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Thermal Analysis for the Optimal Design of Shell and Tube Heat Exchanger

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ABSTRACT-

The Paper, " Thermal Analysis for the Optimal Design of Shell and Tube Heat Exchanger," delves into the complexities of shell and tube designs to enhance the efficiency of heat exchangers. ANSYS CFD serves as the guiding force in interpreting the language of heat and fluid dynamics, bridging the gap between simulations and real-world problems. The narrative unfolds a methodological journey emphasizing precision in aspects ranging from mesh refinement subtleties to determining boundary conditions. This work aims to provide insights addressing unmet needs within the sector and pioneering new frontiers by seamlessly integrating state-of-the-art thermal analysis with Computational Fluid Dynamics (CFD) simulations. Beyond a mere collection of scientific information, these pages serve as a compass for researchers and engineers, aiding them in unraveling the intricacies of heat exchange. The research article aspires to redefine efficiency through a human-centric exploration of thermal dynamics, guided by the compass of technology.

Keywords—SolidWorks, Ansys, Thermal analysis, Heat exchanger, Shell and Tube Heat Exchangers.

1. INTRODUCTION

In the ever-evolving landscape of industrial processes, the efficient transfer of heat stands as a critical element influencing performance, energy utilization, and overall system effectiveness. Heat exchangers, playing a pivotal role in this thermal management paradigm, have become indispensable components in a myriad of industries ranging from chemical and petrochemical to power generation and HVAC systems.

Among the diverse types of heat exchangers, the shell and tube heat exchanger has emerged as a preferred choice for numerous applications due to its inherent advantages in terms of versatility, robustness, and thermal efficiency. The design and optimization of such heat exchangers require a comprehensive understanding of the intricate interplay between fluid dynamics, heat transfer, and structural considerations. This research delves into the thermal and Computational Fluid Dynamics (CFD) analysis of shell and tube heat exchangers, aiming to unearth insights that contribute to their optimal design and enhanced performance.

As the demand for energy-efficient solutions continues to grow, the imperative to refine and innovate heat exchanger technologies becomes increasingly pronounced. Shell and tube heat exchangers, characterized by their distinctive architecture comprising a shell encasing multiple tubes, offer a compelling solution to the complex heat transfer challenges encountered in various industrial processes. This paper explores the unique attributes that render shell and tube heat exchangers superior to their counterparts, emphasizing their adaptability to diverse operating conditions, ease of maintenance, and ability to facilitate efficient heat exchange across different fluid mediums.

With an emphasis on both theoretical and practical aspects, this research endeavours to bridge the gap between traditional design methodologies and contemporary advancements in thermal and CFD analyses. By scrutinizing the intricacies of heat transfer mechanisms within shell and tube configurations, this study aspires to contribute valuable insights that can inform future advancements in the design and application of these heat exchangers, fostering innovation in industries reliant on precise temperature control and energy optimization. Through a systematic exploration of thermal and fluid dynamics phenomena, this research seeks to elevate the understanding of shell and tube heat exchangers, providing a foundation for their continued evolution as indispensable components in the realm of thermal management.

2. Literature Review

Prathamesh S. Tendulkar et. al. [1] discusses the designing of shell and tube heat exchangers with different baffle designs. By studying the velocity and temperature distribution of different designs it is concluded that proper baffle design gives an optimal performance of Shell Tube Heat Exchangers. Farel H. Napitupulu et. al. [2]conducted study to determine whether the oil temperature exits the shell and tube heat exchanger one shell and two tube pass, by calculating the effectiveness of cooling using water as a cooling agent. Effectiveness was studied in terms of fluid flow and it was found that cooling reduces oil temperature by up to 32.3%. R S Anand et. al. [3] deals with the modeling and analysis of mini shell and tube heat exchangers for low-temperature applications. From the results, it was found that it is possible to design a heat exchanger for the required range. Pranita Bichkar et. al. [4] For the effectiveness of shell and tube heat exchangers thermal performance and pressure drop are considered major factors. In this paper numeral simulations are carried out on different baffles and results were obtained in terms of pressure drop and overall efficiency. Ahmet Aydin et. al. [5]. Designed new heat exchanger with multi-segmental baffles has been designed and optimized by CFD analysis and compared with conventional heat exchangers. Ahmed Youcef et. Al. [6]. employs the finite volume method with the simple algorithm for a numerical study on forced convection in a heat exchanger with and without baffles. Ammar Ali Abd et. al. [7]. suggests considering a pull-through head with a triangular pitch for enhanced heat transfer in shell-and-tube heat exchangers while being cautious of increasing baffle spacing and cutting space. M.D.Rajkamal et. at. [8]. validates the heat transfer performance of a helical coiled heat exchanger using POCO HTC material in parallel flow. Results align well with experiments, indicating POCO HTC's superior heat conductivity compared to conventional materials like copper, suggesting its potential industrial replacement. Patricia Anne D. Cruz et. al. [9]. ANSYS Fluent simulations revealed a 48% heat transfer improvement in a CuO-water nanofluid heat exchanger at the highest particle loading, indicating enhanced efficiency and thermal profiles. RNSV. Ramakanth et. Al. [10]. The paper highlights CFD analyses' efficacy in predicting shell and tube heat exchanger performance using turbulence models like k-ε and K-ω in tools like CFX and FLUENT. Gurbir Singh et. al. [11]. uses CFD with the k-ε turbulence model to analyze a shell and tube heat exchanger, validating results with experiments and highlighting CFD's efficacy in optimizing design and predicting performance. Shubham Gupta et al. [12]. employs CFD with ANSYS Fluent to analyze four shell and tube heat exchanger designs, highlighting that baffles and rectangular fins enhance effectiveness compared to other configurations. Ravi Kumar Gupta et.al. [13]. explores tube and shell heat exchangers' diverse applications in industry, emphasizing their crucial role in efficient heat transfer. Using ANSYS simulations and materials like copper, steel, and aluminum, the study finds that copper outperforms, displaying superior effectiveness in temperature control and overall heat transfer compared to steel and aluminum. The insights gained contribute to optimizing tube and shell heat exchanger designs for enhanced performance in practical industrial settings. Aadil Ahmad Rather et.al.[14]. provides a brief overview of shell and tube heat exchangers (STHXs), emphasizing their widespread use in industrial cooling and heating. Efforts to enhance STHX performance, particularly through varying baffle types, have shown promising results. Researchers have explored various alterations, leaving room for future improvements. The focus on key parameters, such as baffles and tube diameter, has led to increased efficiency in STHXs. The study highlights the need for continued work to make these heat exchangers more economically viable and efficient. STEPHENRAJ.V et.al.[15]. focuses on optimizing heat transfer efficiency in heat exchangers through the implementation of a full baffle design and travel tube design, analyzed via CFD flow simulation. The project uses a multi-model optimization method to identify the optimal baffle and tube designs for maximum heat transfer rates. Notably, a CuO + Water coolant fluid is selected based on recent journals, leading to improved temperature drop results in the final analysis. The findings showcase a substantial reduction in working fluid temperature, highlighting the efficacy of the proposed heat exchanger modifications. Abdullah Khan et.al.[16]. delves into optimizing shell and tube heat exchangers through computational fluid dynamics (CFD) simulations and experimental analyses, utilizing both round and hexagonal tubes. The study establishes that hexagonal tubes enhance heat transfer efficiency by up to 13.5% and increase contact surface area by 31.8%. The findings underscore the direct proportionality between heat transfer rates, fluid velocity, and the number of tube turns. Additionally, hexagonal tubes contribute to increased turbulence and pressure drop, showcasing potential advancements in heat exchanger design for improved energy efficiency. Hajabdollahi et al. [17] presented a comparative study for optimization of shell and tube heat exchangers and indicate that a noticeable improvement in the total cost is possible. For the cost optimization nine design parameters in the case of shell and tube heat exchanger were considered: inner and outer diameter of the tube, number of tubes, number of tube pass, the ratio of tube pitch to tube diameter, tube arrangement, and baffle spacing ratio as well as baffle cut ratio. Wang et al. [18] investigated the methods for enhancing the heat transfer of a shell-and-tube heat exchanger. They found the methods to improve the capacity of heat exchanger through the installation of sealers in the shell-side, however at a cost in elevated pressure loss, although the benefit obtained from the capacity increase is much higher. They concluded that the sealers can be used in new heat exchangers or retrofitted into existing installations. The potential gain could be of benefit to many industries using shell-and-tube heat exchangers. Parikshit et al. [19] proposed a model in their paper to predict the shell side pressure drop of a shell and tube heat exchanger using the concept of Finite Element Method. Their model produced friction factors for pressure loss agreeable with those found in the literature. Vera-García et al. [20] proposed in their paper a simplified model for the study of shell-and-tubes heat exchangers. They performed several experiments for a shell and tube condenser and an evaporator used in refrigeration systems to validate their model and conclude that the proposed model constitutes a practical tool which can be easily used by designers, making it unnecessary to know the internal geometry of shell-and tubes HXs in order to obtain their behaviour in a full installation. Wang et al. [21] investigated the thermodynamics ICCPE 105-1 performances for tube banks in crossflow and for the shell sides of shell-and-tube heat exchangers and analysed the relation of fluid flow and heat transfer between them. Three types of STHXs with different structure baffles were selected to investigate the thermo-hydraulic performances for tube bundles in crossflow in the shell sides. Study on characteristics of heat transfer and fluid flow for tube banks in crossflow combining with the characteristics for tube bundles in the STHXs was carried out. Their results indicated that the incline degree of tube does not lead to obvious change on characteristics of fluid flow and heat transfer for fluid flowing across tube banks. Fettaka et al. [22] presented in their paper a multi-objective optimization of the heat transfer area and pumping power of a shell and tube heat exchanger to provide the designer with multiple Pareto-optimal solutions which capture the trade-off between the two objectives. They considered nine decision variables: tube layout pattern, number of tube passes, baffle spacing, baffle cut, tube-to-baffle diametrical clearance, shell-to baffle diametrical clearance, tube length, tube outer diameter, and tube wall thickness. Their results indicated that one can achieve a lower value of the heat transfer area and the pumping power as compared to the previously published values. Costa and Queiroz [23] presented in their paper a study about the design optimization of shell-and-tube heat exchangers. The formulated problem consists of the minimization of the thermal surface area for a certain service, involving discrete decision variables. The obtained results illustrate the capacity of their proposed approach to direct the optimization towards more effective designs, considering important limitations usually ignored in the literature. Raja et al. [24] presents in their paper an investigation of many objective (four-objective) optimization of shell and tube heat exchangers. They formed the many-objective optimization problem by considering maximization of effectiveness and minimization of total cost, pressure drop and number of entropy generation units of heat exchanger. Six design variables which include geometric parameters are considered for optimization. They found that the many objectives approach leads to more desirable design of shell and tube heat exchangers as compared to multi-objective approaches. Haitao et al. [25] established a shell-side heat transfer model was to reveal the effect of tube bundle arrangement for flooded shell-tube evaporator and validated it experimentally. Their simulation results agreed well with the experimental data with a deviation less than 15%. They proposed an optimization method for uneven configuration of the horizontal and vertical tube spaces and obtained the optimized tube spaces. According to their findings, the performance of the optimized heat exchanger showed over 10% higher heat transfer capacity than the original one. Abda et al. [26] investigated the effect of shell diameter and tube length on heat transfer coefficient and pressure drop for shell side with both triangular and square pitches. They concluded that as shell diameter increases the heat transfer coefficient and pressure drop increases and the pull through head with triangular pitch can be the best choice to increase heat transfer coefficient. Zhou et al. [27] proposed an accurate and simplified model for predicting temperature distribution in the shell-and-tube heat exchanger on the basis of the differential theory. According to the baffle arrangement and tube passes, they divided the heat exchanger into a number of elements with tube side current in series and shell side current in parallel and noted that the proposed model can be successfully used for all shell-and-tube heat exchangers with straight tube or U-tube types.

3. Methodology

A. Calculations

Inlet Temp (T1)	C	121
Outlet Temp (T2)	C	80
Flow Rate	kg/hr	10000
Heat Capacity (Cp)	Kj/kgC	2.1
Density	kg/m^3	750
Viscosity	mNs/m^2	0.34
Thermal Conductivity	W/mC	0.19

Table.1- Assumptions for Shell Side Hot Fluid

Inlet Temp (t1)	C	25
Outlet Temp (t2)	C	70
Heat Capacity (Cp)	Kj/kgC	4.2
Density	kg/m^3	995
Viscosity	mNs/m^2	0.37

Table.2- Assumptions for Tube Side Cold Fluid

Further, calculations are carried out using Kern’s method based on above assumptions

Heat Load	kW	233
Cooling Water Flow Rate	kg/s	3.7
LMTD	C	26

Table.3- Basic Calculations

Let us first consider 1 shell pass and 2 tube passes to do further calculations.

Fig no. 1: Standard dimensions for steel tubes

Tube OD (From Fig .)	mm	38
Tube ID (From Fig.)	mm	34.8
Tube Length	m	4.88
Actual Tube Length (L)	m	4.83
Area of One Tube (a)	m^2	0.576
Number of Tubes (Nt)		32

Table.4- Tube Calculations

It is generally recommended that Tube Pitch should be 1.25 times of Tube OD

Fig no. 2: Contants for bundle diameter calculations

Fig no. 3: Bundles Clearance

Pt (From Fig.2)		1.25
K1 (From Fig.2)		0.249
n1 (From Fig.2)		2.207
Bundle Diameter (Db)	mm	343
We are using split-ring floating head type		
Bundle Clearance (From Fig.3)	mm	68
Shell Diameter (Ds)	mm	411

Table.5- Shell Calculations

B. Design

Fig. 5 Model of Shell and tube heat exchanger

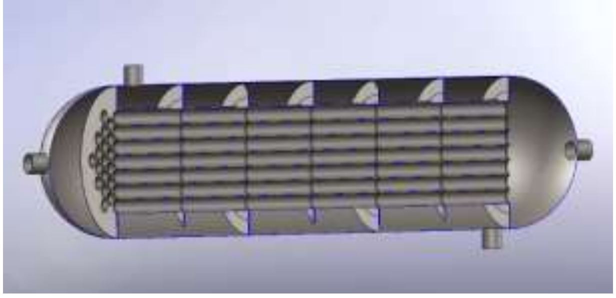

Fig.6 Sectional view of Shell and tube Heat Exchanger

C. Analysis

The outlet temperatures of both fluids fall within the desired range, indicating successful heat exchange. The hot fluid undergoes a temperature decrease from 120°C to 80°C, while the cold fluid experiences a temperature increase from 25°C to 70°C .

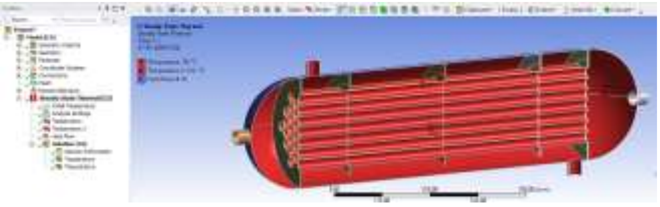

Fig.7 Boundary Conditions

Fig.8 Result

4. Results and Discussions

The FEA analysis indicates successful heat transfer within the heat exchanger system, with the temperatures of the shell and tubes falling within the desired range. This demonstrates effective thermal performance and highlights opportunities for optimization and further analysis to enhance efficiency and reliability.

The given scenario describes a heat exchanger system where a hot fluid with an inlet temperature of 120°C exchanges heat with a cold fluid having an inlet temperature of 25°C. The outlet temperatures of the hot and cold fluids are 80°C and 70°C, respectively. After conducting analysis using Finite Element Analysis (FEA) software, the temperatures of the shell and tubes are found to be within the range of 68-81°C.

5. Limitations and Future Scope

The future scope involves enhancing heat exchanger efficiency with advanced materials, optimizing design parameters, integrating renewable energy sources, examining heat exchangers made of different materials and employing AI for predictive modelling and fault diagnosis, alongside experimental validation for practical applicability.

6. Conclusion

The optimisation of heat transfer efficiency was accomplished through thorough design and engineering. Despite the tiny size of the design, performance was not compromised, ensuring maximum heat exchange within minimal space limits. The use of sturdy and corrosion-resistant materials for both the tubes and the shell increases longevity and reliability. Precise temperature control mechanisms were integrated, demonstrating a high degree of operational precision. In conclusion, the project produces a highly efficient, dependable, and painstakingly engineered shell and tube heat exchanger that meets the highest performance and durability standards.

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