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Reviewing the Impact of Helical Baffles on Heat Exchanger Performance

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Abstract: This study investigates the thermal and hydraulic performance of helical baffles in shell-and-tube heat exchangers, comparing them to traditional segmental baffles. Helical baffles create a continuous helical flow path, enhancing heat transfer by increasing turbulence and reducing dead zones and fouling. Our research, incorporating numerical simulations and experimental data, confirms the superior efficiency of helical baffles. Key findings include a significant improvement in heat transfer coefficients and a reduction in pressure drop, leading to lower pumping power requirements. This makes helical baffles particularly suitable for high-efficiency applications in chemical processing and power generation, emphasizing their role in optimizing industrial heat exchanger performance.
Keywords: Baffles,Dead zones,Fluids, Heat exchanger, Helical baffles, Phase

I. INTRODUCTION

A heat exchanger is a device used to transfer heat between two or more fluids. The fluids can be single or two phase and, depending on the exchanger type, may be separated or in direct contact[1]. Devices involving energy sources such as nuclear fuel pins or fired heaters are not normally regarded as heat exchangers although many of the principles involved in their design are the same[2].In order to discuss heat exchangers it is necessary to provide some form of categorization. There are two approaches that are normally taken. The first considers the flow configuration within the heat exchanger, while the second is based on the classification of equipment type primarily by construction. Both are considered here.

A. Classifications of Heat Exchangers

1) *There are four Basic flow Configurations*

a) *Counter Flow:* In which the two fluids flow parallel to each other but in opposite directions

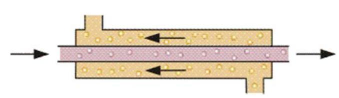

Figure 1 counter flow heat exchanger

b) *Cocurrent Flow:* The streams flow parallel to each other and in the same direction.

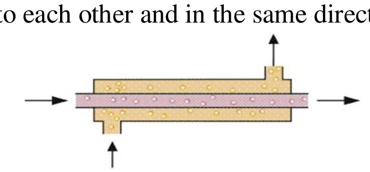

Figure 2 Parallel flow heat exchanger

c) *Crossflow:* Crossflow heat exchangers are intermediate in efficiency between countercurrent flow and parallel flow exchangers.

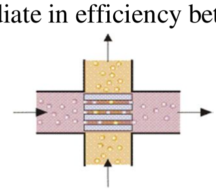

Figure 3 cross flow heat exchanger

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d) *Hybrids such as Cross Counterflow and Multi Pass Flow:* In industrial heat exchangers, hybrids of the above flow types are often found. Examples of these are combined crossflow/counterflow heat exchangers and multi pass flow heat exchangers.

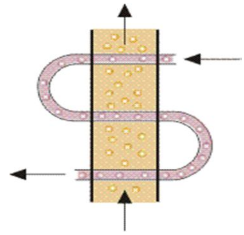

Figure 4 hybrid flow heat exchanger

2) *Classification of heat Exchangers by Construction*

The first level of classification is to divide heat exchanger types into recuperative or regenerative.

A Recuperative Heat Exchanger has separate flow paths for each fluid and fluids flow simultaneously through the exchanger exchanging heat across the wall separating the flow paths.

A Regenerative Heat Exchanger has a single flow path, which the hot and cold fluids alternately pass through.

B. Baffles

Baffles in heat exchangers are often used as a core element in any shell and tube heat exchanger design.[3]

1) *Baffles used for:*

a) *To support tubes in heat exchangers.*

Tubes must be supported at intervals not more than 1.5 m (5 ft), this mainly depends on the diameter of the tube and material of construction. The support intervals can be shorter where flow-induced vibrations occur in certain operations[4].Supporting the tubes using baffles also prevents mechanical vibrations that can result in tubes touching each other and giving rise to leakages and failures mainly near tube sheets[5]

b) *To enhance heat transfer by directing the flow through the shell in a desired pattern.*

This also increases the turbulence and reduces the stagnant pockets in the heat exchanger. We can also maintain a desired velocity by introducing baffles.[6]

2) *Types of baffles*

Segmental:- A Plate type

a) *Single segmental baffle*

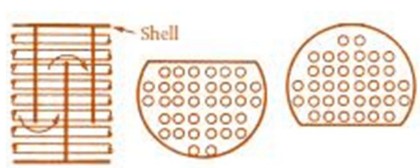

Figure 5 Single segmental baffle

b) *Double segmental baffle (Segmental and strip)*

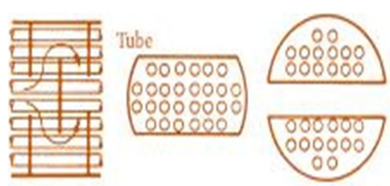

Figure 6 Double segmental baffle (Segmental and strip)

c) Triple segmental baffle

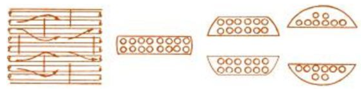

Figure 7 Triple segmental baffle

d) No tubes in window segmental baffles

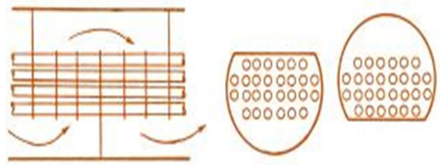

Figure 8 No tubes in window segmental baffles

e) Disk and Doughnut baffles

Disk and Doughnut baffles Has alternating outer rings and inner disks which directs the flow radially across the tube field. They all very effective in pressure drop to heat transfer conversion.[7]

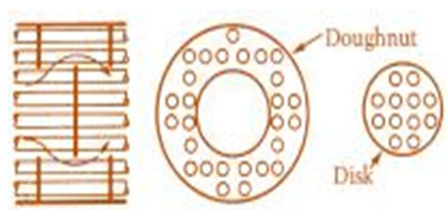

Figure 9 Disk and Doughnut baffles

f) Orifice Baffles

In this type of baffles the shell side fluid follows through the clearance between the tube outside diameter and the baffle hole diameter.[8]

Figure 10 Orifice baffles

g) Rod baffles

This type is metal rods rather than plate metal baffles. The type is use wherever a very low-pressure drop is required. Rod baffles also eliminates the tube vibrations which occur with plate baffles when fluid velocities are high. Rod baffles are mainly used when the pressure drop available is very low or there is a pressure drop issue.[9]

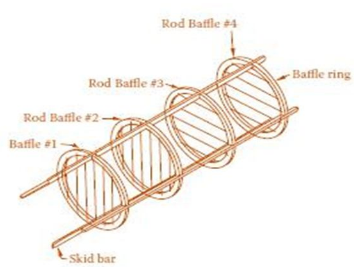

Figure 11 Rod baffles

C. *Industries use heat exchangers*

1) *Food, Dairy, and Beverage Applications*

Heat exchangers reduce or eliminate microbials to make products safe for consumption and to prevent spoilage. Heat exchangers also heat or cool products during a variety of processing stages, including filling, drying, and concentration[10].To meet processing requirements for products of varying viscosities, heat exchangers use innovative designs to maximize efficiency. For example, plate heat exchanger technology is vital to maintaining the exact combination of temperature and holding time in a variety of applications:

a) Milk and cheese milk pasteurization
b) Ultra-high temperature sterilization
c) Beverage and energy drink pasteurization
d) Standard and pulpy juice pasteurization
e) Beer wort heating and beer cooling
f) Liquid egg processing
g) Bottled water treatment
h) Soups, sauces, and starch heating
i) Ketchup and mustard heating and cooling

2) *Pharmaceutical applications*

Pharmaceutical applications require systems that maintain precise temperatures for specific durations to ensure product safety and integrity[13]. Heat exchangers are an effective method of thermal control in a variety pharmaceutical processes:

a) Water-for-injection Temperature control for purified water
b) Cosmetic solutions
c) Pharmaceutical combining and mixing
d) In all industries where heat exchangers are at work, current technologies have several essential functions: Maintaining consistent temperatures for pasteurization
e) Heating cleaning fluids that remove residues from systems components
f) Transferring heat without contaminating heated fluids
g) Saving energy by re-using heated fluids to heat fluids in repeatable cycles
h) Heating water for efficient cleaning-in-place (CIP)
i) Inducing turbulence for self-CIP

II. LITERATURE REVIEW

Mohsen Amini et al explores the thermal performance of shell-and-tube heat exchangers, in their study " Numerical investigation on effects of using segmented and helical tube fins on thermal performance and efficiency of a shell and tube heat exchanger", focusing on the effects of using segmented and helical tube fins. This study fills that gap by examining the impact of fin pitch, height, and design (segmented vs. helical) on the overall thermal performance using numerical methods and CFD simulations.They concluded that using segmented and helical tube fins in a shell-and-tube heat exchanger significantly enhances its thermal performance and efficiency. Helical fins were found to increase efficiency by 9.5%, while segmented fins increased it by 6%.[14]

Y. Aruna Prasanthi et.al emphasies in their study “Design and Thermal Analysis of Segmental baffle and Helical baffle in Shell and Tube Heat Exchangers using Kern method that The modified Kern method effectively analyzes continuous helical baffle heat exchangers. This design offers superior heat transfer capabilities with lower pressure drop compared to traditional segmental baffles. By carefully selecting the helix angle, engineers can achieve a balance between maximizing heat transfer and minimizing pressure drop, ultimately leading to a more efficient heat exchange process. Selecting a 6-degree angle may be optimal for applications prioritizing heat transfer, but considerations should be made for the associated pressure drop increase.[15]

This study by Abdelkadera et al. conclusively demonstrates in their study “Thermal-Hydraulic Characteristics of Helical Baffle Shell-and-Tube Heat Exchangers” the influence of baffle type, angle, and fluid properties on shell-and-tube heat exchanger (STHX) performance. Helical baffles significantly outperform segmental designs, achieving superior heat transfer with lower pressure drops. The optimal baffle angle, balancing these factors, was found to be around 42.138 degrees based on the h/DP ratio. Additionally, the impact of mass flow rate and fluid properties was explored, revealing significant variations across different fluids. These findings emphasize the importance of considering baffle type, angle, mass flow rate, and fluid characteristics when designing STHXs. By optimizing these parameters, engineers can create highly efficient heat exchangers tailored to specific industrial applications, maximizing heat transfer while minimizing energy consumption.[16]

Ashish Sahu et.al Validated in their study "Comparative Analysis and Simulation of Helical & Segmented Baffles in Shell & Tube Heat Exchanger using CFD Method" CFD simulations confirm the dominance of helical baffles (HB) in shell-and-tube heat exchangers (STHXs) over segmental baffles (SG). At a tube velocity of 0.89 m/s, HB-STHXs achieved a remarkable 35-46% boost in heat transfer coefficients compared to SG-STHXs at the same Reynolds number. This translates to a 25-32% increase in overall heat transfer, maximizing thermal efficiency. Additionally, HB-STHXs demonstrated a significant 20-28% reduction in pressure drop, leading to lower pumping power needs. These improvements stem from the superior flow characteristics induced by the helical design. It promotes a more uniform and directed flow across the tube bundle, enhancing heat transfer. The longer flow path within the shell further contributes to efficient heat exchange. In conclusion, HB-STHXs emerge as the clear choice for STHX design, offering superior thermal-hydraulic performance through enhanced heat transfer and reduced pressure drop.[17]

The study by Eshwar Biradar et al. emphasizes the critical role of baffle design in optimizing the performance of shell-and-tube heat exchangers. Through simulations and a comprehensive literature review, it is determined that a heat exchanger with a 20-degree baffle inclination angle and a 25% baffle cut significantly outperforms configurations with 0-degree and 10-degree angles. This optimized design results in a 3% reduction in shell-side pressure drop and provides effective support for tube rows. Additionally, maintaining mass flow rates below 2 kg/s is recommended to ensure efficient operation. These findings highlight the intricate balance of design parameters, such as baffle angle, cut size, and mass flow rate, in enhancing heat transfer efficiency and reducing pressure drops[18].

The study by Yingshuang wang et.al investigated in their study "Experimental investigation of shell-and-tube heat exchanger with a new type of baffles" the influence of design factors on heat exchanger performance. The interplay between baffle configurations, materials, flow patterns, and other factors was explored. The research showed that baffle inclination angles, cut size, and mass flow rate significantly affect pressure drop and heat transfer efficiency. The flower baffle design exhibited a 50% lower Nusselt number but a 30% lower pressure drop compared to the segmental baffle design at the same Reynolds number.expand_more Notably, when considering both factors comprehensively, the flower baffle design demonstrated a 60% improvement in performance. This suggests that flower baffles can be a promising approach to enhancing heat transfer efficiency while reducing pressure drop in heat exchangers, leading to better energy efficiency.[19]

J Mahendran et al. introduced in their study "Experimental analysis of shell and tube heat exchanger using flower baffle plate configuration" that a shell-and-tube heat exchanger design with flower plate baffles, demonstrating its superior cooling efficiency compared to conventional models. A 3D computational fluid dynamics (CFD) model was used to investigate thermal-hydraulic performance, including temperature, pressure, and velocity distributions. The results validated the flower baffle plate design's effectiveness through numerical simulations and experimental verification. This innovative design offers a valuable alternative for engineering applications, enhancing heat exchanger performance. Advanced simulation tools like SolidWorks were instrumental in this analysis, providing new insights for industrial implementation.[20]

Yonghua You et al. proposed in their a new computer model for shell-and-tube heat exchangers. This model takes into account factors like tube placement and turbulence to simulate how fluids flow and transfer heat on the shell side. The model was validated with real-world experiments and showed that flower baffles improve heat exchanger performance. The model also revealed how the flow and heat transfer vary throughout the exchanger. Compared to traditional designs, flower baffles create better flow patterns and improve overall heat exchanger performance. This new model is a cost-effective way to predict how heat exchangers will behave and provides engineers with valuable insights to optimize their designs.[20]

This research by Ram kunwer et al. explores in their study "Comparison of selected shell and tube heat exchangers with segmental and helical baffles" that how different baffle designs impact the performance of shell and tube heat exchangers. They compared various configurations and found that segmented baffles (SB-30, SB-50) significantly outperform designs with no baffles at all. While numerical simulations suggested a special type (AB-30) might be even more effective, experiments showed segmented baffles remained a good choice with a slight performance difference (around 10%). The study also considered pressure drop, finding helical baffles to be more efficient than segmented ones under certain conditions. Overall, the research suggests segmented baffles are a cost-effective option due to their good performance and favorable Colburn factors, while helical baffles can be ideal for industrial applications where reducing pumping power is crucial.[21]

The study by Pranita Bichkar et al. explores in their study "Study of Shell and Tube Heat Exchanger with the Effect of Types of baffles" That how different baffle configurations affect the performance of shell and tube heat exchangers. It reveals that single segmental baffles lead to dead zones and higher pressure drops, which can be improved by using double segmental baffles. However, helical baffles are the most effective, as they eliminate dead zones, reduce pressure drops, and lower pumping power, resulting in enhanced thermal efficiency. The benefits of helical baffles are attributed to improved fluid flow paths and reduced operational costs.

The study's findings are validated through experimental results, supporting the use of helical baffles to optimize heat exchanger performance in industrial applications.[22]

III. CONCLUSION

Helical baffles are superior to segmental baffles and other types of baffles in shell-and-tube heat exchangers. This is because helical baffles improve heat transfer performance and provide better flow distribution. According to research, helical baffles have been shown to outperform other baffle designs in terms of heat transfer and flow characteristics. For instance, one study found that helical baffles resulted in 1.8 times better heat transfer performance compared to traditional segmental baffles. Additionally, helical baffles have been found to provide more uniform flow and heat transfer rates, leading to improved overall performance. Overall, the advantages of helical baffles make them a better choice than segmental baffles or other baffle designs for shell-and-tube heat exchangers.

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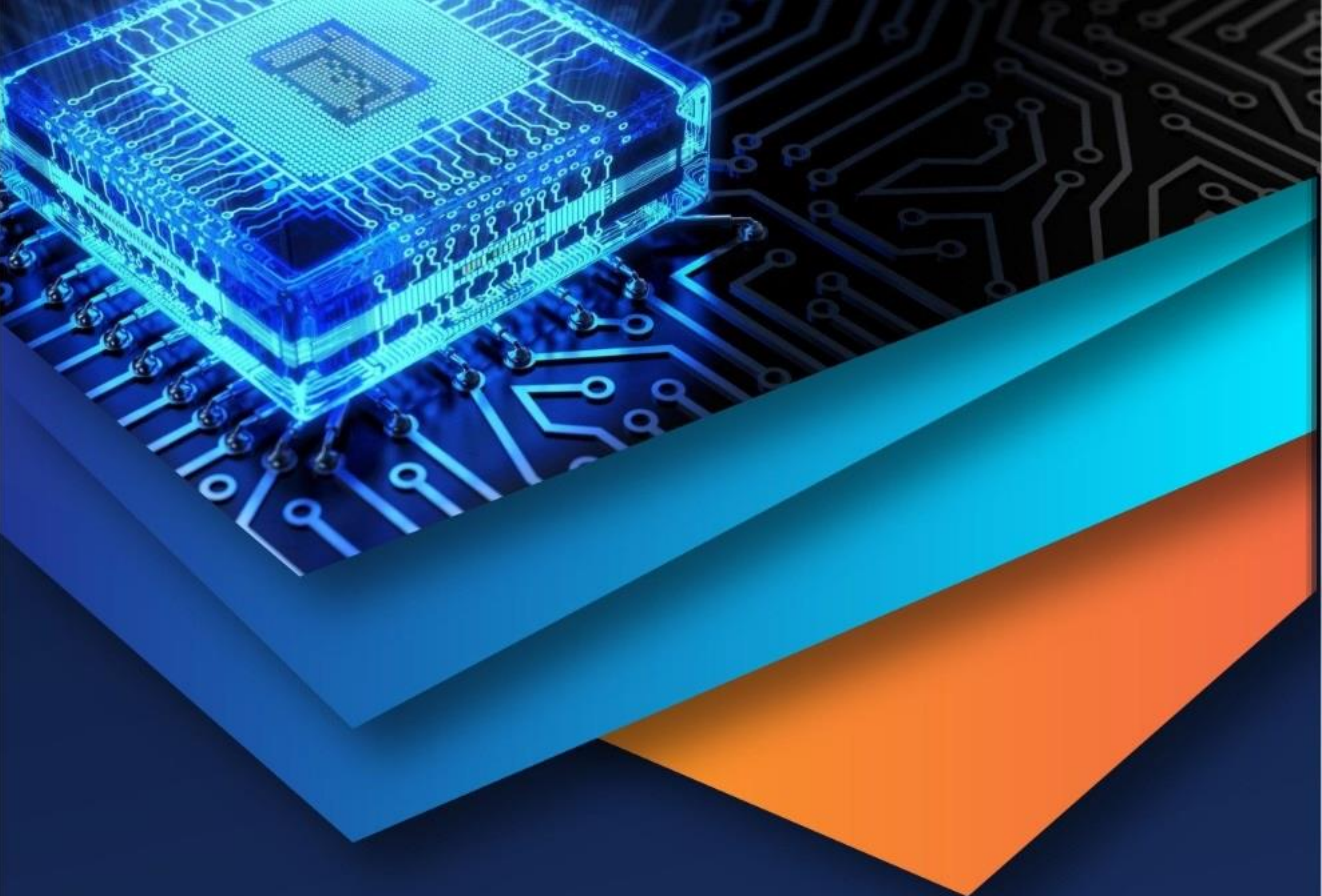

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