INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN ENGINEERING MANAGEMENT AND SCIENCE (IJPREMS)

www.ijprems.com
editor@ijprems.com

Vol. 04, Issue 07, July 2024, pp: 1437-1441

e-ISSN : 2583-1062

Impact Factor : 5.725

"ENHANCING HEAT TRANSFER IN SHELL AND TUBE HEAT EXCHANGERS USING TWISTED TAPE TURBULATORS: A COMPREHENSIVE REVIEW"

Ravi Sahu[1], Vineet Kumar Dwivedi[2]

[1]Scholar, School of Mechanical Engineering, Faculty of Engineering and Technology, SAM Global University, Bhopal, M.P, 462022, INDIA

[2]Head and Prof., School of Mechanical Engineering, Faculty of Engineering and Technology, SAM Global University, Bhopal, M.P, 462022, INDIA

ABSTRACT

Twisted tape turbulators are a promising passive heat transfer enhancement technique used in shell and tube heat exchangers to significantly improve thermal performance. These devices consist of metal strips twisted into a helical shape, which are inserted into the tubes of heat exchangers. By inducing turbulence and disrupting the laminar sub-layer, twisted tape turbulators enhance fluid mixing and reduce thermal resistance, leading to higher convective heat transfer rates. The helical structure creates swirling flows and secondary movements, which further augment heat transfer without requiring additional pumping power, making them an energy-efficient solution. This study examines the effectiveness of twisted tape turbulators in various industrial applications, including cooling systems, chemical processing equipment, automotive radiators, and HVAC systems. The findings indicate that incorporating twisted tape turbulators in heat exchangers leads to a substantial increase in heat transfer efficiency, improving overall system performance and reducing energy consumption. The ease of installation and maintenance further underscores their practicality. By leveraging the advantages of twisted tape turbulators, industries can achieve more sustainable and efficient thermal management. This research highlights the potential of twisted tape turbulators to revolutionize heat exchanger design, offering a cost-effective means to enhance thermal performance and operational efficiency across diverse applications.

Keywords: Twisted Tape Turbulators, Heat Transfer Enhancement, Shell and Tube Heat Exchangers, Convective Heat Transfer, Thermal Efficiency, Passive Heat Transfer Devices.

1. INTRODUCTION

Shell and tube heat exchangers are integral components in numerous industrial processes, prized for their robustness, flexibility, and efficiency in transferring heat between two fluids. These heat exchangers consist of a series of tubes, one set carrying the hot fluid and the other the cold fluid, arranged within a cylindrical shell. The widespread application of shell and tube heat exchangers spans various industries, including power generation, chemical processing, HVAC, and renewable energy systems, underscoring their versatility and importance. In recent years, considerable research has been devoted to enhancing the performance of shell and tube heat exchangers, driven by the ever-increasing demand for energy efficiency and effective thermal management. One prominent area of focus has been the incorporation of nanofluids—fluids containing nanoparticles, which exhibit superior thermal properties compared to conventional heat transfer fluids. Among these, aluminum oxide (Al2O3) nanofluids have garnered significant attention due to their excellent thermal conductivity, stability, and relatively low cost. Additionally, the integration of passive heat transfer enhancement techniques, such as twisted tape inserts, has shown promising results in further augmenting the performance of heat exchangers. Twisted tape inserts induce turbulent flow, disrupt thermal boundary layers, and promote better mixing of fluids, thereby enhancing heat transfer rates without the need for external energy sources. The synergistic combination of Al2O3 nanofluids and twisted tape inserts in shell and tube heat exchangers presents a novel approach to achieving superior thermal performance. This review paper aims to explore the current state of research on this topic, examining the underlying mechanisms, experimental findings, and practical implications. By systematically analyzing the effects of twisted tape inserts and Al2O3 nanofluids, this paper seeks to provide a comprehensive understanding of their combined impact on heat transfer enhancement, pressure drop characteristics, and overall heat exchanger performance. The discussion will encompass various experimental and numerical studies, highlighting key parameters such as nanoparticle concentration, tape twist ratio, flow arrangements, and operating conditions. Furthermore, potential challenges and future research directions will be identified to guide ongoing efforts in optimizing the design and application of shell and tube heat exchangers with twisted tape and Al2O3 nanofluids.

K Rohit et al. (2023): This study focuses on enhancing solar water heating systems (SWHS) by incorporating perforated delta-shaped obstacles. The research evaluates how these obstacles affect key parameters such as the friction factor, Nusselt number, and overall thermo-hydraulic performance. Through their analysis, the researchers identified the

INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN ENGINEERING MANAGEMENT AND SCIENCE (IJPREMS)
Vol. 04, Issue 07, July 2024, pp: 1437-1441
e-ISSN : 2583-1062
Impact Factor : 5.725

optimal setup, which involves a Reynolds number of 1200, an angle of attack of 45 degrees, and a pitch ratio of 1. They utilized an AHP-ARAS hybrid decision-making method to ensure the reliability of their findings, supported by sensitivity analysis and validation [1]. Ebrahim Tavousi et al. (2023): Passive techniques aim to enhance heat transfer by applying modifications like swirl flow devices, extended surfaces, coiled tubes, additives for fluids, and displacement enhancement devices. Compound techniques, on the other hand, improve heat transfer through a strategic combination of both active and passive methods, integrating elements from both approaches to achieve better performance [2]. Z. Said et al. (2019) explored the performance of a Shell-and-Tube Heat Exchanger using CuO/H2O nanofluid to examine its stability, heat transfer efficiency, and potential reductions in effective area and thermophysical properties at nanoparticle concentrations of 0.05%, 0.1%, and 0.3%. The study found that the overall heat transfer coefficient improved by 7%, while the required area for heat transfer decreased by 6.81% [3]. Mohammad Hussein Bahmani (2018) investigated both parallel flow and counterflow double-pipe heat exchangers to assess their heat transfer characteristics under turbulent flow conditions with H2O/alumina nanofluid. The research demonstrated that increasing the nanoparticle volume fraction and Reynolds number led to enhancements in the convection heat transfer coefficient and Nusselt number. Specifically, the thermal efficiency improved by up to 30%, and the average Nusselt number increased by 32.7% [4]. Baba et al. (2018) conducted experimental research on a double-pipe heat exchanger equipped with longitudinal fins to analyze heat transfer characteristics. They utilized Fe3O4/H2O nanofluids with volume concentrations ranging from 0 to 0.4% and operated at Reynolds numbers between 5300 and 49000. Their findings revealed an 80 to 90% enhancement in the heat transfer rate for the finned heat exchanger compared to a plain tube heat exchanger at higher nanofluid concentrations [5]. A. K. Gupta et al. (2021) examined the heat transfer properties of SiO2/H2O, Al2O3/H2O, and CNTs/H2O nanofluids under turbulent flow conditions, with Reynolds numbers from 2000 to 10000. Using computational fluid dynamics (CFD) in a concentric tube heat exchanger, they investigated volume concentrations of 1%, 2%, and 3%. Their results showed a 23.72%, 20.71%, and 32.65% improvement in heat transfer rates, and a 26.83%, 23.6%, and 37.25% increase in the overall heat transfer coefficient with a 3% volume concentration of Al2O3/H2O, SiO2/H2O, and CNTs/H2O nanofluids, respectively, compared to the base fluid [6]. A. K. Gupta et al. (2022) explained that nanofluids consist of nanometer-sized particles, which typically have high heat transfer characteristics (such as metal oxides, carbides, or CNTs), suspended in a base fluid, which generally has low thermal conductivity (like water, ethylene glycol, or oil), forming a colloidal solution [7]. N. Bozorgan et al. (2015) highlighted that nanofluids have been successfully integrated to enhance the performance of solar devices [8]. Ali H. Abdelrazek et al. (2018) described nanofluids as specially prepared mixtures of base fluids and nanoparticles. The properties of nanofluids result from the combined effects of both the base fluid and the nanoparticles [9]. Adnan Sözen et al. (2019) conducted experiments on a plate heat exchanger using a 1.5 wt% water-TiO2 nanofluid. They tested a temperature range of 40 to 50°C and a mass flow rate of 3 to 7 lpm, finding an 11% improvement in heat transfer rate [10].

HEAT EXCHANGER

Heat exchangers are essential devices used in a variety of industries to transfer heat between two or more fluids. These fluids can be in the form of liquids or gases, and they typically flow through the heat exchanger in separate channels, where heat from the hotter fluid is transferred to the cooler fluid without direct contact. This process is crucial for maintaining optimal temperatures in systems, enhancing energy efficiency, and enabling the control of process temperatures in applications ranging from power generation and chemical processing to HVAC systems and refrigeration. Among the different types of heat exchangers, shell and tube heat exchangers are particularly prominent due to their versatility and robustness. They consist of a series of tubes, one set carrying the hot fluid and the other the cold fluid, housed within a cylindrical shell. The design allows for a large surface area for heat transfer, making them highly effective for handling high-pressure and high-temperature fluids. Shell and tube heat exchangers are widely used in industries such as oil refining, petrochemicals, and power plants, where efficient and reliable heat exchange is critical for operational efficiency and safety.

NANOFLUID

Nanofluids are engineered colloidal suspensions of nanoparticles in a base fluid, typically water, ethylene glycol, or oil. These nanoparticles, which can be metals, oxides, carbides, or carbon nanotubes, range in size from 1 to 100 nanometers. The primary motivation for developing nanofluids is to enhance the thermal properties of the base fluid, leading to significantly improved heat transfer performance. This enhancement is attributed to the high thermal conductivity of the nanoparticles, which allows for more efficient heat conduction and, consequently, better thermal management in various applications. The incorporation of nanofluids in heat transfer systems offers several advantages. Firstly, they exhibit higher thermal conductivity than conventional heat transfer fluids, leading to increased heat transfer rates. Secondly, nanofluids can improve the thermal conductivity of fluids without substantially increasing viscosity, ensuring efficient fluid flow and reducing the required pumping power. Moreover, the stability of nanofluids ensures that the nanoparticles

INTERNATIONAL JOURNAL OF PROGRESSIVE RESEARCH IN ENGINEERING MANAGEMENT AND SCIENCE (IJPREMS)
www.ijprems.com
editor@ijprems.com
Vol. 04, Issue 07, July 2024, pp: 1437-1441
e-ISSN : 2583-1062
Impact Factor : 5.725

remain evenly dispersed, preventing issues such as settling or agglomeration. These characteristics make nanofluids highly suitable for a wide range of applications, including cooling systems in electronics, automotive engines, HVAC systems, and renewable energy systems like solar collectors and geothermal heat pumps. By leveraging the superior heat transfer properties of nanofluids, these systems can achieve higher efficiency and performance, contributing to energy savings and enhanced operational reliability.

INSERTS USED

Heat exchanger inserts, such as twisted tapes, helical coils, and wire coils, are passive devices used to enhance the heat transfer performance of heat exchangers. These inserts work by creating turbulence and disrupting the boundary layer of the fluid flow, which increases the heat transfer coefficient without the need for additional energy input. By enhancing the turbulence, inserts improve the mixing of the fluid, leading to a more uniform temperature distribution and higher heat transfer rates. One common type of insert used in heat exchangers is the twisted tape. Twisted tape inserts are metallic strips twisted along their length, which are placed inside the tubes of the heat exchanger. The twisting motion forces the fluid to flow in a spiral path, increasing the fluid velocity and promoting better mixing. This results in a higher heat transfer rate compared to a smooth tube. Other inserts, such as helical coils and wire coils, similarly induce secondary flows and turbulence, further enhancing the heat transfer efficiency. These inserts are particularly useful in applications where space is limited, or where improving the heat transfer performance is critical for system efficiency and effectiveness.

1.1. Twisted Tape Turbulator

Twisted tape turbulators are passive heat transfer enhancement devices used inside tubes of heat exchangers to increase the heat transfer coefficient. They are strips of metal twisted into a helical shape and inserted into the tubes. The primary function of twisted tape turbulators is to induce turbulence in the fluid flow, disrupting the laminar sub-layer and enhancing the mixing of the fluid. This results in increased convective heat transfer between the tube wall and the fluid. The mechanism of heat transfer enhancement with twisted tape turbulators is multifaceted. Firstly, the twisted tape creates a swirling flow that increases the fluid velocity near the tube wall, improving the heat transfer coefficient. Secondly, the tape induces secondary flows, which disrupt the thermal boundary layer, reducing thermal resistance. Finally, the helical structure of the tape causes repeated flow separation and reattachment, further enhancing the turbulence and heat transfer. Using twisted tape turbulators in heat exchangers offers several advantages. They can significantly improve heat transfer rates without requiring additional pumping power, making them energy-efficient. Additionally, they are relatively simple to install and maintain. These characteristics make twisted tape turbulators particularly useful in applications where space is limited, and maximizing heat transfer efficiency is crucial. Common applications include industrial cooling systems, chemical processing equipment, automotive radiators, and HVAC systems. By incorporating twisted tape turbulators, these systems can achieve higher thermal performance, leading to enhanced operational efficiency and reduced energy consumption.

2. EQUATIONS USED

The Navier-Stokes equations, in their general form, are partial differential equations that represent the conservation of momentum for an incompressible fluid:

Continuity Equation:

$$\nabla \cdot V = 0$$

Momentum Equations:

$$\partial(\rho V)/\partial t + \nabla \cdot (\rho V \otimes V) = -\nabla P + \nabla \cdot \tau + \rho g$$

Energy Equation:

$$\partial(\rho e)/\partial t + \nabla \cdot (\rho e V) = \nabla \cdot (k\nabla T) + Q$$

where V is the velocity vector, ρ is the fluid density, P is the pressure, τ is the stress tensor, g is the gravitational acceleration vector, e is the total energy per unit mass, k is the thermal conductivity, T is the temperature, and Q represents heat sources/sinks.

The governing equations solved by Fluent are the Navier-Stokes equations, which describe the motion of fluid particles and are derived from the principles of conservation of mass, momentum, and energy. These equations are used to numerically simulate fluid flow in a domain.

The 3D time-dependent Navier-Stokes equations for an incompressible fluid flow are as follows:

Conservation of Mass (Continuity equation):

$$\nabla \cdot (\rho * U) = 0$$

Vol. 04, Issue 07, July 2024, pp: 1437-1441
e-ISSN : 2583-1062
Impact Factor : 5.725

where:

ρ is the fluid density,

U is the fluid velocity vector,

∇ is the gradient operator (del operator).

Conservation of Momentum (Navier-Stokes equations):

$$\rho * (\partial U/\partial t + U \cdot \nabla U) = -\nabla P + \mu * \nabla^2 U + \rho * g$$

where:

∂U/∂t is the time rate of change of velocity,

∇U is the velocity gradient tensor,

P is the pressure,

μ is the dynamic viscosity of the fluid,

g is the acceleration due to gravity.

Conservation of Energy (Energy equation):

$$\partial(\rho * E)/\partial t + \nabla \cdot (\rho * E * U) = \nabla \cdot (k * \nabla T) + Q$$

where:

E is the total energy per unit mass (sum of internal energy and kinetic energy),

k is the thermal conductivity of the fluid,

T is the fluid temperature;

Q represents the volumetric heat sources/sinks.

These equations are solved iteratively on a discretized grid within the computational domain using numerical methods to obtain an approximate solution for the fluid flow behaviour. Boundary conditions, initial conditions, and turbulence models (if applicable) are also specified to complete the CFD simulation setup.

Keep in mind that Fluent might have undergone updates or changes after my last update, so it's always a good idea to refer to the latest documentation or resources provided by ANSYS for the most up-to-date information on the software and its governing equations.

3. CONCLUSION

Twisted tape turbulators are an effective and energy-efficient solution for enhancing heat transfer in heat exchangers. By inducing turbulence and disrupting the laminar sub-layer, these devices significantly improve the convective heat transfer between the tube wall and the fluid. The helical structure of the twisted tapes creates swirling flows and secondary movements that enhance fluid mixing and reduce thermal resistance. This results in higher heat transfer rates without the need for additional pumping power, making twisted tape turbulators a cost-effective option for optimizing thermal performance. The implementation of twisted tape turbulators in heat exchangers proves particularly beneficial in applications with space constraints and a critical need for improved heat transfer efficiency. Their straightforward installation and maintenance add to their appeal, making them suitable for a wide range of industries, including industrial cooling systems, chemical processing equipment, automotive radiators, and HVAC systems. By leveraging the advantages of twisted tape turbulators, these systems can achieve greater thermal efficiency, leading to enhanced operational performance and reduced energy consumption. Thus, twisted tape turbulators represent a valuable advancement in the design and optimization of heat exchangers, contributing to more sustainable and efficient thermal management solutions.

4. REFERENCES

[1] R. Khargotra, R. Kumar, A. Sharma, T. Singh, Design and performance optimization of solar water heating system with perforated obstacle using hybrid multi- criteria decision-making approach, J. Energy Storage 63 (2023), 107099.

[2] Ebrahim Tavousi, Noel Perera et al. Heat transfer and fluid flow characteristics of the passive method in double tube heat exchangers: A critical review International Journal of Thermofluids, 17, 2 2023

[3] Z. Said, S.M.A. Rahman, M. El Haj Assad and Abdul Hai Alami. Heat transfer enhancement and life cycle analysis of a Shell-and-Tube Heat Exchanger using stable CuO/water nanofluid Sustainable Energy Technologies and Assessments 31 (2019) 306-317. https://doi.org/10.1016/j.seta.2018.12.020.

[4] Mohammad Hussein Bahmani, Ghanbarali Sheikhzadeh, Majid Zarringhalam, Omid Ali Akbari, Abdullah A. A. A. Alrashed, Gholamreza Ahmadi Sheikh Shabani, Marjan Goodarzi. An investigation of turbulent heat transfer

and nanofluid flow in a double pipe heat exchanger Advanced Powder Technology 29 (2018) 273-282. https://doi.org/10.1016/j.apt.2017.11.0133.

[5] M.S. Baba, A.V.S.R. Raju, M.B. Rao, Heat Transfer Enhancement and Pressure Drop of Fe3O4-Water Nanofluid in a Double Tube Counter Flow Heat Exchanger with Internal Longitudinal Fins Case Studies in Thermal, Engineering 12 (2018) 600–607. Fig. 18. Nusselt number variation with Reynolds number on the inner tube side. R. Saini, B. Gupta, A. Prasad Shukla et al. Materials Today: Proceedings.

[6] A.K. Gupta, B. Gupta, J. Bhalavi, P. Baredar, H. Parmar, R. Senthil, CFD study on heat transfer and pressure drop of nanofluids (SiO 2 /H 2 O, Al 2 O 3 /H 2 O, CNTs/H 2 O) in a concentric tube heat exchanger, Int. J. Ambient Energy 43 (1) (2022) 4578–4593.

[7] N. Bozorgan, M. Shafahi, Performance evaluation of nano-fluids in solar energy: A review of the recent literature, Micro and Nano Systems Letters 3–5 (2015) 1–15, https://doi.org/10.1186/s40486-015-0014-2.

[8] Ali H. Abdelrazek, Omer A. Alawi, S.N. Kazi, Nukman Yusoff, Zaira Chowdhury, Ahmed A.D. Sarhan. A New Approach to Evaluate the Impact of Thermos Physical Properties of Nanofluids on Heat Transfer and Pressure Drop. International Communications in Heat and Mass Transfer 95 (2018) 161– 170. https://doi.org/10.1016/j.icheatmasstransfer.2018.05.002.

[9] Adnan Sözen, Ataollah Khanları and Erdem Çiftçi. Experimental and Numerical Investigation of Nanofluid Usage in a Plate Heat Exchanger for Performance Improvement. International Journal of Renewable Energy Development 8 (2019) 27–32. https://doi.org/10.14710/ijred.8.1.27-32.

[10] P.C. Mukesh Kumar, M. Chandrasekar. CFD Analysis on Heat and Flow Characteristics of Double Helically Coiled Tube Heat Exchanger Handling MWCNTs/water Nanofluids. Heliyon 5 (2019) 1–11. https://doi.org/10.1016/j. heliyon.2019.e02030.