

Thermal Augmentation in Refrigeration Systems Using Nano Fluid Assisted Double Pipe Heat Exchangers

G.B.S.V. Akshaya^{1,*}, V. Mouni Sashi Tej²

Abstract

Improving thermal transport in refrigeration equipment plays a vital role in reducing energy usage and enhancing operational effectiveness. Among different exchanger arrangements, double-pipe heat exchangers are widely selected for applications involving high pressure and elevated temperature because of their compact structure and economical fabrication. Despite these advantages, thermal losses and limited heat transfer capability remain major concerns during operation. The present investigation focuses on the thermal behaviour of a Nano fluid assisted double-pipe heat exchanger employed in refrigeration systems. Numerical analysis has been carried out using the ANSYS simulation environment to evaluate the influence of internal tabulators on convective heat transfer characteristics. Different configuration containing dimple-type inserts are analysed and compared with a plain tube arrangement. The study examines parameters such as temperature distribution, Reynolds number variation, pressure behaviour, and overall heat transfer performance using both water and TiO₂ Nano fluid as working media. Simulation outcomes indicate that the incorporation of internal inserts promotes enhanced turbulence intensity, leading to improved thermal exchange inside the exchanger section. The nano fluid-based model exhibits superior heat transfer capability when compared with conventional water flow conditions. Results obtained from the analysis demonstrate that the combined effect of Nano fluids and tabulators can considerably improve refrigeration heat exchanger efficiency while maintaining practical operating conditions. Furthermore, the comparative evaluation reveals that the optimized insert configuration contributes to a more uniform thermal profile and reduced thermal resistance across the flow domain. The findings of this investigation may support the development of compact, energy-efficient refrigeration heat exchangers suitable for industrial and commercial cooling applications.

Keywords: Inserts, double pipe heat exchanger, nano fluids, ANSYS

INTRODUCTION

A heat exchanger is a thermal device designed to transfer heat between two fluids, such as liquids and gases, without allowing them to mix physically. The transfer of thermal energy generally occurs through a separating surface manufactured from highly conductive materials, including copper, aluminium, or stainless steel.

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BASIC WORKING PRINCIPLE

Thermal energy naturally moves from a region of higher temperature to a region of lower temperature until balance is achieved. A heat exchanger was developed to efficiently regulate and accelerate this thermal interaction.

CLASSIFICATION

Heat exchangers are commonly grouped according to the following aspects:

- *Flow pattern*: parallel, counter, and cross-flow arrangements.
- *Construction type*: Tubular, plate, finned surface, and similar configurations.
- *Mode of heat transfer*: Direct-contact and indirect-contact systems.

TYPES OF HEAT EXCHANGERS

Shell-and-Tube Heat Exchanger

Construction

- A bundle of small tubes carries one working fluid.
- The outer shell encloses another fluid around the tube assembly.

Operation

One fluid travels through the internal tubes, whereas the second fluid circulates within the shell region surrounding the tube bundle, enabling thermal interaction across the tube walls.

Applications

It is widely employed in petroleum processing plants, chemical manufacturing units, thermal power facilities, and industrial heating operations.

LITERATURE REVIEW

S. Padmanabhan, Obulareddy Yuvatejeswar Reddy et al., Materials Today: Proceedings, Elsevier (2021) [1]

Researchers have examined the influence of enhanced thermal performance on the efficiency and economic viability of heat exchangers. An improved heat transfer capability reduces energy losses and supports better operational performance in thermal systems. Owing to their compact structure, double-pipe exchangers are highly suitable for high-pressure and elevated-temperature environments. Although they are economical, these exchangers experience comparatively greater distribution losses than alternative configurations. Several enhancement techniques have been introduced to achieve effective heat transfer while maintaining acceptable pumping requirements and a long service life. Among these methods, helical inserts have been identified as highly effective in improving the performance of heat exchangers. The study evaluated double-pipe exchangers equipped with helical inserts using ANSYS CFX software and compared them with conventional exchangers lacking inserts, focusing on the heat flux behavior and temperature variation along the tube length.

Kumbhar et al., IRJMETS (2023) [2]

They investigated the thermal behavior of concentric tube exchangers and observed that counter-flow arrangements produced greater effectiveness than parallel-flow systems. The incorporation of Nano fluids enhanced the convective heat transfer coefficients, particularly at elevated Reynolds numbers.

The effect of triangular baffles on the performance of double-pipe heat exchangers was evaluated in 2020. The results indicated that the induced turbulence significantly enhanced the thermal transfer rates, whereas the copper tubes fitted with inserts outperformed the conventional smooth tubes in terms of heat dissipation [3].

A study conducted in 2023 examined the use of Fe_3O_4 nanofluids with twisted tape inserts to improve heat exchanger performance. Using Taguchi-based optimization and artificial neural network approaches, the study demonstrated that variations in nanoparticle loading and tape design substantially affected the thermal efficiency and pressure drop characteristics, as reflected by changes in the Nusselt number and friction factor [4].

A study conducted in 2023 evaluated the accuracy of theoretical heat transfer models by comparing them with experimental results obtained using nanofluids. The study observed that the actual heat transfer coefficients exceeded conventional predictions, particularly when inserts were employed, resulting in further improvement of thermal enhancement and overall heat exchanger efficiency [5].

Numerical simulations performed in 2023 examined the influence of nanoparticle diameter and concentration on heat transfer under laminar-flow conditions. The findings revealed that smaller nanoparticles combined with higher particle concentrations significantly improved the thermal conductivity and reduced the thermal boundary layer, resulting in enhanced heat transfer characteristics [6].

A 2019 study evaluated the effect of twisted tape inserts under counterflow operating conditions. The results indicated that the induced turbulence significantly improved the heat transfer characteristics, whereas the use of nanofluids further enhanced the thermal performance owing to their superior heat-conducting properties compared with those of water [7].

A study conducted in 2021 investigated the thermal behavior of CuO–water nanofluids flowing through a double-pipe heat exchanger. The findings showed that higher nanoparticle concentrations improved the heat transfer efficiency, whereas the combined application of inserts and nanofluids produced a synergistic effect, further increasing the overall heat transfer rate [8].

A 2018 study evaluated the effect of helical coil inserts on heat exchanger performance. The induced swirling motion intensified the turbulence and promoted better heat transfer between the fluid and the heat transfer surface. Additionally, the use of nanofluids with superior thermal conductivity contributes to enhanced thermal efficiency and overall heat exchanger effectiveness [9].

A 2020 study investigated the influence of Al₂O₃ nanofluids on the heat transfer characteristics of horizontal heat exchangers. This study highlighted the significant roles of fluid velocity and nanoparticle dimensions in determining the thermal behavior. Furthermore, inserts enhance heat transfer by minimizing thermal resistance and promoting more effective energy exchange within the system [10].

PROBLEM STATEMENT AND OBJECTIVES

Problem Statement

Heat transfer plays a major role in determining the effectiveness and operational performance of double-pipe heat exchangers. The thermal capability of a conventional exchanger can be enhanced using different augmentation methods, among which protrusion-based techniques are considered passive enhancement approaches that provide comparatively lower pressure losses than many other methods.

In this study, both numerical and experimental investigations were performed to analyze the thermal behavior of a double-pipe heat exchanger. The study was conducted using a three-dimensional steady viscous Computational Fluid Dynamics (CFD) approach with an unstructured mesh arrangement. For the investigation, two exchanger configurations were considered: a plain inner tube and an inner tube with dimple-shaped protrusions. Water and 2% TiO₂ nanofluid were selected as the working media for evaluating the thermal performance characteristics.

OBJECTIVES

The main objectives of this investigation are listed below:

- To design a double-pipe heat exchanger without protrusions and develop models containing dimple-type protrusions by considering different working fluids, such as water and 2% TiO₂ nanofluid.
- To establish a CFD-based simulation procedure for estimating the heat transfer rate of the exchanger and compare the thermal behavior obtained using water and TiO₂ nanofluid.
- To evaluate the thermal enhancement achieved by incorporating dimple protrusions on the inner tube surface of a double-pipe exchanger.
- To compare the performance of the exchanger models with and without protrusions under varying fluid conditions and determine the most efficient configuration

DESIGN MODELS USING WITHOUT INSERTS

Figure 1 illustrates the geometry of the concentric double-pipe heat exchanger without protrusions. To enhance the heat transfer surface area in the later configurations, inserts were introduced over the inner tube surface. Figure 2 shows the geometry of the dimple inserts. A total of 252 protrusions were considered, arranged with 42 protrusions in a linear pattern and six protrusions distributed circumferentially.

The illustrated Figure represents a two-dimensional sketch developed in the CATIA software for a double-pipe heat exchanger without any inserts. The design contains multiple concentric circles that indicate the positions of the inner and outer tubes. The appropriate dimensions were incorporated to define the flow channels for the hot and cold fluids.

The smallest inner circle corresponds to the passage carrying one fluid, generally the hot stream. The annular space formed between the concentric tubes allows the second fluid, which is usually colder, to circulate in the opposite direction. Dimensions of 8.5, 14, 27.5, and 33.5 mm represent different tube diameters and clearance regions that ensure suitable flow passages.

Because inserts are absent in this configuration, thermal transfer depends mainly on the available tube surface area and the turbulence naturally generated by fluid motion.

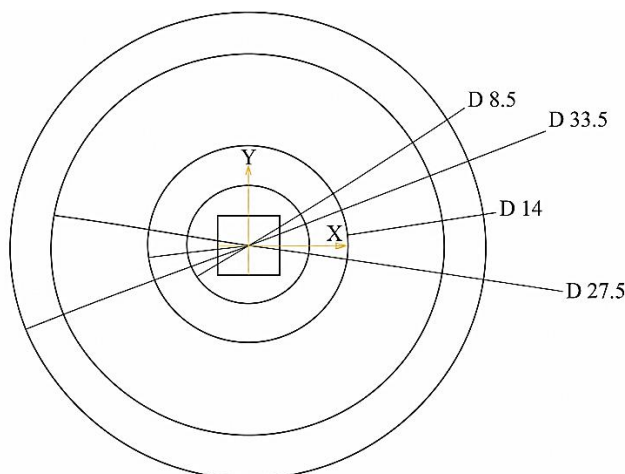


Figure 1. 2D sketch model of double pipe heat exchanger.

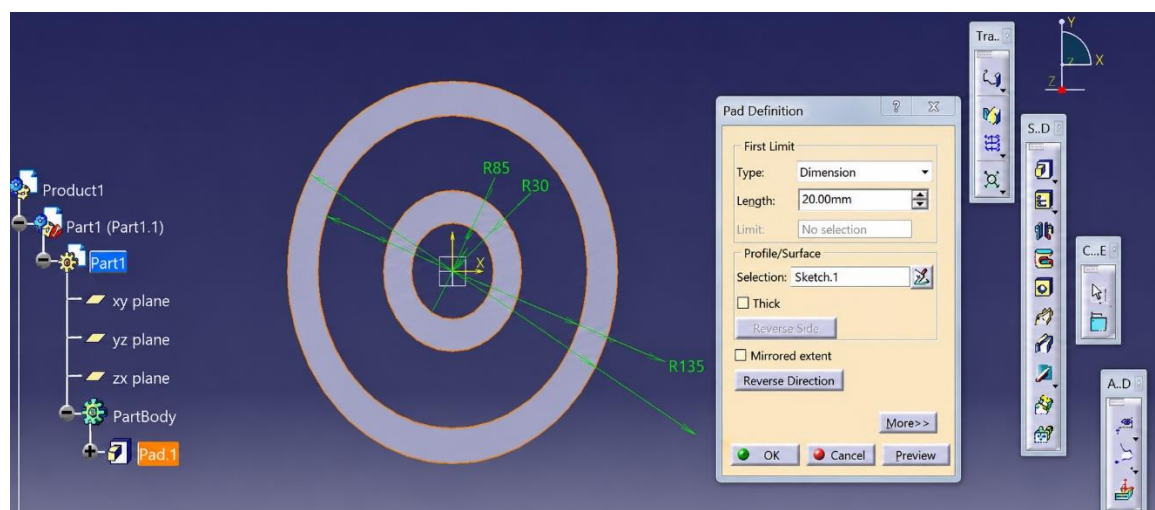


Figure 2. 3D model of double pipe heat exchanger.

The earlier concentric sketch was extruded to a specified length to create a complete three-dimensional tubular structure. The extrusion length of 2440 mm defines the total axial dimension of the heat exchanger.

The central tube forms a passage for one working fluid, whereas the annular region between the tubes serves as a flow path for the second fluid. Dimensions such as D8.5, D14, D27.5, and D33.5 mm define the tube diameters and spacing. These values are important because they influence the hydraulic diameter, pressure variation, velocity distribution, and overall thermal performance.

As the exchanger does not contain inserts, its efficiency mainly relies on the natural turbulence, thermal conductivity of the working fluid, and effective contact surface area. Inserts are commonly introduced to disturb the laminar boundary layer and intensify turbulence; however, in this configuration, the exchanger performance depends entirely on the geometric arrangement and flow characteristics.

The CATIA-generated model provides a clear visualization of the actual exchanger geometry and serves as the foundation for meshing, CFD simulations, and thermal analyses. Such double-pipe exchangers are commonly applied in laboratory systems, pilot-scale units, and moderate heat-duty applications because of their simple construction and compact design (Figure 3).

These Figures represent the CATIA model of a double-pipe heat exchanger integrated with dimple-shaped inserts. This arrangement introduces uniformly spaced protrusions within the annular flow region. Dimples were generated using a circular pattern operation, in which several protrusions were distributed symmetrically around the central axis with equal angular spacing. In the illustrated configuration, six dimples were positioned at intervals of 60° , providing a balanced circumferential distribution (Figure 4).

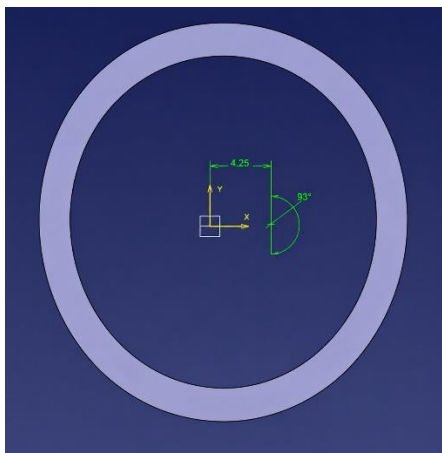


Figure 3. 2D sketch model of double pipe heat exchanger with dimple inserts.

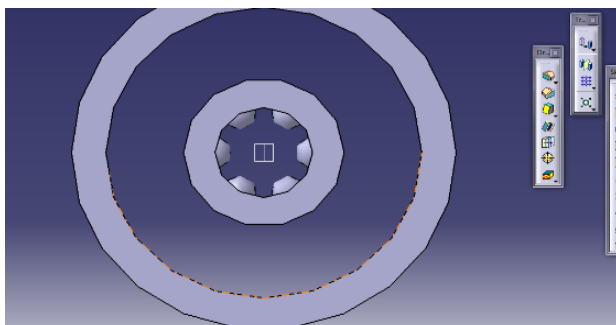


Figure 4. 3D model of double pipe heat exchanger with dimple inserts.

The developed arrangement of dimples inside the annular section functions as a turbulence-enhancement mechanism. These protrusions disturb the fluid stream and weaken the thermal boundary layer, thereby improving the mixing and increasing the convective heat transfer between the hot and cold fluids. Simultaneously, the dimples were designed such that they did not completely obstruct the flow passage. Instead, they alter the streamline pattern and generate additional turbulence while producing a comparatively lower pressure loss than twisted-tape or helical inserts.

Another Figure emphasizes the dimensions of a single dimple, where a diameter of 3 mm and an offset distance of 4.25 mm are specified. These geometric parameters significantly affect the flow characteristics and thermal behavior of the exchanger. Smaller dimples create localized disturbances with minimal resistance, whereas larger protrusions generate stronger mixing effects accompanied by an increased pressure drop.

The dimple-insert configuration effectively enhances the thermal performance of double-pipe heat exchangers. By introducing these protrusions, improved heat transfer can be achieved without substantially increasing the total area of heat transfer. Such configurations have been widely investigated because they provide a balanced combination of enhanced thermal efficiency and moderate pumping power requirements.

RESULTS OF DOUBLE PIPE HEAT EXCHANGER USING WATER AND TiO₂ NANO FLUID

Experimental Results

Percentage of error from analytical to experimental results

$$\begin{aligned}\% \text{ of error} = error &= \frac{1026.1976 - 889.7375}{1026.1976} \times 100 \\ &= 13.2\%\end{aligned}$$

Analytical Results

Figure 5 illustrates the variation in the heat transfer coefficient (W/m²K) for different heat exchanger configurations with and without inserts. The horizontal axis represents three operating conditions: the plain tube without inserts, tube fitted with 3 mm dimple inserts, and configuration containing triangular inserts. The vertical axis indicates the heat transfer coefficient values, extending from 0 to 1200 W/m²K. Two separate curves are included in the graph: one corresponding to water used as the working fluid and the other representing TiO₂ nanofluid employed as the cold fluid while water flows as the hot fluid (Table 1).

From the Figure 6, it can be observed that the heat transfer coefficient increases significantly when inserts are introduced into the heat exchanger compared with the plain tube arrangement. The configuration without inserts exhibited the lowest thermal performance because the fluid flow developed a comparatively stable boundary layer, resulting in lower turbulence intensity and reduced convective heat transfer.

When 3 mm dimple inserts were provided, the heat transfer coefficient increased noticeably. The dimples disturb the fluid stream, enhance mixing, and weaken the thermal boundary layer formed near the tube surface. This disturbance promotes improved interactions between the fluid particles and heated surface, thereby increasing the rate of heat transfer.

Table 1. Experimentation results without inserts using water as fluid.

Fluid	Heat transfer rate (w)	Temperature cold in (k)	Temperature cold out (k)	Temperature hot in (k)	Temperature hot out (k)
Water	889.7375	302.15	309.15	324.15	321.15

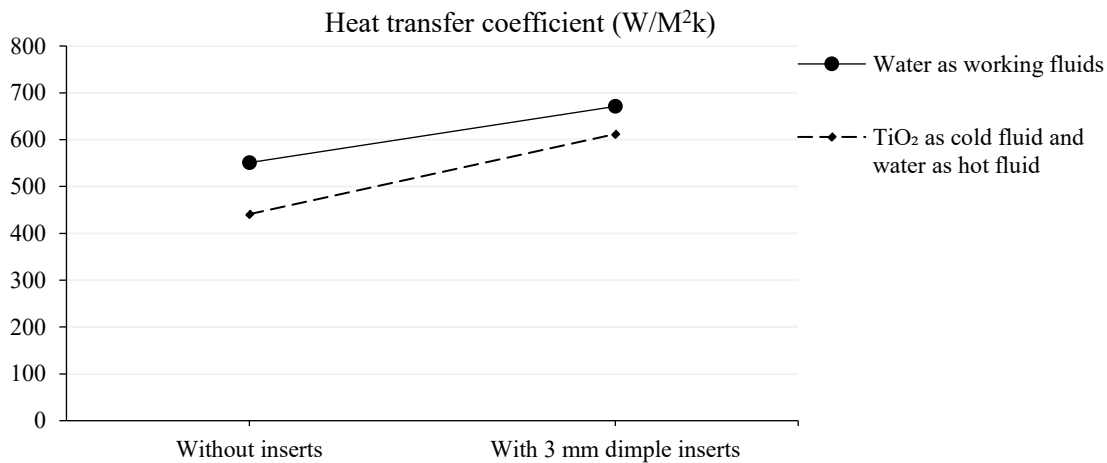


Figure 5. Comparison of heat transfer coefficient between 2 inserts and 2 fluids.

The triangular insert configuration exhibited the highest heat transfer coefficient among all tested cases. The sharp geometry of the triangular inserts generated stronger turbulence and greater flow disturbance inside the tube. Consequently, fluid mixing becomes more effective, leading to enhanced convective heat transfer performance.

The graph also indicates that the heat transfer coefficients of the TiO₂ nanofluid were higher than those of water under all operating conditions. This improvement is mainly due to the superior thermal conductivity of Nano fluids compared to that of conventional fluids. The suspended nanoparticles improve energy transport within the fluid, resulting in improved thermal performance.

Overall, the graph confirms that both the addition of inserts and the use of TiO₂ nanofluid contribute significantly to enhancing the thermal characteristics of the heat exchanger. Among the investigated cases, the exchanger equipped with triangular inserts and operated using TiO₂ nanofluid provided the maximum heat transfer coefficient and, therefore, exhibited the best thermal efficiency.

COMPARATIVE INTERPRETATION

Lowest Efficiency

Plain tube without inserts.

Nano Fluid (TiO₂–Water) Versus Pure Water

In every case, the TiO₂ nanofluid exhibited lower heat transfer coefficients than pure water (Figures 6–8). This may be explained by the higher viscosity of the nanofluid, which increases the flow resistance and decreases the overall convective heat transfer rate despite its better thermal conductivity (Tables 2–4).

Table 2. Comparison of Nusselt no for 2 different designs with 2 different fluids used.

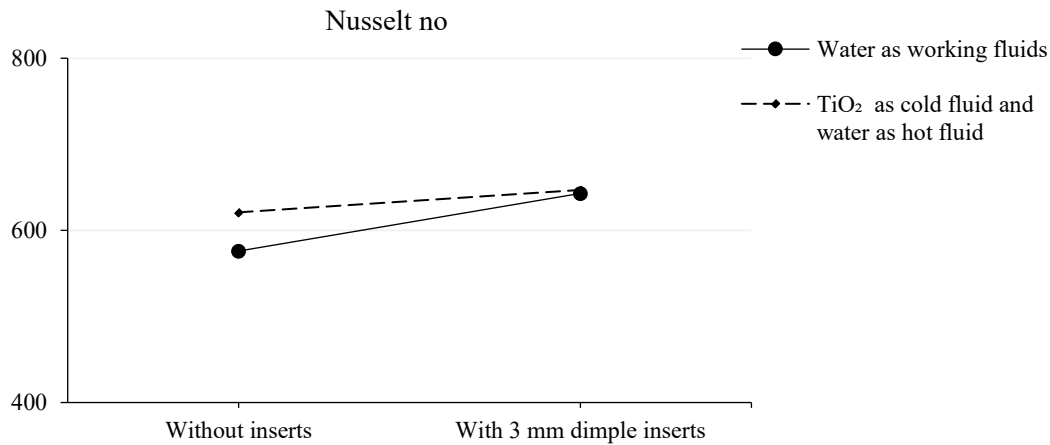
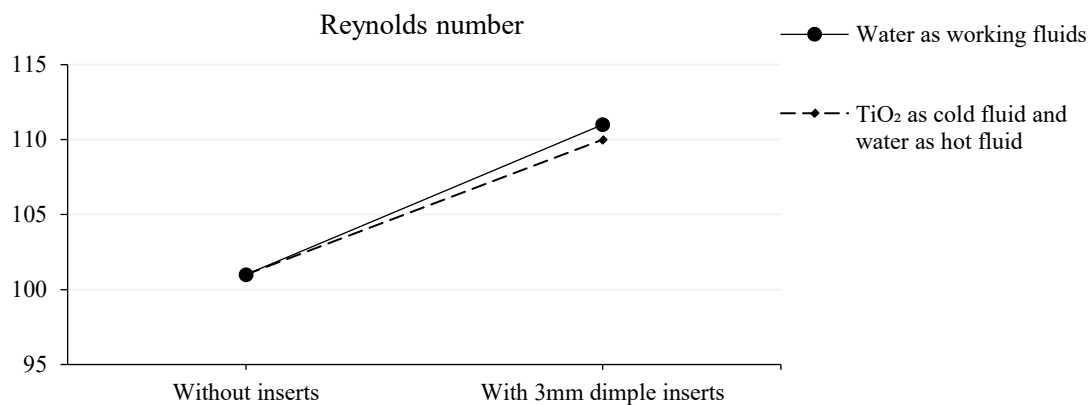
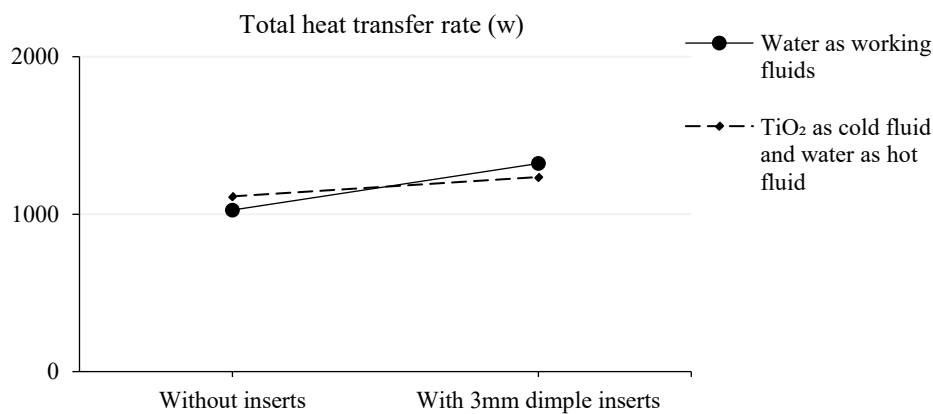
Configuration	Water only (Nusselt no)	TiO ₂ + water (Nusselt no)	Insight
Without inserts	~570	~620	Baseline
3 mm dimple inserts	~640	~640	Balanced gain

Table 3. Comparison of heat transfer rate for 2 different designs with 2 different fluids used.

Configuration	Water only (W)	TiO ₂ + water (W)	Insight
Without inserts	~1200	~1200	Baseline
3 mm dimple inserts	~1500	~1400	Best for water-only

Table 4. Comparison of flow rates for 2 different designs with 2 different fluids used.

Configuration	Cold outlet (water)	Hot outlet (water)	Cold outlet (nano)	Hot outlet (nano)
Without inserts	~0.1 m/s	~0.35 m/s	~0.1 m/s (assumed)	~0.4 m/s
3 mm dimple inserts	~0.1 m/s	~0.35 m/s	~0.1 m/s (assumed)	~0.38 m/s

**Figure 6.** Comparison of Nusselt no between 2 inserts and 2 fluids.**Figure 7.** Comparison of Reynolds no between 2 inserts and 2 fluids.**Figure 8.** Comparison of heat transfer rate between 2 inserts and 2 fluids.

CONCLUSION

The present investigation compared the thermal performance of two double-pipe heat exchanger configurations: a plain tube exchanger without inserts and a modified exchanger fitted with 3 mm dimple inserts. The analysis was performed using two working fluids, namely, water and 2% TiO₂ nanofluid. Parameters such as the Nusselt number, Reynolds number, total heat transfer rate, and flow characteristics were evaluated to determine the most effective configuration.

Nusselt Number Comparison

For the exchanger without inserts, the Nusselt number obtained was nearly 570 for water and approximately 620 for the TiO₂ nanofluid. After introducing 3 mm dimple inserts, the Nusselt number increased to approximately 640 for both fluid conditions.

This enhancement occurred because the dimples disturbed the fluid motion and weakened the thermal boundary layer formed near the tube wall. Improved fluid mixing increases convection inside the exchanger, thereby increasing the thermal efficiency. The TiO₂ nanofluid also produced slightly higher values because the nanoparticles possessed superior thermal conductivity compared with ordinary water.

Reynolds Number Comparison

The Reynolds number comparison showed an increase after the introduction of the dimple inserts. The exchanger without inserts produced Reynolds values close to 100, whereas the dimpled insert configuration reached nearly 110 for both working fluids.

This increase confirmed that the dimples generated additional turbulence within the flow passage. Greater turbulence intensity improves the momentum transfer and enhances the thermal interaction between the fluid and tube surface. The Reynolds number trend also indicated that the insert arrangement improved the fluid circulation without causing excessive resistance.

Heat Transfer Rate Comparison

The plain exchanger produced nearly 1200 W for both water and TiO₂ nanofluid conditions. In comparison, the exchanger fitted with 3 mm dimple inserts achieved approximately 1500 W with water and around 1400 W with the TiO₂ nanofluid.

The increase in the heat transfer rate occurred because the dimples intensified the turbulence and promoted stronger interactions between the fluid stream and heat transfer surface. The inserts also increased local mixing, allowing the thermal energy to be distributed more effectively throughout the exchanger.

Flow Rate Comparison

The flow rate analysis showed only small variations between the two exchanger configurations. For both designs, the cold-water outlet velocity remained nearly 0.1 m/s, whereas the hot-water outlet velocity remained close to 0.35 m/s.

In the nanofluid case, the outlet velocity slightly decreased from nearly 0.4 m/s for the plain tube to approximately 0.38 m/s after adding dimple inserts. This small reduction was due to the additional flow disturbance generated by the protrusions. However, the reduction in flow velocity was comparatively minor compared to the achieved thermal enhancement.

Overall Conclusion

The comparative study revealed that the double-pipe heat exchanger equipped with 3 mm dimple inserts exhibited better thermal performance than the conventional exchanger without inserts. The modified configuration produced higher Nusselt number values, improved Reynolds number, and greater heat transfer rates for both water and 2% TiO₂ nanofluid.

The dimple inserts acted as turbulence promoters by disturbing the fluid stream and reducing the thermal boundary layer thickness, which significantly improved the convective heat transfer. Simultaneously, the pressure and flow variations remained within acceptable limits, making the design thermally efficient and practically suitable.

Among the two working fluids, the TiO₂ nanofluid demonstrated superior thermal characteristics because of its enhanced thermal conductivity and better energy transport capability. However, the highest heat transfer rate was obtained with a 3 mm dimpled insert configuration using water as the working fluid.

Therefore, the study concluded that the exchanger fitted with 3 mm dimple inserts represented the most effective design among the investigated configurations. The combined use of dimple inserts and TiO₂ nanofluid can further improve the efficiency of heat exchangers and can be effectively applied in industrial thermal systems requiring enhanced heat transfer performance with moderate pumping power consumption.

REFERENCES

1. Padmanabhan S, Reddy OY, Yadav KVA, Raja VKB, Palanikumar K. Heat transfer analysis of double tube heat exchanger with helical inserts. *Mater Today Proc.* 2020;46:3588-3595.
2. Kumbhar S, et al. Performance analysis of concentric pipe heat exchangers using nanofluids. *IRJMETS.* 2024;72(3).
3. Rashid FL, Al-Obaidi MA, Al Maimuri NM, Abdalrahem MK, Ameen A, Ibrahim OA, et al. Enhancing efficiency in double-pipe heat exchangers: a detailed review of nanofluids and their impact on thermal performance. *Heat Transf.* 2026;55(1):212-240.
4. Xing M, Zhang H, Zhang C. An update review on performance enhancement of refrigeration systems using nanofluids. *J Therm Sci.* 2022;31(4):1236-1251.
5. Gnanavel C, Saravanan R, Chandrasekaran M. Heat transfer augmentation by nanofluids and circular fin insert in double tube heat exchanger: a numerical exploration. *Mater Today Proc.* 2020;21:934-939.
6. Ponshanmugakumar A, Rajavel R. Enhancement of heat transfer in double pipe heat exchanger. *Mater Today Proc.* 2019;16:706-713.
7. Al Rajeh AY, El Hassan M. Enhancement of heat transfer in double pipe heat exchanger: a review paper. In: 2025 8th International Conference on Energy, Electrical and Power Engineering (CEEPE); 2025 Apr 25. p. 1214-1224.
8. Sarafraz MM, Hormozi FJ. Intensification of forced convection heat transfer using biological nanofluid in a double-pipe heat exchanger. *Exp Therm Fluid Sci.* 2015;66:279-289.
9. Gabir MM, Albayati IM, Hatami M, Alkhafaji D. An experimental investigation of the convective heat transfer augmentation in U-bend double pipe heat exchanger using water-MgO-CMC fluid. *Sci Rep.* 2024;14(1):12442.
10. Alhussen AY, Hussein AM. Availability prediction of a double pipe heat exchanger using twisted tape and nanofluids. *Int J Heat Technol.* 2024;42(5).