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Design and Rating of STHE

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Abstract: *Shell and tube heat exchangers (STHE) are widely used in industrial applications due to their robust design and high thermal efficiency. The present study focuses on the thermal rating and performance evaluation of a shell and tube heat exchanger using the Bell-Delaware method. A detailed analytical model was developed to calculate key performance parameters such as heat duty, overall heat transfer coefficient, log mean temperature difference (LMTD), and pressure drop. The heat exchanger performance was evaluated under multiple operating conditions to investigate the influence of design and flow parameters on thermal efficiency. A parametric analysis was carried out by varying key factors such as flow configuration and geometric parameters, and their impact on heat transfer area, overall heat transfer coefficient, and overdesign percentage was studied. The results indicate that while all configurations satisfy the required heat duty, significant variation exists in thermal performance and design efficiency. Among the evaluated cases, one configuration demonstrated superior performance with a higher overall heat transfer coefficient and reduced overdesign, indicating a more optimized design. The study highlights the importance of systematic rating and optimization in improving heat exchanger performance and reducing material and operational costs. The findings of this work provide a practical approach for the design and optimization of shell and tube heat exchangers and can be extended to industrial applications for enhanced thermal performance.*

Keywords: Shell-and-tube heat exchanger, Bell–Delaware method, OpenMDAO, Optimization, Mechanical design, Thermal-hydraulic design, Catia V5

I. INTRODUCTION

Background and Introduction Heat exchangers are essential components in a wide range of industrial applications, including power plants, chemical processing, refrigeration, and oil and gas industries. Their primary function is to transfer heat between two fluids at different temperatures without direct mixing. Among various types, the shell and tube heat exchanger (STHE) is the most widely used due to its simple construction, mechanical reliability, and ability to operate under high pressure and temperature conditions. The thermal performance of a shell and tube heat exchanger depends on several parameters, including flow configuration, fluid properties, tube geometry, and baffle arrangement. Accurate prediction of heat transfer and pressure drop is crucial for efficient design and operation. Traditional design approaches are often based on empirical correlations; however, more refined methods such as the Bell-Delaware method provide improved accuracy by accounting for leakage streams, bypass effects, and non-ideal flow behavior on the shell side. In recent years, there has been increasing emphasis on optimizing heat exchanger performance to achieve higher efficiency with reduced material and operational costs. Researchers have focused on enhancing heat transfer rates while minimizing pressure drop and overdesign. Parametric studies involving variations in tube diameter, pitch, baffle spacing, and flow rates have been widely used to identify optimal configurations. In this study, a detailed thermal rating of a shell and tube heat exchanger is performed using the Bell-Delaware method. Key performance parameters such as heat duty, overall heat transfer coefficient, LMTD, and heat transfer area are evaluated. Multiple design cases are analyzed to understand the influence of operating and geometric parameters on exchanger performance. The objective of this work is to identify an optimal configuration that satisfies thermal requirements while minimizing overdesign and improving overall efficiency.Tubes Tubes are long, hollow cylindrical elements through which the tube-side fluid flows. They are commonly made from materials such as copper alloys, stainless steel, carbon steel, or titanium, depending on thermal conductivity, corrosion resistance, and cost considerations. Tube Sheets Tube sheets are

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thick metal plates used to hold the tubes in position and separate the shell-side and tube-side fluids. They are located at one or both ends of the heat exchanger and are drilled with precision holes to accommodate the tubes. Baffles Baffles are thin metal plates installed inside the shell to direct the shell-side fluid across the tube bundle rather than allowing it to flow straight through the shell. The primary functions of baffles are to increase turbulence, enhance heat-transfer rates, and provide mechanical support to the tubes. Common types of baffles include single-segmental, double-segmental, and disc-and-doughnut baffles. The spacing and cut of baffles significantly influence shell-side heat-transfer coefficient and pressure drop. Nozzles Nozzles are openings provided on the shell and channel heads for fluid entry and exit. Proper nozzle design ensures uniform flow distribution and minimises pressure losses at the inlet and outlet. The size and location of nozzles affect flow maldistribution and overall performance. Tie Rods and Spacers Tie rods and spacers are structural components used to maintain proper spacing between baffles and to hold the tube bundle assembly together. They ensure mechanical stability and prevent vibration-induced damage to the tubes during operation.

Thermal Design Parameters of Shell-and-Tube Heat Exchanger

The thermal performance of a shell-and-tube heat exchanger is governed by several key design parameters that determine its ability to transfer heat efficiently while operating within acceptable pressure-drop limits. One of the most important parameters is the heat duty, which represents the amount of heat to be transferred between the hot and cold fluids. The heat duty depends on mass flow rates, specific heat capacities, and temperature change of the fluids. The log mean temperature difference (LMTD) is used to represent the effective temperature driving force for heat transfer. It accounts for the temperature variation of both fluids along the length of the heat exchanger and plays a crucial role in determining the required heat-transfer area. The overall heat-transfer coefficient (U) combines the effects of tube-side and shell-side heat-transfer coefficients, tube wall resistance, and fouling resistance. A higher value of U indicates better thermal performance. The heat-transfer area is determined based on the required heat duty, overall heat-transfer coefficient, and LMTD. Increasing the surface area enhances heat transfer but also increases material cost and size. In addition to thermal considerations, pressure drop on both the tube side and shell side must be maintained within allowable limits to avoid excessive pumping power and operational inefficiency. These thermal design parameters form the theoretical basis for analytical calculations and OPTIMIZATION procedures applied in subsequent chapters.

Problem Statement

Shell and tube heat exchangers are extensively used in industrial applications; however, their design often involves conservative assumptions that lead to excessive heat transfer area and high overdesign. While such approaches ensure safe operation, they result in increased material cost, larger equipment size, and inefficient utilization of thermal capacity. Accurate prediction of thermal performance is further complicated by nonideal flow conditions on the shell side, including leakage streams, bypassing, and flow maldistribution. In the present work, it is observed that multiple design configurations can satisfy the required heat duty; however, significant variations exist in parameters such as overall heat transfer coefficient, available heat transfer area, and percentage overdesign. This raises the need for a systematic evaluation to identify the most efficient configuration rather than relying on a single conservative design. Therefore, the key problem addressed in this study is to evaluate and compare different design cases of a shell and tube heat exchanger using a detailed rating method, and to identify an optimized configuration that achieves the required thermal performance with minimum overdesign and improved efficiency.

Objectives and Scope

Objectives

The primary objective of this study is to perform the thermal rating and performance evaluation of a shell and tube heat exchanger using a systematic and analytical approach. The specific objectives are as follows:

- To evaluate the thermal performance of the shell and tube heat exchanger using the Bell-Delaware method.

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- To calculate key parameters such as heat duty, overall heat transfer coefficient, LMTD, and heat transfer area.
- To analyze the effect of different operating and geometric conditions on heat exchanger performance. • To compare multiple design cases based on parameters such as heat transfer efficiency and overdesign.
- To identify the most efficient configuration that satisfies the required heat duty with minimum overdesign.
- To ensure that the design meets practical engineering constraints such as thermal efficiency and reliability