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

www.ijprems.com
editor@ijprems.com

Vol. 04, Issue 07, July 2024, pp: 881-885

e-ISSN : 2583-1062

Impact Factor: 5.725

REVIEW OF HEAT TRANSFER ENHANCEMENT IN SHELL AND TUBE HEAT EXCHANGERS: INNOVATIONS AND APPLICATIONS

Sunil Kumar Shah[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

Shell and tube heat exchangers (STHEs) play a critical role in industrial processes by facilitating efficient heat transfer between fluids. This review explores key advancements and strategies aimed at enhancing heat transfer within STHEs. The discussion covers various types of STHEs including fixed tube sheet, floating head, U-tube, and kettle reboilers, each tailored to specific operational requirements. Inserts such as twisted tapes, helical coils, and wire coils are examined for their ability to promote turbulence and improve convective heat transfer without excessive pressure drop. Nanofluids, incorporating nanoparticles like metals and oxides into base fluids, demonstrate significant potential for enhancing thermal conductivity and heat transfer efficiency, though challenges such as stability and cost-effectiveness persist. Baffle plates, including segmental, rod, disc, and orifice baffles, are highlighted for their role in inducing turbulence and optimizing fluid mixing within STHEs. The abstract underscores ongoing research efforts aimed at advancing heat exchanger technology through innovative designs and computational modeling, aiming to achieve higher energy efficiency and sustainability across diverse industrial applications.

Keywords: Keywords: Shell and tube heat exchangers, Heat transfer enhancement, Inserts in heat exchangers, Nanofluids, Baffle plates, Industrial applications

1. INTRODUCTION

In the realm of heat exchanger design, achieving efficient heat transfer is a perennial goal driven by the need for enhanced performance and energy efficiency across various industrial applications. Shell and tube heat exchangers (STHEs) represent a cornerstone in thermal management systems, widely utilized in sectors ranging from chemical processing to power generation and HVAC systems. The effectiveness of these exchangers hinges significantly on the configuration and design of their internal components, such as baffle plates, which play a critical role in promoting heat transfer through fluid turbulence. Recent advancements in computational fluid dynamics (CFD) have revolutionized the ability to simulate and optimize heat exchanger designs with unprecedented accuracy and detail. This capability has spurred innovative approaches to enhancing heat transfer within STHEs, particularly through the integration of novel baffle plate geometries. One such promising design involves the use of flower-shaped baffle plates, which are engineered to induce controlled turbulence and thereby intensify thermal exchange between the shell-side and tube-side fluids. This review explores the application of CFD analysis in investigating heat transfer enhancement mechanisms within STHEs equipped with flower baffle plates. By examining the fluid dynamics and thermal behaviors under various operating conditions, the study aims to elucidate the benefits and challenges associated with this emerging technology. Through a comprehensive review of recent literature and case studies, this paper seeks to provide insights into the performance improvements achievable through innovative baffle plate designs, paving the way for more efficient and sustainable heat exchange solutions in diverse industrial contexts.

A heat exchanger serves to recycle heat energy present in the working fluid and is crucial in various industries such as power generation, oil refining, and HVAC systems. Among these, the versatile shell and tube heat exchanger (STHE) accounts for a significant portion due to its adaptable design and widespread applications in turbine and compressor cooling, refrigeration, and more. Baffle plates within the STHE shell play a pivotal role by inducing turbulence to enhance heat transfer rates and support tube stability. Types of baffle plates include longitudinal flow baffles, impingement baffles for high-velocity protection, and orifice baffles. Efforts to improve heat transfer efficiency in applications like air conditioning and chemical processing focus on reducing thermal resistance through surface modifications such as ribs and corrugations. These alterations increase surface area and disrupt flow, thereby lowering resistance. Research spans experimental, analytical, and numerical studies involving various fluids in roughened channels, encompassing conventional fluids, nanofluids, and hybrid nanofluids. By investigating heat transfer impacts, this research lays groundwork for future studies on nanofluid and hybrid nanofluid use in ribbed and corrugated channels, potentially enhancing overall system performance [1]. A numerical analysis of tubular heat exchanger air-side performance with flower baffles (FBs) examines both in-line and staggered arrangements at different pitch ratios (PR)

Vol. 04, Issue 07, July 2024, pp: 881-885
e-ISSN : 2583-1062
Impact Factor: 5.725

and Reynolds numbers (Re). Findings highlight FBs' disruption of stagnation zones and enhanced air mixing near tube walls, significantly improving thermal transfer coefficients. Higher PR values, with a fixed blockage ratio, lead to increased Nusselt numbers (Nu) and friction factors (f). Optimal thermal performance (η of 1.77) occurs with in-line baffles at PR=2.5, blockage ratio (BR)=0.5, and Re=3000. Correlations are provided to predict Nu and f, enhancing practical application feasibility [2]. Numerical modeling investigates convective heat transfer in a rectangular channel carrying viscous, non-Newtonian fluid, focusing on corrugation impact (rectangular, triangular, semi-circular) on fluid dynamics and thermal characteristics. Results demonstrate significant variations in heat exchange performance due to different corrugation shapes, ranking rectangular > triangular > semi-circular for heat transfer superiority, and vice versa for low pressure drop [3]. An axial flow tubular heat exchanger study utilizes circular baffle plates with trapezoidal air deflectors at varied inclination angles to induce swirl flow, enhancing turbulence and heat transfer from heated tubes. By adjusting baffle plate pitch ratio and maintaining Reynolds numbers (16000–28000), a 7.4% average performance enhancement is achieved with 30° deflectors under counter flow compared to parallel flow conditions [4]. CFD analysis of a helical screw tape insert in pipe flow reveals significant heat transfer rate (Nusselt number) and friction factor increases compared to plain tubes, with a peak thermal performance factor of 3.79 under constant pumping power. Pressure drop rises due to increased flow restriction caused by the inserted coils, validated through sensitivity analysis and experimentation [5]. Experimental analysis of fluid flow in tubes with helical screw inserts evaluates various strip numbers and twist ratios at transition flow regimes. CFD analysis using the k-kl-w model confirms thermohydraulic characteristics, showing enhanced Nusselt numbers at higher Reynolds numbers and lower twist ratios for double strip inserts compared to single strips [6]. Numerical investigation assesses power dissipation and heat transfer enhancement in circular-orifice baffled tubes under combined net and oscillatory flows. Analysis of unsteady pressure drop across tubes under different conditions and fluids aligns well with existing experimental data, examining hydrodynamic and thermal developing flow with uniform heat flux [7]. Comparative study of double shell-pass rod baffle heat exchanger (DS-RBHX) and single shell-pass counterpart (SS-RBHX) performance using water as the working fluid reveals DS-RBHX consistently outperforms SS-RBHX. DS-RBHX exhibits higher shell-side heat transfer coefficients (33.5–54.0%) and pressure drop (34.0–74.3%) compared to SS-RBHX under varying shell-side volume flow rates [8]. Evaluation of various baffled longitudinal flow shell-and-tube heat exchangers (STHX) using experimental data with municipal water reveals rod baffle STHX (RB-STHX) offers superior thermal-hydraulic performance and energy efficiency. RB-STHX displays significantly lower tube bundle section pressure drop compared to segmental baffle STHX (SG-STHX) and large-and-small hole baffle STHX (LSHB-STHX) [9]. Study on different baffle patterns' impact on heat transfer and fluid flow in shell-and-tube heat exchangers explores tri-flower baffle and pore plate baffle, demonstrating higher heat transfer coefficients and lower pressure drops compared to segmental baffle configurations [10]. Analysis of dead zones in trefoil-baffle heat exchangers reveals significant volume fractions near shell walls and baffles, proposing optimized tube layouts to reduce dead zone volume fractions and enhance overall heat exchanger performance [11]. Review of heat transfer strategies in concentric pipe heat exchangers focuses on double and triple concentric pipe configurations, analyzing heat transfer enhancement and flow characteristics. Insights gained aim to guide future research and applications in industries utilizing concentric pipe heat exchangers [12]. Study on efficient fluid heating and cooling techniques, including corrugated absorber plates and jet impingement for solar air heaters, highlights the need for comprehensive research on diverse jet configurations. The review provides essential insights into optimal roughened geometries and parameters for enhanced heat transfer, benefiting researchers and technical professionals [13]. Investigation of ladder helical, orifice, and segmental baffles in power plant feedwater heaters and U-tube heat exchangers assesses overall and shell-side heat transfer coefficients and pressure drop. Results indicate ladder helical baffles offer higher heat transfer coefficients, while orifice baffles demonstrate lower shell-side pressure drops compared to ladder helical and segmental schemes [14]. Numerical analysis of turbulent fluid flow through a two-dimensional horizontal rectangular channel, enhanced by transverse flat rectangular and V-shaped obstacles, aims to improve mixing and heat transfer by creating vortices within the channel [15].

2. HEAT EXCHANGER

Shell and tube heat exchangers (STHEs) are widely used in diverse industrial applications due to their robust design and efficient heat transfer capabilities. They consist of a series of tubes bundled within a cylindrical shell. One of the most common types is the fixed tube sheet heat exchanger, where the tube sheets are welded to the shell, fixing the tube bundle in place. This design is simple and economical but limits thermal expansion and contraction of the tubes. Floating head heat exchangers address this limitation by allowing one tube sheet to float, accommodating differential thermal expansion between the shell and tubes. This enhances thermal efficiency but adds complexity and cost. U-tube heat exchangers feature tubes bent in a U-shape within the shell, facilitating thermal expansion and simplifying tube bundle removal for maintenance. They are ideal for applications with high temperature differentials. Kettle reboilersuse a bundle of tubes immersed in a liquid-filled shell, typically employed in distillation processes to provide vaporization.

These variations highlight the adaptability of shell and tube heat exchangers across industries, offering solutions tailored to specific operational requirements and fluid handling capabilities.

NANOFLUID

Nanofluids represent a cutting-edge innovation in thermal engineering, blending conventional heat transfer fluids with nanoparticles to enhance their thermal conductivity and heat transfer capabilities. These nanoparticles, typically less than 100 nanometers in size, are dispersed in base fluids like water, ethylene glycol, or oils. The addition of nanoparticles, such as metals (e.g., copper, silver) or oxides (e.g., alumina, titanium dioxide), significantly improves thermal properties due to their high surface area-to-volume ratio and unique thermal conductivity characteristics. Nanofluids exhibit superior heat transfer rates compared to conventional fluids, making them promising candidates for enhancing the performance of heat exchangers, cooling systems, and thermal management in various industries. Research focuses on optimizing nanoparticle concentration and size to balance thermal enhancement with practical considerations like stability, viscosity, and cost-effectiveness. As nanotechnology continues to advance, nanofluids hold considerable potential for revolutionizing heat transfer applications, paving the way for more efficient and sustainable thermal management solutions.

3. INSERTS USED

Inserts in heat exchangers play a crucial role in enhancing heat transfer efficiency by altering fluid dynamics within the exchanger's tubes or channels. These inserts, which can be in the form of twisted tapes, helical coils, or wire coils, are strategically placed to induce turbulence and disrupt laminar flow patterns. By increasing fluid mixing and promoting heat exchange between the fluid and the heat transfer surface, inserts effectively improve the overall thermal performance of heat exchangers. Twisted tape inserts, for example, are known for their ability to generate swirl flow and intensify heat transfer rates, while helical coils enhance surface area and create secondary flow patterns that enhance convective heat transfer. The design and placement of inserts depend on specific operational requirements, such as flow rate, fluid properties, and desired heat transfer enhancement. Research continues to explore innovative insert designs and configurations to optimize heat exchanger performance across various industrial applications, ranging from HVAC systems to chemical processing and power generation.

3.1 Baffle Plates

Baffle plates are integral components within shell and tube heat exchangers (STHEs), strategically placed inside the shell to enhance heat transfer efficiency by promoting fluid turbulence. These plates are typically perforated or solid structures that direct the flow of fluids through the exchanger. Their primary function is to induce turbulence by creating obstacles that cause the fluid to change direction multiple times as it passes through the shell. This turbulence disrupts the formation of boundary layers and enhances the rate of heat transfer between the fluid inside the tubes and the fluid outside the tubes (shell-side fluid).

There are several types of baffle plates used in STHEs, each serving specific purposes based on flow characteristics and thermal requirements:

- **Segmental Baffles**: These are the most common type, consisting of semicircular cutouts that allow fluid to pass around the tubes, promoting mixing and turbulence.

- **Rod Baffles**: Straight rods or spacers placed across the shell to support the tube bundle and create turbulence by directing flow around the tubes.

- **Disc and Doughnut Baffles**: Circular discs or rings placed inside the shell to induce swirling flow patterns, enhancing heat transfer in specific applications.

- **Orifice Baffles**: Baffles with holes or slots that control flow distribution and velocity, useful in maintaining flow stability and preventing fluid bypass.

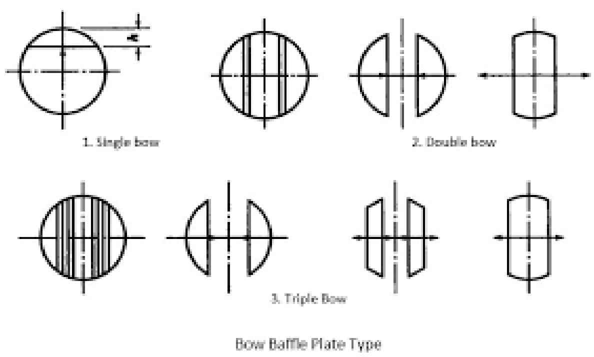

Fig. 1: Different Types of Baffles Plates [16]

4. 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):

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

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:

$\partial U/\partial t$ 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.

5. CONCLUSION

Based on the discussions on heat exchangers, including their various types, the role of inserts, nanofluids, and baffle plates, it is evident that heat transfer technology continues to advance with a focus on enhancing efficiency and performance across diverse industrial applications. Shell and tube heat exchangers (STHEs) stand out for their versatility and widespread use in industries such as power generation, HVAC systems, and chemical processing. The discussion highlighted different configurations like fixed tube sheet, floating head, U-tube, and kettle reboilers, each tailored to specific operational needs, demonstrating the adaptability of STHEs in managing thermal energy effectively. Inserts such as twisted tapes, helical coils, and wire coils were explored for their ability to disrupt laminar flow and promote turbulence, thereby improving heat transfer rates within heat exchangers. These inserts play a critical role in optimizing thermal performance by enhancing convective heat transfer without significantly increasing pressure drop.

Nanofluids emerged as a promising frontier in thermal engineering, leveraging nanoparticles to boost thermal conductivity and heat transfer properties of base fluids. The integration of nanoparticles like metals and oxides in fluids such as water and oils showed significant potential for enhancing heat exchanger efficiency, though challenges such as stability and cost-effectiveness remain under active research. Baffle plates were discussed as essential components that induce turbulence within STHEs, crucial for augmenting heat transfer between tube-side and shell-side fluids. Various types of baffle plates, including segmental, rod, disc, and orifice baffles, were highlighted for their roles in improving fluid mixing and heat transfer efficiency. In conclusion, ongoing advancements in heat exchanger technology continue to drive improvements in energy efficiency, operational reliability, and environmental sustainability across industries. Future research endeavors are likely to focus on further optimizing heat transfer processes through innovative designs, advanced materials, and computational modeling techniques, aiming to meet the evolving demands for efficient thermal management solutions in a rapidly changing global landscape.

6. REFERENCES

[1] Sohal, K. Kumar, R. Kumar, Heat transfer enhancement with channel surface roughness: a comprehensive review, Proc. Inst. Mech. Eng., Part C: J. Mech. Eng. Sci. Vol. 236 (11) (2022) 6308–6334 https://doi.org/10.1177/095440622110656.

[2] Sahel Djamel, Thermal performance assessment of a tubular heat exchanger fitted with flower baffles, J. Thermophys. Heat. Transf. 35 (4) (2021) 726–734 https:// doi.org/10.2514/1.T6208.

[3] H. Ameur, D. Sahel, Effect of some parameter on the thermal-hydraulic characteristics of a heat exchanger with corrugated walls, J. Mech. Energy Eng. 3 (1) (2019) 53–60 https://doi.org/10.30464/jmee.2019.3.1.53.

[4] Md Atiqur Rehman, Performance evaluation of turbulent circular heat exchanger with a novel flow deflector-type baffle plate, Journal of Engineering research, https://doi.org/10.1016/j.jer.2023.100105

[5] M. Tusar, K. Ahmed, M. Bhuiya, CFD study of heat transfer enhancement and fluid flow characteristics of laminar flow through tube with helical screw tape insert, Energy Procedia vol.160, (2019) 699–706, https://doi.org/10.1016/j.egypro.2019. 02.190

[6] S.R. Chaurasia, R.M. Sarviya, Comparative thermal hydraulic performance analysis on helical screw insert in tube with different number of strips in transition flow regime, Heat. Mass Transf. vol.57, (2021) 77–91, https://doi.org/10.1007/s00231- 020-02934-6

[7] D. Gonz´ alez-Ju´ arez, R. Herrero-Martín, J.P. Solano, Enhanced heat transfer and power dissipation in oscillatory-flow tubes with circular-orifice baffles: a numerical study, Appl. Therm. Eng. 141 (2018) 494–502, https://doi.org/10.1016/j.applthermaleng.2018.05.115.

[8] X. Wang, Y. Liang, Y. Sun, Z.C. Liu, W. Liu, Experimental and numerical investigation on shell-side performance of a double shell-pass rod baffle heat exchanger, Int. J. Heat Mass Tran. 132 (4) (2019) 631–642, https://doi.org/10.1016/j.ijheatmasstransfer.2018.12.046.

[9] N. Li, J. Chen, T. Cheng, J.J. Kleme, M. Zeng, Analysing thermal-hydraulic performance and energy efficiency of shell-and-tube heat exchangers with longitudinal flow based on experiment and numerical simulation, Energy 202 (2020), 117757, https://doi.org/10.1016/j.energy.2020.117757.

[10] J. Chen, N. Li, Y. Ding, J.J. Kleme, P.S. Varbanov, Q. Wang, M. Zeng, Experimental thermal-hydraulic performances of heat exchangers with different baffle patterns, Energy 205 (2020), 118066, https://doi.org/10.1016/j.energy.2020.118066.

[11] K. Wang, C.P. Bai, Y.Q. Wang, M.S. Liu, Flow dead zone analysis and structure optimization for the trefoil-baffle heat exchanger, Int. J. Therm. Sci. 140 (2019) 127–134, https://doi.org/10.1016/j.ijthermalsci.2019.02.044.

[12] H. Li, Y. Wang, Y. Han, W. Li, L. Yang, J. Guo, Y. Liu, J. Zhang, M. Zhang, F. Jiang, A comprehensive review of heat transfer enhancement and flow characteristics in the concentric pipe heat exchanger, Powder Technol. 397 (2022), 117037, https://doi.org/10.1016/j.powtec.2021.117037.

[13] R. Kumar, R. Nadda, S. Kumar, S. Saboor, C.A. Saleel, M. Abbas, A. Afzal, E. Linul, Convective heat transfer enhancement using impingement jets in channels and tubes: a comprehensive review, Alex. Eng. J. 70 (2023) 349–376, https://doi.org/10.1016/j.aej.2023.02.013.

[14] J. Su, Y. Chen, J. Wu, F. Fei, S. Yang, H. Gu, Experimental investigation on heat transfer performances in half-cylindrical shell space of different heat exchangers, Int. J. Heat Mass Tran. 189 (2022), 122684, https://doi.org/10.1016/j.ijheatmasstransfer.2022.122684.

[15] Y. Menni, A. Azzi, A.J. Chamkha, S. Harmand, Effect of wall-mounted V-baffle position in a turbulent flow through a channel Analysis of best configuration for optimal heat transfer, Int. J. Numer. Methods Heat Fluid Flow 29 (10) (2019) 3908–3937, https://doi.org/10.1108/HFF-06-2018-0270.

[16] https://www.jetvisionengineering.com/newsdetail/559.html