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Optimizing thermal efficiency: Advancements in flat plate heat exchanger performance through baffle integration

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Abstract

Compact heat exchangers have been gaining popularity in many industrial applications. Various types of passive turbulising structures such as corrugations, protrusions and ribs are introduced in the flow path to increase the effective heat transfer area and the level of turbulence in the flow path. This study investigates the impact of introduction of baffles on the performance of PHEs in terms of flow characteristics, pressure drop, and heat transfer. Two distinct types of baffle structures, namely wedge and aerofoil configurations, were introduced at varying numbers - 1, 3, and 5. An extensive experimentation is conducted for a FPHE in a thermal power plant of 500×2MW and various flow and thermal parameters are measured. Computational Fluid Dynamics is utilized in this study to find the optimum baffle configuration. A detailed validation study is executed to obtain the correct computational algorithm, that is the right mesh count, optimum turbulence model, and precise numerical algorithm by comparing the numerical results with the available experimental results. Wedge- type baffles create increased turbulence and pressure drop, while aerofoil-type baffles minimize stagnation and exhibit lower pressure drop. Both baffle configurations lead to a substantial increase in heat transfer, with the 5-wedge-baffle setup showing the highest up to a 55% enhancement of Nusselt number. The Performance Evaluation Criterion (PEC) of wedge and aerofoil type is about 1.24 to 1.3 and 1.22 to 1.24 to that of conventional one respectively.

Introduction

PHEs are eminently being used in industries such as thermal power plants, nuclear plants, and pharmaceutical industries because of their compact size and low weight, superior thermal performance, and ease of cleaning. The PHE was first debuted in Germany in the 1870s [1]. The gasketed PHEs market was estimated at 3.1 billion globally in 2021 and is anticipated to grow to 5.1 billion by 2031. Due to COVID-19's peak, gasketed PHE system manufacturing was halted, which declined sales but performed well after their manufacture resumed due to increased GPHE use in medical, oil, gas, and food industries worldwide, the market will rise significantly in the next years [2]. Moreover, different experimental studies and industry testing reveal that PHE fouling is 5 to 20 times lower than shell and tube heat exchangers for the same workload and process circumstances in heating water solutions [3].

The broad requirements for research in heat exchangers include: How to design more compact heat exchangers, have higher thermal efficiency, achieve a balance between increased heat transfer and the resulting pressure drop, manufacturing techniques, fouling, and material problems, primarily in applications involving high temperatures and erratic operation. Different types of enhancement strategies, such as passive, active, and hybrid procedures, have been used [4].

In the pursuit of enhancing convective heat transfer efficiency, Amnart and Jedsadaratanachai [5] introduced double-V baffles to create a vortex and impinging flows, thereby disrupting the thermal boundary layer on the circular tube's isothermal surface. Meanwhile, Soliman et al. [6] conducted a numerical analysis involving different rib types within an FPHE. Their results highlighted that the rectangular ribs outperformed the others, exhibiting the highest thermal-hydraulic parameters, with values of 1.62 for the hot side and 1.84 for the cold air side.

Montazerifar et al. [7] for the first time designed novel fractal fins and analyzed oil/MWCNT turbulent flow at six angles of attack on the multi-stream plate-fin heat exchanger performance. The results showed that maximal flow impingement occurs at higher *Re* and that fluid mixing improves at maximum fractal fin angles of attack. Researchers studied the different types of inserts, that function as a vortex generator, by varying their sizes and shapes. These investigations demonstrate that heat transfer and pressure drop are increased while exergy losses are reduced by putting inserts into PHE channels [[8], [9], [10], [11], [12]]. N. K. Pandya et al. [13] also modified the Wilson Plot method for finding heat transfer coefficients.

Gherasim et al. [14] analyzed water flow in a CPHE, assessing Nusselt number, friction factor, and temperature distribution under laminar and turbulent conditions. Temperature measurements from the plate's exterior surface indicated the most significant gradient occurred at the side plate, with the highest and lowest temperatures at the hot and cold inlets, respectively. The undulations in the Pillow plate heat exchanger (PPHE) channels improve heat transfer by enhancing fluid boundary layer aeration, but further optimization is needed for PPHE to compete with CPHE. CFD simulations were done to examine the impact of the dimples. Piper et al. [15] modified the conventionally undulating surface with the addition of supplementary dimple features. Hence, fluids are better-mixed close to the wall because the dimples frequently disrupt the turbulent boundary layer. When compared to conventional PPHE, the novel channel improves thermo-hydraulic efficiency by 11.2%. And also, more importantly, this novelty enhances heat transfer and also reduces the pressure drop.

Fuji et al. [16] were the pioneers in examining the impact of various types of surface roughness on natural convection. Kang et al. [17] observed that equilateral triangular ducts with increased surface roughness exhibited improved heat transfer efficiency in their experimental studies, albeit at the expense of higher friction losses. Research focusing on the influence of surface roughness on PHEs has revealed a direct correlation between increased roughness and enhanced heat transfer, accompanied by a notable rise in pressure drop [[18], [19], [20], [21]].