Enhancing Heat Transfer in Double-Pipe Heat Exchangers with Segmental Perforated Baffles: A Comprehensive Review

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Abstract: - *In many industrial applications where efficiency is the determining factor in maximum performance, heat exchangers are an absolute necessity. When building an efficient heat exchanger, it is important to take pressure drop, costs, and heat transfer rates into consideration. This study reviews eight studies on heat exchanger enhancements, with a focus on modifications intended to improve thermal performance. The study looks into segmental baffles with semi-circular perforations, twisted tapes with various geometries, and helical turbulators with holes. Segmental baffles improved heat transfer by as much as 80.6% with smaller perforations, while discontinuous twisted tapes outperformed continuous ones in terms of pressure drop and heat transfer. Examples of passive methods to enhance heat transfer without consuming extra energy are fins and baffles. Different forms of baffles were used in shell-and-tube heat exchangers, and the performance of segmental and aligned baffles was particularly good. Rectangular cut twisted tapes and helical turbulators with perforations achieved higher thermal performance factors, increasing the heat transfer coefficient by as much as 600%. The impact of holes in twisted tapes and obstacles in smooth air channels were also investigated. This comparison analysis shows the value of different techniques to enhancing heat exchanger performance and highlights the need to select enhancements that balance enhanced heat transfer with manageable pressure decreases.*

Keywords *Heat Exchangers, Thermal Performance Enhancement, Segmental Baffles, Perforated Baffles, Heat Transfer Rate.*

I. INTRODUCTION

These days, heat exchangers are used in numerous technical and industrial applications. Engineers have trouble designing an efficient heat exchanger, this is what they say. The reason for this is that, aside from pinpointing how well the asset will perform over time and its associated costs, heat transfer, pressure drop and effectiveness from all angles must also be examined which requires a lot of manual labor. Additionally, using methods to improve such transferring of heat leads to an increase in the drop of the pressure as well as to an increase in the pumping power required. It thus follows that some of these techniques aimed at enhancing the mode of conduction may negatively affect even the ideal wall that has both pressure drop rates and heat influx rates. Therefore caution should be taken when selecting the strategies used to improve heating systems. Many devices like electric power systems, computers, and vehicle engines among others are believed to always possess high appropriate rates of transferring heat [1].

Double pipe heat exchangers (DPHEs) are primarily used in the food, chemical, and oil and gas industries. In addition to being some of the most basic and practical heat exchangers, they also rank among the most commonly employed. A double-pipe heat exchanger, often called a tube within tube or double duct or simply as DPHE is one of the ways that can be used to increase passive heat transfer. In a double-pipe exchanger, one fluid flows through one pipe while another flows in the available space between the outer and inner pipes. It is regarded as one of those simplest yet practical heat exchanger designs – it's like concentric tubes. Based on the type of pipe used, double-pipe heat exchangers are classified into helical and straight coiled pipe configurations. The best type of heat exchangers to fit all purposes in many industries such as cooling applications are helical coiled double pipe heat exchangers due to their compact volume, high heat transfer rate and high performance. A double pipe heat exchanger may have counter-current or co-current flow. In most cases, double-pipe heat exchangers operate as countercurrent heat exchangers instead of shell-and-tube types. While designing double-pipe heat exchangers, the main factors taken into account are the friction factor and the heat transfer coefficient. Their four designing elements include return-bend housing, shell nozzles, tube nozzles and shell-to-tube closure [2].

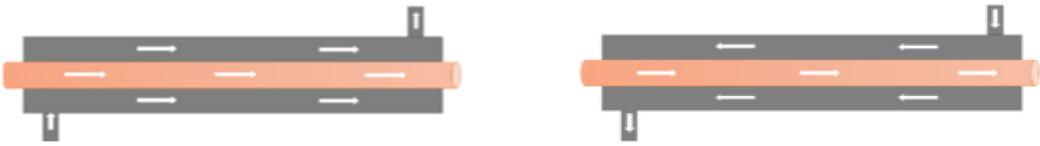

Figure 1: Double-pipe heat exchangers using (a) parallel flow and (b) counter flow [3]

A schematic diagram of a double-pipe heat exchanger is illustrated in Figure 1. This arrangement, representing a basic heat exchanger model, enables the hot and cold liquids to move either together or in reverse manner. The cold liquid travels through the annular space between the two pipes, while the warm fluid flows through the inside pipe. Flow can occur in two distinct configurations for these fluids; as indicated by Figure 1a, in the parallel flow configuration both fluids enter at one end and proceed in the same direction. On the contrary, as shown in Figure 1b, counter flow mode involves introducing them from opposite sides to flow against one another.

II. SEGMENTAL PERFORATED BAFFLES

Among the passive enhancement methods used to raise the thermal efficiency of heat exchangers used extensively in the chemical, biological, petrochemical, biomedical, and other sectors are baffles. The reason baffles are used so often in heat exchangers is that they generate turbulence and ensure proper mixing of the fluid layers by directing the shell-side fluid to travel back and forth across the internal tube. They also reduce dead patches and speed up the pace of heat transfer. In addition, they reduce thermal strains by minimizing tube-to-tube temperature variations in shell and tube heat exchangers. Besides, supporting the inner tubes avoids bending and vibration during operation. Since baffles are widely adopted, it is important to have knowledge about heat transfer and shell side fluid flow attributes [4].

The increasing application of computational fluid dynamics (CFD) in addition to heat transfer studies is a result of advancements in computer power and numerical modeling techniques. A baffled or unbaffled tubular heat exchanger is an option. Effective utilization of the heat transfer area is achieved by directing the flow inside the shell from the inlet to the outlet using baffles while facilitating effective fluid circulation on the shell side. In the double pipe heat exchanger, baffles are utilized for the purpose of providing support for tubes, maintaining an optimal velocity of fluid flow on the annulus side, and minimization of tube oscillations. In addition, baffles alter the direction of annulus side flow through the tube, increasing heat transfer coefficient and fluid speed simultaneously. The most common type is single segmental perforated baffles (SSPB), which enhance the heat transmission by allowing the annulus side fluid to zigzag in between tubes thus intensifying local mixing and turbulence[5]–[12].

Segmental perforated baffles are unique components that enhance fluid motion patterns and heat transfer effectiveness in heat exchangers, specifically shell-and-tube heat exchangers. These baffles, which typically look like fractions of circles or rings, are designed as segmented obstacles or divisions implanted within the shell side of a heat exchanger. Their distinguishing feature is their perforated arrangement comprising several different-shaped slots or holes like squares or circles. The main purpose of segmental perforated baffles is improving fluid flow turbulence. These baffles disrupt the laminar flow patterns and promote mixing, which ultimately increases the rate at which heat is transferred between hot and cold fluids by providing a more convoluted path for the flow. Furthermore, the holes enhance the efficiency of heat exchangers through preventing the fluid from bypassing heat transfer surfaces as a result of flow short-circuiting. More effective heat exchange can be obtained through introducing turbulence and better fluid mixing thus increasing the heat transfer coefficient. Perforated baffles that are segmented are commonly used in several industrial applications like HVAC systems, power generation, and chemical processing where increased heat transfer efficiency is critical. By optimizing fluid dynamics and maximizing the effectiveness of heat transfer, their innovative design greatly improves the performance of heat exchangers [13]–[16].

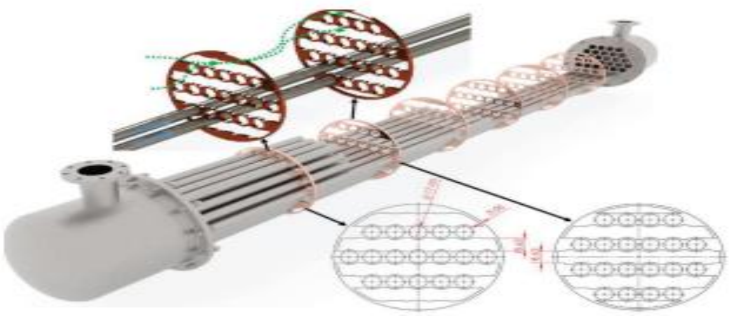

Figure 2: Diagram of Segmental Perforated Baffle [6]

As seen in Figure 2, the baffle has a segmental and perforated outline, with an incomplete form of a ring and other series of holes upon it. This enables the fluid to become more turbulent and mixes better thus allowing for more efficient heat transfer.

III. REVIEW OF PREVIOUS STUDIES

The following table summarizes eight researches that examine various designs and variations of heat exchangers to enhance their thermal functioning. To achieve better transfer of heat, various methods are employed in each study such as baffles, twisted tapes, perforations, and passive augmentation. For instance, in an air-water double pipe heat exchanger, the first study looks into segmental baffles with semi-circular perforations and observes that smaller-sized holes result into a much higher increase in heat transfer coefficient by as much as 80.6%. In the second research project, intermittent twisted tapes are compared to constant tapes; the latter exhibited improved heat exchange and drop on pressure performance compared to various levels of perforation geometries. The third research focuses on passive amplification methods including bafflers and fins that effectively increase heat transfer rates without necessitating any additional power requirements. In a separate study, it was found that segmental baffles had better performance than continuous helical counterparts at low flow rates, whereas shell-and-tube heat exchangers with different integrated baffle configurations revealed that aligning a baffle with a 30° cut would give maximum effectiveness. There were massive strides made within another study focused on helically-shaped turbulators containing small perforations in double pipe heat exchangers; the complete heat transfer coefficient went up to as much as six-fold (600%). In an evaluation of the relative performance of rectangular cut twisted tape (RCT) against that of conventional twisted tape (TT), it was observed that a certain ratio regarding the cut made in RCTs led to increased thermal performance parameters. A review of obstacles present in smooth air channels further proved that their various arrangements directly influenced both turbulence and heat transfer. In conclusion, it was found that when compared to those without one, twisted tapes with holes were more efficient in terms of heat transfer while minimizing pressure drops and the most effective configurations had circular perforations. On the whole, these investigations feature the different techniques employed in improving heat exchanger efficiency, specifically focusing on improving heat transmission coefficients, reducing friction and increasing thermal capacity.

Table 1: Comparative Analysis of Heat Exchanger Performance with Various Modifications and Configurations

Study	**Heat Exchanger Type**	**Modifications/Configurations**	**Key Findings**	**Performance Metrics**
Study 1 [17]	Air-Water Double Pipe HE	Segmental baffles with semi-circular perforations	Thermal performance improved with smaller perforations; average overall heat transfer coefficient increased by 29.7%, 62%, and 80.6% for 30, 25, and 20 mm diameters respectively.	Nusselt Number, Overall Heat Transfer Coefficient, Friction Factor, Thermal Performance Factor (TPF)
Study 2[18]	Double Pipe Heat	Continuous and	Discontinuous tapes	Heat Transfer

	Exchanger	Discontinuous Twisted Tapes (perforated and non-perforated)	showed better heat transfer and lower pressure drop compared to continuous ones. Perforated tapes further improved heat transfer and reduced pressure drop.	Enhancement, Pressure Drop Coefficient
Study 3 [19]	Double Pipe Heat Exchanger	Various passive augmentation techniques (fins, inserts, etc.)	Passive techniques enhance heat transfer without additional power requirements. Techniques include twisted tapes, baffles, and extended surfaces.	Heat Transfer Rate, Nusselt Number, Friction Factor
Study 4 [20]	Shell and Tube Heat Exchanger	Segmental Baffles, Align Baffles, Continuous Helical Baffles	AB-30 configuration had superior effectiveness with a 10.1% deviation from numerical results. Segmental baffles performed better at lower mass flow rates.	Heat Transfer Coefficient (HTC), Pressure Drop
Study 5 [21]	Double Pipe Heat Exchanger	Helical Turbulator with Perforations	Helical turbulator with small perforations showed significant improvement with up to 600% increase in heat transfer coefficient and 45% increase in thermal effectiveness.	Overall Heat Transfer Coefficient, Thermal Effectiveness
Study 6 [22]	Double Pipe Heat Exchanger	Rectangular Cut Twisted Tape (RCT) vs. Typical Twisted Tape (TT)	RCTs showed higher Nusselt number and thermal performance factor compared to TT. Best performance with cut depth ratio DR = 0.33 and width ratio WR = 0.15.	Nusselt Number, Friction Factor, Thermal Performance Factor
Study 7 [23]	Smooth Air Channels	Various obstacles (baffles, fins, ribs)	Obstacles used to increase turbulence and improve heat transfer. The study reviewed different configurations and their impact on heat transfer enhancement.	Heat Transfer Rate, Local Heat Transfer Coefficient
Study 8 [24]	Double Pipe Heat Exchanger	Continuous and Discontinuous Twisted Tapes with Perforations	Discontinuous tapes with various perforation geometries (triangular, square, rectangular, circular, diamond) showed varying improvements in heat transfer and pressure drop reduction. Circular perforations provided the best performance.	Heat Transfer Increase, Pressure Drop Reduction

IV. CONCLUSION

Discontinuous twisted-tapes with perforations plus segmental baffles with smaller holes are distinguished from the rest for the reason that they result in more substantial reduction of pressure drop as well as greater heat transfer performance. On the other hand, segmental perforated baffles, twisted tapes and helical turbulators create remarkable augmentation in heat transfer rates and thermal efficiency despite their costs in terms of pressure drop. To summaries, different methods for improving heat exchanger function have been demonstrated to yield unique contributions. Optimizing heat exchanger design requires careful trade-offs between these improvements that yield the intended effectiveness, and hence energy use and costs are minimized since everything is thought out. Therefore, this analysis provides relevant information on how to build better heat exchanger designs that can serve in various industries.

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