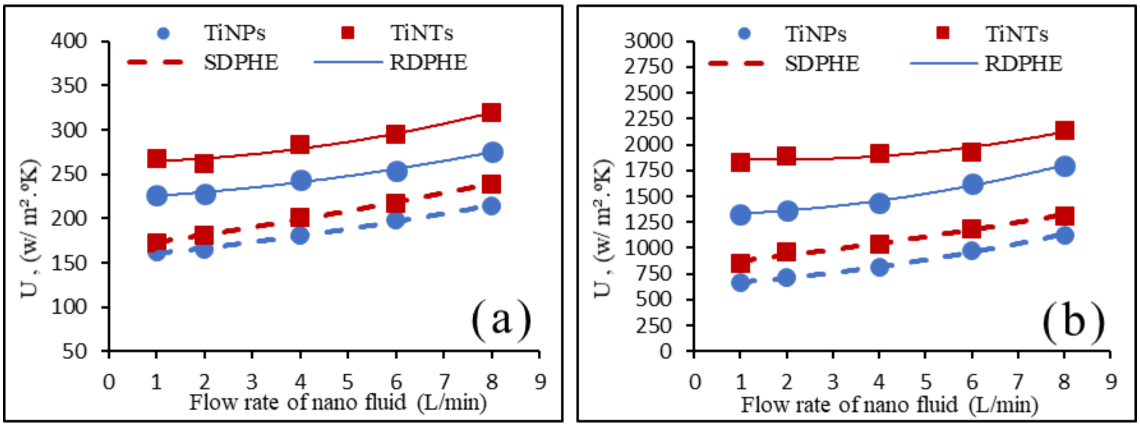

Figure 5. Comparison between overall heat transfer coefficients in SDPHE and RDPHE at two hot fluid flow rates; (a) 1 and (b) 8 L/min.

3.3 Average Heat Transfer Rate (Qavg)

Figure 6 illustrates a comparative indication of the heat transfer rates (*Qavg*) for TiNPs and TiNTs nano fluids in SDPHE and RDPHE at hot fluid flow rates of 1 L/min (a) and 8 L/min (b). At the maximum nanofluid flow rate (8 L/min), RDPHE regularly exhibits higher Qavg values. For TiNTs, Qavg in RDPHE is around 573.5 W at 1 L/min and 3569.7 W at 8 L/min, compared to 455.5 W and 2283.2 W in SDPHE, representing improvements of around 25.9 and 56.35%, respectively. For TiNPs, Qavg in RDPHE is around 509.2 W at 1 L/min and 3170.0 W at 8 L/min, whereas SDPHE reaches 415.1 W and 2067.6 W with an enhancement of around 22.67 and 53.31%. These findings demonstrate that the ribbed design greatly increases heat transfer rates, with TiNTs demonstrating the best overall performance across all tested conditions.

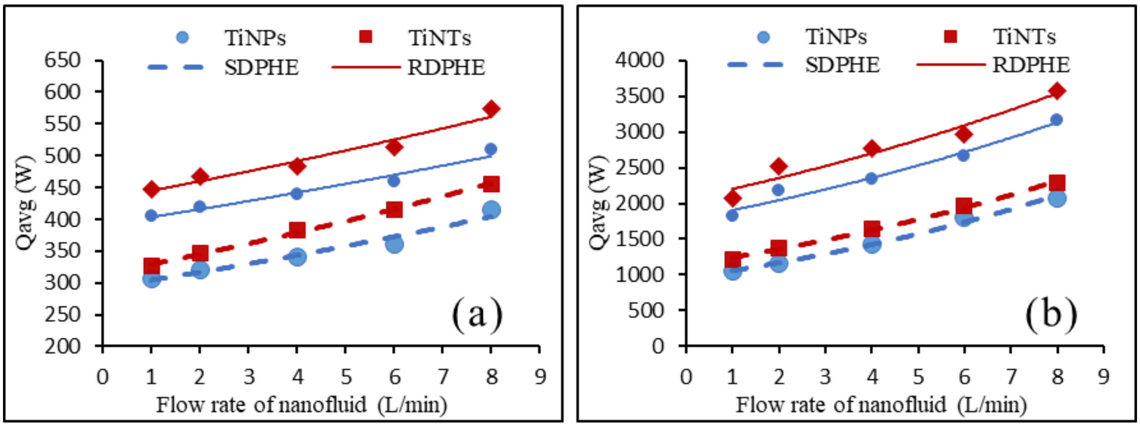

Figure 6. Comparison between heat transfer rates in SDPHE and RDPHE at two hot fluid flow rates: (a) 1 and (b) 8 L/min.

3.4 Thermal efficiency (η)

Figure 7 is the thermal efficiency (η) for TiNPs and TiNTs nano fluids in SDPHE was compared to that of RDPHE at hot fluid flow rates of 1 L/min (a) and 8 L/min (b). At the highest nano fluid flowrate (8 L/min), the RDPHE exhibits better thermal efficiency for both TiNPs and TiNTs. For TiNTs, η reaches about 35.7% at 1 L/min and 25.8% at 8 L/min, compared to 27.8 and 17.4% in the SDPHE, representing 28.4 and 48.3% improvements, respectively. For TiNPs, η in the RDPHE is roughly 32.0% at 1 L/min and 22.9% at 8 L/min, compared to 25.3 and 15.8% in the SDPHE, resulting in increases of 24.5 and 44.9%. These findings prove that the ribbed design and the use of TiNTs provide the highest thermal efficiency, especially at elevated nano fluid flow rates, indicating the combined effect of pipe ribbing and advanced thermos-physical properties of nano fluids on exchanger performance.

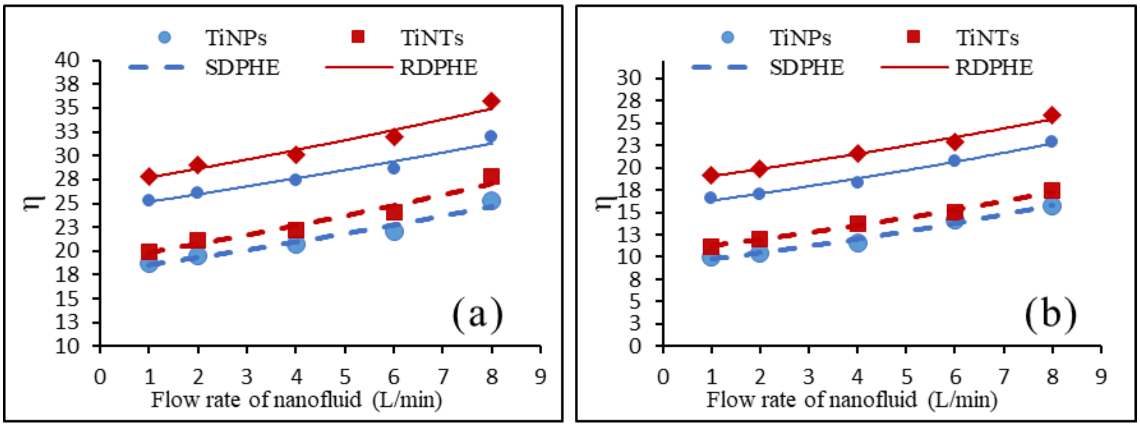

Figure 7. Comparison between thermal efficiencies in SDPHE and RDPHE at two hot fluid flow rates: (a) 1 and (b) 8 L/min.

To close up, **Table 2** summarizes the comparison and improvement percent of the studied variables for TiNPs and TiNTs nano fluids in both smooth and ribbed double pipe heat exchangers configurations.

Table 2. Comparison and performance improvement percent of smooth and ribbed double pipe heat exchangers (SDPHE and RDPHE)

Item	TiNPs			TiNTs		
	SDPHE	RDPHE	*En%*	SDPHE	RDPHE	*En%*
ΔTh (ºC)	3.9	6.0	**53.85**	4.2	6.5	**54.76**
Qavg (w)	2067.6	3170.7	**53.3**	2283.2	3569.7	**56.3**
U (w/m². ºk)	1129.7	1797.6	**59.1**	1312.1	2142.6	**63.3**
η	15.8	22.9	**45.2**	17.4	25.8	**48.0**

Across all studied cases, RDPHE consistently outperforms SDPHE, particularly when combined with the use of TiNT nano fluid. Ribbed pipes enhance heat transfer and fluid flow compared to smooth pipes through creating vortices that disrupt fluid flow, leading to increased heat transfer coefficients by affecting velocity, temperature, and turbulent kinetic energy, hence leading to greater heat transfer enhancement, in addition to the increment of effective heat transfer surface area.

TiNTs offer superior thermal conductivity and larger aspect ratio compared to TiNPs, especially at higher cold fluid flow, which increases Reynolds number, enhancing convective heat transfer and maximizing the nano fluid's thermal potential, leading to improved energy transport and interaction with the fluid medium.

4. CONCLUSION

The obtained results show that the addition of nanoparticles to the base fluid improves both heat transfer and system efficiency. The improvement was found to rise proportionally with higher nanoparticle concentration and greater nano fluid flow velocity. Furthermore, titanium nanotubes (TiNTs) consistently outperformed titanium dioxide nanoparticles (TiNPs) in all studied variables and parameters, due to their unique tubular geometry, high aspect ratio, and larger effective surface area, all of which contribute to more efficient heat and energy transport within the exchanger.

A comparison of SDPHE and RDPHE heat exchanger designs found that the ribbed shape considerably enhances the positive effects of nano fluid addition. The ribbed design maximizes the thermal capabilities of nano fluids by increasing turbulence and decreasing the thickness of the thermal boundary layer. The most significant improvements were made with 0.2 wt% TiNTs in the ribbed exchanger in overall heat transfer coefficient over the base fluid under the same operating conditions.

The comparison of overall performance and enhancement percent of the studied variables for TiNPs nano fluid and RDPHE were 53.85% in ΔTh (°C), 59.1% in overall heat transfer coefficient, 53.3% in average heat transfer rate and 45.2% in thermal efficiency while they were 54.76% in ΔTh (°C), 63.3% in overall heat transfer coefficient, 56.3% in average heat transfer rate and 48.0% in thermal efficiency for TiNTs nano fluids for RDPHE at the same studied conditions.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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