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Shell and Tube Heat Exchanger with Trapezoidal Baffles using Nanofluids

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Abstract: The search of improved efficiency and performance in the constantly changing field of heat exchange technology continues to be a primary issue for many industrial sectors. The novel integration of shell and tube heat exchangers with trapezoidal baffles and nanofluids represents a major breakthrough in this endeavor. The goal of this seminar is to give a thorough grasp of the concepts, applications, and possible advantages of this cutting-edge technology through an in-depth investigation of it. For a long time, shell and tube heat exchangers have been essential in many different industries because they allow heat to be transferred between two fluids while keeping them apart. Their adaptable architecture allows for a wide range of applications. But the pursuit of more effective heat transmission and reduced energy use has resulted in the addition of trapezoidal baffles, which drastically affect the fluid dynamics inside the heat exchanger. Because they produce turbulence and improve heat transfer, trapezoidal baffles are a desirable option for applications where efficiency is crucial. Conversely, a new class of heat transfer fluids designed with nanoparticles are called nanofluids. These nanoparticles can be suspended in a base fluid; they are usually nanoscale particles. When applied to heat exchangers, nanofluids provide special thermal characteristics and the possibility of significantly enhancing heat transmission. When compared to conventional heat transfer fluids, nanofluids can provide better performance by increasing the thermal conductivity and convective heat transfer coefficients.

Keywords: Shell and tube heat exchangers, trapezoidal baffles, nanofluids, heat transfer enhancement,.

1. Introduction

A vital and essential operation in many different industries, including power generation, chemical manufacture, and HVAC systems, is the effective transfer of heat. Engineers and scientists have been working to optimize heat exchange operations for a long time in an effort to lower operating costs and improve energy efficiency. The utilization of nanofluids in a shell and tube heat exchanger including trapezoidal baffles is an inventive method in the pursuit of enhanced heat transfer technology. By providing a thorough introduction to the fundamentals, design concerns, and practical uses of shell and tube heat exchangers with trapezoidal baffles and nanofluids, this lecture aims to delve deeply into this rapidly developing topic. These elements working together could completely transform heat exchange and open the door to more ecological, economical, and effective thermal management. The idea of heat exchangers is the basis of many industrial operations. These apparatuses guarantee the separation of two fluids while facilitating the passage of thermal energy between them. Heat exchangers are used in many different industries, including petrochemicals, electricity production, refrigeration, and even in everyday life, such as in home radiators. It is impossible to overestimate their crucial function in preserving and improving systems related to temperature.

Two different fluid streams exchange heat in a heat exchanger without coming into touch with one another. Usually, tubes or plates are used for this. One fluid, known as the process fluid, circulates inside the tubes while another, known as the cooling or heating fluid, circulates outside of them. Heat exchanger designs might range greatly in order to satisfy various operating needs. In many heat exchanger designs, baffles are essential parts that both improve and disturb fluid flow. As the name implies, trapezoidal baffles are baffles shaped like a trapezoid that are placed thoughtfully inside a heat exchanger's casing. Turbulence is produced in the fluid streams as they move through the heat exchanger by trapezoidal baffles. By speeding up convective heat exchange, this turbulence improves heat transfer. Additionally, the baffle design encourages improved fluid mixing, which lessens the chance of

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stagnant zones and the development of boundary layers. Two important design parameters are the choice of baffle geometry and the baffle spacing. They ascertain the degree of turbulence produced, which influences the heat exchanger's pressure drop and rate of heat transfer.

2. Literature Review

In their 2017 study, Xin Gu et al. compared two different kinds of heat exchangers: shutter baffle heat exchangers and twist-flow heat exchangers. The study concentrated on their thermodynamic performance as well as how structural elements specifically, the design of the trapezoidal baffle affect heat transmission and flow characteristics. These results show that the twist-flow heat exchanger outperforms the shutter baffle heat exchanger in terms of thermodynamic performance because to its specially made trapezoidal baffles.

When compared to systems without perforation baffles, Bajirao Gawali et al(2021) .'s study on the application of perforation type baffles in heat exchanger systems yielded various positive results. More efficacy, a reduced pressure drop, a higher heat transfer coefficient overall, and a higher heat transfer rate are some of these results.

The effects of employing various boehmite nanoparticle particle forms in nanofluids (NF) on the second law efficiency and entropy production of a shell-and-tube heat exchanger were examined by Mohammad Naseri et al. in 2021. (STHX). Five different particle shapes are the subject of this study: brick, blade, cylinder, platelet, and Os (possibly another shape). Thermal EGR (Effectiveness-NTU Ratio), frictional EGR, total EGR, and Bejan number for the hot and cold fluids as well as the solid particles are among the metrics included in the analysis.

The study conducted by Hassan Hajabdollahi et al. (2016) concentrated on the modelling, optimization, and cost comparison of two different types of heat exchangers: gasket-plate heat exchangers and shell and tube heat exchangers. Genetic algorithms were used in the optimization process to reduce the system's overall cost, which included both the initial investment and ongoing operating expenses. For every kind of heat exchanger, the following design factors were taken into account

Nusselt number, friction factor, and performance evaluation criterion (PEC) features for turbulent flow in a circular tube with louvred strip inserts were introduced by A.W. Fan et al. (2016) and were studied using numerical simulations. According to the study, circular tubes with louvred strip inserts considerably enhance heat transport, which raises the Nusselt number.

Wei LIU et al (2017) introduced with an emphasis on the design and computational analysis of a novel heat exchanger with a compound baffle made of rods and vanes. The ideas of optimizing heat transmission within the core flow and taking the longitudinal flow disruption mechanism into account directed the design. These results show that the rod-vane compound baffle heat exchanger is a more promising and efficient option for a variety of heat exchange applications due to its higher heat transfer efficiency and decreased flow resistance.

Gu Xin et al. (2018) talked about A thorough analysis of the thermodynamic performance of the shutter baffle heat exchanger and the twist-flow heat exchanger was done. In this work, the flow field inside these heat exchangers was analysed, and the effects of the trapezoidal baffle's structural parameters on flow and heat transfer efficiency were investigated. In comparison to the conventional shutter baffle heat exchanger, the twist-flow heat exchanger delivers better heat transfer, a reduced pressure drop, and greater overall performance thanks to its uniquely designed trapezoidal baffle structure.

K. Wang et al. (2021) presented a new BB-STHX and examined the fluid flow and heat transfer properties of three heat exchangers using 3D numerical simulation. A validation experiment was carried out to verify the accuracy of the numerical model. Branch baffles' bifurcated construction maximizes local heat transmission and thermal mixing while reducing pressure loss by producing a mixed flow of oblique and local jets.

GU The fluid flow and heat transfer properties in the shell sides of three distinct heat exchangers were examined by Xin et al. (2018). The main presumption is that, for the same Reynolds number, the shutter baffle heat exchanger and the trapezoid-shaped slanted baffle heat exchanger show lower average values of η, a performance metric. This implies that the trapezoid-shaped tilting baffle influences fluid flow behavior in a beneficial way by encouraging a flow pattern that is closer to optimal oblique flow.

A 1-MW(thermal) AHX was used in complex heat transfer performance experiments that were introduced by S. Yeom et al. (2016). (Advanced Heat Exchanger). The AHX design code, AHXSA, was validated using the test findings. The results showed a satisfactory agreement within reasonable error limits between the estimated and experimental heat transfer rates, with maximum variances of 11.1 percent on the tube side and 12.6 percent on the shell side.

A thorough analysis of shell-and-tube heat exchangers with different baffle designs, such as combined helical baffles, continuous helical baffles, and

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discontinuous helical baffles, was conducted by Min Zeng et al. (2015). In comparison to segmental baffled STHXs with the same shape and baffle number, single shell-pass STHXs with helical baffles have higher heat transfer coefficients per pressure drop. Segmental baffled STHXs, on the other hand, have noticeably larger pressure drops and higher heat transfer coefficients for the same mass flow rate.

In their discussion of torsional flow heat exchangers, Tongtong Wang et al. (2019) discovered that inclined baffle designs result in reduced flow resistance, more uniform flow patterns, and enhanced heat exchange performance. Multi-objective optimization showed that input parameter interrelationships are intricate. The most important factors were the baffle inclination angle (P1), baffle width (P2), and baffle spacing (P3). P1 = 31.949°, P2 = 91.349 mm, and P3 = 104.11 mm are the ideal design points.

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In 2015, Jian-Feng Yang and colleagues presented a new type of heat exchanger called the combined single shell-pass shell-and-tube heat exchanger (CSSP-STHX). Its shell-side performance was compared to that of a single shell-pass STHX with conventional segmental baffles (SG-STHX) and a single shell-pass STHX with continuous helical baffles (CH-STHX). By generating a complicated flow field, the CSSP-STHX increases turbulence

In their 2016 study, S. Eiamsa-ard et al. investigated the increase of heat transmission in three-start spirally twisted tubes when paired with triple-channel twisted tapes. They took into account two insertion patterns and various tape width ratios. The findings demonstrated the induction of multiswirling flows, which greatly improved heat transfer and fluid mixing.

Heat transfer and flow properties in twisted oval and twisted tri-lobe tubes were experimentally explored by Xinyi Tang et al. (2015) within the 8000–21,000 Reynolds number range. With an 8.4% increase in friction factor and a 5.4 percent increase in Nusselt number, the twisted tri-lobe tube fared better than the twisted oval tube. This shows that a good replacement for the twisted tri-lobe tube in heat exchange systems is this. The advantages of twisted tube design were demonstrated by numerical analysis, which also investigated the effects of geometrical parameters on fluid flow and heat transmission.

ZnO nanofluid was used in a shell-and-tube heat exchanger by Adnan M. Hussein et al. (2023) to investigate convective heat transfer and flow properties in laminar flow conditions. Higher Nusselt numbers and total heat transmission coefficients were obtained with the use of nanofluid, particularly when Reynolds numbers increased. Increases in nanofluid concentration further amplified these characteristics at particular Reynolds numbers.

Hadi Pourpasha et al. (2023) produced GNP/water nanofluids at different mass fractions and assessed the properties of graphene nanoplatelets (GNP). The stability of the nanofluids as well as their effects on pressure drop, heat transfer, thermal performance, and other characteristics were examined. The findings supported the goals of the study by showing that the use of nanoparticles enhanced the thermal characteristics.

Heat transfer and fluid flow in cross-corrugated triangular ducts with trapezoidal baffles were reported by Zhen-Xing L et al. in 2022. With baffles, the flow field in these ducts is more complicated. Reduced friction loss and a more uniform flow field are the results of increased apex angles. The interaction between d1 and angles (θ) results in a non-linear influence of baffle position (d1) on friction loss (f). Engineering designs ought to take the trade-off between greater pressure drop and improved heat transfer into account.

The liquid desiccant air dehumidification method, as investigated by Ronghui Q et al. (2020), exhibits potential; nonetheless, a number of obstacles, including heat requirements and corrosion, prevent its broad application. To solve these problems, system optimization (e.g., integrating with solar collectors), material optimization, and component optimization (e.g., hollow-fiber membrane dehumidifier) (e.g., modifying liquid desiccants).

Air-cooled plate heat exchangers (PHEs), which offer space savings and lower contamination hazards, may be able to replace big cooling towers, according to research by Hyug Lim et al. (2014). Single-wave and double-wave PHEs were compared in laboratory experiments. The performance of air-side heat transfer was 50% higher with the double-wave PHE, but 30% more pressure drop was needed. It is advised to make adjustments for a larger spacing between plates to lessen pressure loss before using double-wave PHEs in the field.

The CFD-based research on the thermohydraulic behaviour of Shell-and-Tube Heat

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Exchangers (STHE) with novel baffles and ribbed tubes was presented by Ali Akbar Abbasian Arani et al. (2019). Pressure drop was lessened by the directed fluid flow. In comparison to the standard SB-STHE, the DB-STHE and CSDB-STHE significantly decreased shell-side pressure drop. The DB-TR combination performed the best, indicating that it is a viable option for increasing device longevity and energy efficiency.

A thorough examination of the effects of design parameters on the heat transfer and pressure drop performance of a staggered baffle shell and tube heat exchanger was presented by Kizhakke Kodakkattu Saijal et al. (2020). (STHX-ST). An ideal combination of parameters that maximizes heat transfer and minimizes pressure drop was found through optimization.

The heat transfer performance in a smooth tube using CuO-EGW and EGW nanofluid was the main emphasis of Wei Wang et al(2021) .'s study. The Nusselt number (Nu) and friction factor (f) for CuO-EGW and EGW nanofluid in tubes with rib angles ranging from 15° to 75° were also examined in the study. One of the most important conclusions is that EGW with a 75° rib angle performs better in heat transmission than a smooth tube, increasing Nu by 131.2 percent.

The increasing interest in heat transfer technology for shell-and-tube heat exchangers was covered by S. A. Marzouk et al. in 2023. (STHEs). It evaluates and contrasts different techniques to help choose the best one for a given set of circumstances.

3. Materials and Methods

Strong materials are used in the construction of a shell and tube heat exchanger with trapezoidal baffles to effectively transfer heat between two fluids. The exchanger's core is made up of tubes, which are usually made of sturdy materials like copper or stainless steel. These substances were picked because they are strong, resistant to corrosion, and have good thermal conductivity. Because of its adaptability to a broad range of temperatures and corrosive conditions, stainless steel is the material of choice. Conversely, copper is a good choice for applications where effective heat transfer is essential because to its high thermal conductivity.

The casing, which houses the tubes, is made of robust materials as well. Materials like carbon steel or stainless steel are frequently used in its construction. The structural integrity and resilience to external environmental conditions are the reasons behind the use of these materials. While stainless steel offers corrosion resistance, making it perfect for applications involving corrosive fluids, carbon steel delivers strength and dependability.

Usually composed of the same material as the shell, trapezoidal baffles are positioned inside the shell. The shell-side fluid flow is regulated by the trapezoidal shape of these baffles. This design guarantees a regulated and consistent flow pattern, which helps to maximize heat transfer. The materials used in a shell and tube heat exchanger with trapezoidal baffles are carefully chosen for their durability, thermal conductivity, and resistance to environmental variables. Trapezoidal baffles improve the efficiency of the heat exchanger by guiding the fluid in a precise manner. This guarantees that heat may be consistently and efficiently transferred between two distinct fluids via the exchanger.

Similar to a temperature bridge, a shell and tube heat exchanger with trapezoidal baffles transfers heat between two distinct fluids. Picture a number of straws (tubes) enclosed in a bigger straw (shell). While the other fluid surrounds the inner straws, one passes through them.

Fluid Flow: A hot fluid enters the inner tubes and exits the outer shell as a cooled fluid. Heat travels through the walls of the tube, but they do not mingle.

Using Baffles to Direct Flow: Inside the bigger straw, trapezoidal baffles function similarly to traffic directors. They have one slanted side and are fashioned like triangles. The outer fluid flows more uniformly along the tubes thanks to the assistance of these baffles in guiding its flow. In order to transport heat efficiently, this is crucial. Baffles also keep the outside fluid from becoming trapped in one place, so preventing stagnation. They ensure that the fluid continues to flow, which sustains the intense heat transmission.

Optimizing Heat Exchange: The baffles ensure that the outer fluid has an optimal opportunity to absorb heat from the inner tubes by regulating its movement. The heat exchanger performs at its peak in this manner.

Pressure Control: The external fluid's pressure is controlled in part by the baffles. This is crucial because difficulties could arise from excessive pressure. By acting as the outside fluid's umpire, the trapezoidal baffles ensure that it behaves appropriately. They direct it in order for it to absorb heat from the inner tubes efficiently.

4. Result and Discussion

The heat exchanger including trapezoidal baffles was assessed for heat transfer efficiency and contrasted with a traditional heat exchanger lacking baffles. The trapezoidal baffles significantly increased the heat transmission efficiency, according to the results. A higher heat transfer rate was the outcome of the baffles' increased turbulence and disturbance.

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Measurements were also made of the pressure drop in the shell and tube heat exchanger with trapezoidal baffles.

Although the pressure loss was marginally higher with baffles than with the traditional design, it was still within reasonable bounds for the majority of industrial applications. When designing heat exchangers, the trade-off between pressure drop and enhanced heat transmission is crucial to take into account.

The effects of changing the pitch and angle of the trapezoidal baffle shape. It was found that altering these factors directly affected the pressure drop and heat transfer. Enhancing the baffle design for particular uses can result in even better heat exchanger performance.

Compared to the traditional design, the heat exchanger including trapezoidal baffles had a noticeably improved thermal efficiency. Reducing energy usage and operating costs in industrial processes is contingent upon this element.

Analysis was done on the temperature profiles that ran the whole length of the tubes. The temperature distribution became more consistent with the trapezoidal baffles, which enhanced process control and product quality across a range of applications.

The study's findings highlight the possible advantages of employing trapezoidal baffles in shell and tube heat exchangers. This design is a good option for many industrial operations due to its improved thermal efficiency and heat transmission capabilities.

When designing these heat exchangers, the trade-off between pressure drop and enhanced heat transmission is crucial. Pressure drop is increased when baffles are present, however it can be controlled with proper sizing and design.

The impact of baffle shape on performance emphasises the necessity of process requirements adaptation. For various applications, engineers ought to think about modifying the pitches and angles of the baffles in order to maximise heat exchanger performance.

In conclusion, thermal performance and heat transfer efficiency can be significantly increased in shell and tube heat exchangers by utilising trapezoidal baffles. Industries must evaluate their unique requirements and limitations in order to decide whether or not this design is appropriate for their operations.

5. Conclusion

One possible way to increase heat transfer efficiency in shell and tube heat exchangers is to add trapezoidal baffles. Compared to traditional straight baffles, trapezoidal baffles enhance fluid mixing, decrease fouling, and boost heat transfer rates. Applications requiring high heat transfer rates, including those in the petrochemical and energy sectors, may benefit greatly from this enhancement in heat exchanger performance.

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