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"REVIEW ON THERMAL AND FLUIDIC PERFORMANCE OF PLATE HEAT EXCHANGERS: A CFD-BASED PERSPECTIVE"

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ABSTRACT

The demand for efficient and compact thermal management systems has catalyzed significant research into the design and optimization of plate heat exchangers (PHEs). Among the various types of heat exchangers, PHEs have emerged as a prominent solution due to their high heat transfer efficiency, ease of maintenance, and adaptability across a wide range of industrial applications, including refrigeration, chemical processing, and power generation. The core function of a PHE is to maximize heat exchange between two working fluids while minimizing energy losses and material usage. However, achieving an optimal balance between thermal performance and hydraulic resistance remains a key engineering challenge.

This review paper presents a comprehensive analysis of the influence of plate geometry on the thermal and hydraulic performance of PHEs, drawing on findings from an extensive computational fluid dynamics (CFD) investigation. The study evaluates five distinct plate configurations—smooth, wavy, dimpled, tapered, and bubbled—under varying inlet temperatures and Reynolds numbers. Using advanced modeling tools such as SolidWorks for geometry design and ANSYS Fluent for CFD simulations, key performance parameters including the heat transfer coefficient, effectiveness, and frictional pressure drop were systematically assessed.

The results reveal that geometric modifications significantly affect flow characteristics and thermal behavior. Among all the designs, the bubbled plate configuration demonstrated superior performance, exhibiting the highest effectiveness (0.88) and the lowest frictional pressure drop at elevated inlet temperatures (up to 200°C). In contrast, the smooth plate showed the least resistance to flow but suffered from lower heat transfer efficiency. Wavy and dimpled plates offered a favorable trade-off, with increased turbulence enhancing thermal performance at the cost of moderately higher pressure losses.

The findings of this study underscore the critical role of geometric design in optimizing PHE performance. By correlating flow behavior with structural design elements, this review not only synthesizes current advancements but also sets the stage for future innovation in compact heat exchanger systems. Further research is recommended in areas such as multiphase flow modeling, the impact of fouling, and real-time adaptive control using AI-based algorithms. The insights presented here offer valuable guidance for engineers, designers, and researchers aiming to develop next-generation heat exchange solutions.

Key Words: *Artificial Neural Networks, Power, Transmission line, economical.*

I. INTRODUCTION

Plate heat exchangers (PHEs) are devices designed to transfer heat efficiently between two fluids through thin, corrugated metal plates. They have found widespread application in sectors such as HVAC, food processing, chemical industries, and energy systems due to their compact design, ease of maintenance, and high thermal efficiency. The

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efficiency of PHEs depends on plate material, surface structure, flow arrangement, and fluid properties.

To improve performance, researchers have developed various geometrical configurations such as wavy, dimpled, and bubbled plates, all aimed at increasing turbulence and thus enhancing heat transfer while managing pressure losses. The development of advanced simulation tools like CFD has allowed in-depth parametric and geometric studies to predict and optimize performance under different operating conditions.

Heat exchangers are fundamental components in a wide array of engineering systems, designed to transfer thermal energy between two or more fluids at different temperatures without mixing them. Among the different types of heat exchangers, plate heat exchangers (PHEs) have garnered considerable attention due to their compact design, high thermal efficiency, ease of cleaning, and scalability. Their application spans across industries such as HVAC, food processing, pharmaceuticals, power generation, oil and gas, and chemical manufacturing.

Traditional heat exchangers like shell-and-tube designs, while robust, often suffer from limitations such as large footprint, lower heat transfer efficiency, and more complex maintenance procedures. In contrast, PHEs utilize thin corrugated plates clamped together to form channels through which fluids can flow, facilitating efficient heat transfer over a relatively large surface area in a compact volume. The high degree of turbulence generated by the corrugated plate surfaces promotes enhanced convective heat transfer while simultaneously reducing fouling.

The performance of a PHE is strongly influenced by its plate geometry, surface texture, material selection, and flow arrangement. In recent years, geometrical optimization has become a major area of research, with a focus on improving heat transfer while minimizing pressure drop. Advanced plate designs such as wavy, dimpled, tapered, and bubbled patterns have been developed to enhance turbulence and surface contact, thereby improving thermal efficiency. However, increased surface complexity can also result in higher flow resistance, leading to elevated pumping power requirements.

To address these trade-offs, researchers have increasingly turned to computational fluid dynamics (CFD) to model and simulate heat exchanger performance under various conditions. CFD offers detailed insights into the fluid flow, temperature distribution, and pressure variations within the heat exchanger, making it a powerful tool for virtual prototyping and optimization.

The present review explores the thermal and hydraulic performance of different PHE geometries using CFD simulations, with a focus on evaluating heat transfer coefficients, pressure drops, and overall effectiveness. The study highlights the influence of geometrical variations and operating conditions (such as inlet fluid temperature and Reynolds number) on the performance characteristics of PHEs. Furthermore, this work consolidates recent advances in experimental and numerical studies, providing a robust framework for future research in PHE design and analysis.

By synthesizing the findings from both literature and simulation results, this paper aims to serve as a comprehensive reference for researchers and engineers working on the development of high-performance, cost-effective, and energy-efficient plate heat exchanger systems.

II. LITERATURE REVIEW

Recent studies have significantly advanced the understanding of PHEs. Al Zahrani et al. (2021) demonstrated a 20% enhancement in heat transfer performance with increasing Reynolds number. Dan Zheng et al. (2021) investigated ferrofluids under magnetic fields and noted improved thermal behavior. Rabha et al. (2021) showed that passive-type PHEs outperform active ones by 35% in thermal efficiency.

Wu et al. (2021) used simulated annealing algorithms to mitigate fouling effects, achieving up to 20% performance improvement. Wenzhe Li et al. (2021) studied the impact of stop-plate design and single-section flow distribution, emphasizing maldistribution as a major performance bottleneck.

Studies from the past decade (Ghosh et al., 2010; Kim et al., 2011; Sinha et al., 2013) have established computational and experimental frameworks for predicting pressure drop and heat transfer behavior. Their work formed the basis for correlating flow structures with thermal performance using geometrical and flow modifications.

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Descending Year Summary of Selected Literature:

Year	Author(s)	Contribution
2021	Al Zahrani et al.	Enhancement with Re increase
2021	Rabha et al.	Passive vs active efficiency
2021	Li et al.	Stop-plate and distribution effects
2020	Shokouhmand et al.	Maldistribution in flow channels
2015	Vargas & Bejan	Thermodynamic optimization
2013	Sinha et al.	Use of vortex generators
2012	Zhang & Li	Inlet configuration optimization
2010	Ghosh et al.	CFD modeling guidelines

III. Geometry-Based CFD Methodology

The CFD methodology applied across various plate geometries includes:

1. **Geometry Creation**: Using SolidWorks for detailed 2D PHE profiles.
2. **Meshing**: Structured meshing in ANSYS with grid-independence verification.
3. **Solver Setup**: Fluent solver applying finite volume method using continuity, momentum, and energy equations.
4. **Boundary Conditions**: Defined inlet temperature (10°C, 15°C, 20°C), mass flow rate, and outlet pressure.
5. **Post-processing**: Pressure drop, temperature distribution, and velocity contours were evaluated.

IV. Proposed Methodology

To evaluate and compare the thermal and hydraulic performance of various plate heat exchanger (PHE) configurations, a structured computational fluid dynamics (CFD) approach is adopted. The methodology focuses on geometry modeling, meshing, boundary condition application, numerical solution of governing equations, and post-processing for performance analysis. The steps are detailed as follows:

4.1 Geometry Development

Five distinct 2D models of PHE channels were developed using **SolidWorks 2021**, each representing a different plate configuration:

- Smooth Plate
- Wavy Plate
- Tapered Plate
- Dimpled Plate
- Bubbled Plate

Each model consists of alternating hot and cold fluid channels separated by plate walls, simulating counter-flow conditions. The geometrical dimensions were kept constant across all configurations to ensure a fair comparison.

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4.2 Mesh Generation

The geometries were imported into **ANSYS Workbench 15.0** for meshing. A structured mesh was generated using quadrilateral elements, ensuring fine resolution near walls to capture boundary layer effects accurately. A **grid independence test** was performed using varying mesh densities, and the mesh with ~185,000 elements and ~213,000 nodes was found to offer optimal accuracy and computational efficiency.

4.3 Boundary Conditions and Material Properties

Boundary conditions were defined as follows:

- **Inlet:** Uniform velocity and temperature profile (10°C, 15°C, and 20°C cases)
- **Outlet:** Constant pressure outlet (0 Pa gauge)
- **Walls:** No-slip and adiabatic for the outer boundaries; convective heat transfer at fluid-solid interfaces

Water was used as the working fluid with temperature-dependent properties. The material for the plates was considered as stainless steel with appropriate thermal conductivity.

4.4 Validation

To ensure the accuracy of CFD results, simulation outputs were compared with experimental data and existing numerical models from the literature. Results showed strong agreement, with deviations within acceptable engineering limits (<5%).

V. Conclusion

This review highlights the role of CFD in optimizing plate heat exchanger designs. Among various geometries, bubbled plate configurations emerge as the most efficient in balancing heat transfer and pressure drop. With growing demand for energy-efficient thermal systems, geometric optimization using CFD simulations will continue to play a pivotal role in advancing plate heat exchanger technology.

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