PROSIDING SNTTM XXIII 2025
Volume 23, No. 1, Tahun 2025, 9 Oktober 2025
e-ISSN 2623-0313
p-ISSN 3032-1972

Plate heat exchangers: A comprehensive review and future research directions

Emil Mahfuzi[a,1], **Azridjal Aziz**[b], **Rahmat Iman Mainil**[c]
[abc]Deparment of Mechanical Engineering, Universitas Riau, Pekanbaru, 28293
[1]Email korespondensi: emil.mahfuzi7120@grad.unri.ac.id

Abstract. Plate heat exchangers (PHEs) are indispensable devices in numerous industrial applications due to their high heat transfer efficiency, compact design, and operational flexibility. This article provides a comprehensive review of advancements in PHE technology, drawing upon recent research to consolidate current knowledge and identify future research directions. The review employs a thematic approach, categorizing research into key areas: plate geometry and configuration, fluid flow distribution and pressure drop characteristics, analytical and numerical modeling and simulation techniques, design optimization methodologies, the application of nanofluids and other advanced working fluids, and innovations in materials and configurations. A critical review of selected influential articles is also presented, highlighting their specific contributions and methodologies. The discussion reveals that continued advancements in plate design, sophisticated modeling tools such as CFD, and the exploration of novel fluids, such as nanofluids, are significantly enhancing PHE performance. However, challenges persist, particularly in accurately modeling two-phase flows, mitigating fouling, and developing advanced materials. Future research directions include integrating additive manufacturing for complex geometries, implementing smart and adaptive control systems, and placing greater emphasis on lifecycle sustainability. This review underscores the pivotal role of PHEs in driving energy efficiency and sustainability across various industrial sectors.

Keywords: Plate Heat Exchanger; Heat Transfer Enhancement; Design Optimization; Nanofluids; CFD; Fouling; Waste Heat Recovery

Received: 30 September 2025; **Presented:** 9 October 2025; **Publication:** 9 March 2026
DOI: https://doi.org/10.71452/b1k1jd19

INTRODUCTION

Plate heat exchangers (PHEs) are efficient heat transfer devices preferred in numerous sectors due to their small design, exceptional thermal performance, and operational versatility [1]. They have considerable benefits compared to conventional shell-and-tube exchangers, such as enhanced heat transfer coefficients, less fouling, and simplified maintenance, rendering them suitable for applications spanning HVAC, refrigeration, chemical processing, and waste heat recovery [2]; [3].

A PHE consists of corrugated metal plates that form complex flow channels. The corrugations generate turbulence, markedly improving heat transmission even at low Reynolds numbers [4]; [5]. The precise configuration of these corrugations—their geometry, chevron angle, and pressing depth—significantly affects the heat transmission and pressure drop attributes of the exchanger [6]; [7]. Researchers consistently examine these features to enhance PHE performance for particular applications [8].

Precise forecasting of PHE thermal-hydraulic performance is crucial for effective design. Many studies have concentrated on the development and validation of models for heat transfer and pressure drop in single-phase and two-phase flows [9]; [10]. Experimental research yields essential data for validating these models, including flow distribution and heat transfer coefficients [11]; [12]. Dynamic modeling and control solutions have been investigated to manage transient circumstances and improve stability [13].

Recent advances aim to further enhance PHE performance. Nanofluids represent a promising method for enhancing heat transmission owing to their superior thermophysical properties [14]; [15]; [16]. Additional improvements include the use of metal-foam-filled channels [17], the examination of end-plate effects [18], and the optimization of designs through sophisticated computational methods [9]; [19]. Research continues on the development and evaluation of correlations for boiling and condensation heat transfer in phase-change applications [20]; [21]. As companies emphasize energy efficiency and sustainability, PHEs will continue to be essential, with research dedicated to innovative designs and advanced control for various demanding applications [22]

METHODOLOGY

This review technique seeks to locate, assess, and synthesize pertinent information from the scientific literature regarding plate heat exchangers (PHEs). The review process was executed by evaluating the subsequent article selection criteria and analytical methodology:

Article Selection Criteria:

The selected publications focus on experimental, computational, and theoretical investigations of the design, performance, optimization, and use of PHEs. This review primarily covers the years 2000 to 2021, while also integrating earlier foundational works to provide a comprehensive background. The literature review was methodically performed across prominent scientific databases, including ScienceDirect and Google Scholar, utilizing a predetermined array of keywords such as "plate heat exchanger," "PHE design," "heat transfer," "pressure drop," "nanofluids PHE," "optimization," "modeling and simulation," and "novel configurations." Furthermore, review articles were used to obtain a comprehensive understanding of recent developments.

Analytical Approach:

Each chosen paper was thoroughly examined to extract essential information, encompassing its study objectives, methodology (experimental, numerical, or analytical), principal findings, and contributions to the discipline. The gathered information was methodically categorized into distinct categories, including plate geometry, fluid flow distribution, modeling, optimization, enhanced working fluids, and advances in materials and configurations. This thematic approach facilitated a thorough synthesis of knowledge, enabling the identification of key trends, research gaps, and potential avenues for future research.

RESULTS AND DISCUSSION

Plate Geometry and Configuration

Each chosen paper was thoroughly examined to extract essential information, encompassing its study objectives, methodology (experimental, numerical, or analytical), principal findings, and contributions to the discipline. The gathered information was methodically categorized into distinct categories, including plate geometry, fluid flow distribution, modeling, optimization, enhanced working fluids, and advances in materials and configurations. This thematic approach facilitated a thorough synthesis of knowledge, enabling the identification of key trends, research gaps, and potential avenues for future research.

Variations in Corrugation Patterns and Chevron Angles:

The corrugation design on the plates, particularly chevron or herringbone configurations, is crucial in generating the requisite turbulence to improve heat transfer coefficients. Various chevron angles (e.g., 30°, 45°, 60°) yield distinct flow characteristics and thermohydraulic performance. [4] Consult Figure 1, which presents a theoretical framework for forecasting the efficacy of chevron-type plate heat exchangers. Experimental investigations were conducted on heat transmission and pressure drop in PHEs with varying surface profiles, demonstrating the impact of profile alterations on performance. Research by [7] experimentally examined the single-phase convective heat transfer coefficient in a corrugated plate heat exchanger across several plate designs, underscoring the significance of plate design.

Influence of Plate Gaps and Channel Configurations:

The interstice between plates plays a critical role in influencing flow dynamics and thermal transmission. Research by [23] investigated heat transfer enhancement in a redesigned flat-plate heat exchanger, demonstrating that channel design advancements can optimize performance. Similarly, [24] conducted an experimental analysis comparing the performance of three distinct plates for gasketed plate heat exchangers, highlighting the impact of specific plate designs on overall performance, as illustrated in Figure 2. In addition, [18] examined the effect of end plates on thermal transfer in plate heat exchangers, suggesting that regions adjacent to the end plates may exhibit distinct heat transfer characteristics.

Flow Distribution and Pressure Drop

Non-uniform flow distribution within PHE channels can diminish heat transfer efficiency and substantially increase pressure drop, resulting in higher pumping costs. Comprehending and regulating flow distribution are essential for effective design.

Numerical and Experimental Analysis:

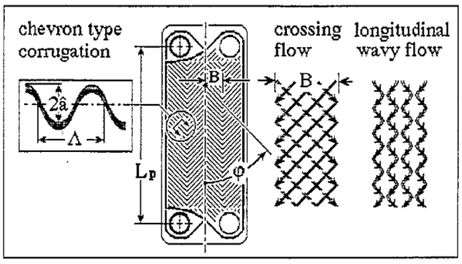
Numerous studies have employed Computational Fluid Dynamics (CFD) simulations and experiments to elucidate and quantify flow dispersion and pressure drop. Reference [11] conducted an experimental study on heat transfer and fluid dynamics in a plate heat exchanger, providing empirical data on flow parameters within the PHE. Similarly, [12] developed a three-dimensional numerical model of a plate heat exchanger, which is crucial for understanding the complex flow dynamics and pressure distribution within the device.

Heat Transfer and Pressure Drop Correlations:

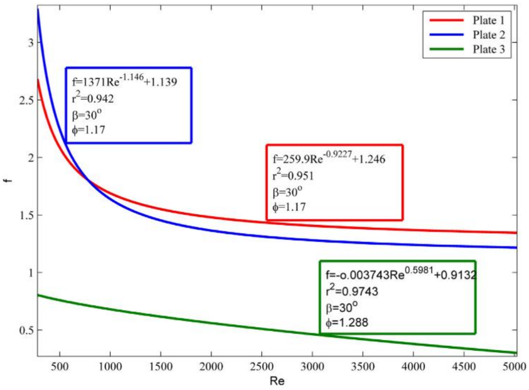
Empirical and semi-empirical correlations for heat transport and pressure drop are crucial for practical design. [3] presented a comprehensive analysis of the relationships between heat transmission and pressure drop during the processes of evaporation and condensation in plate heat exchangers. Likewise, [20] evaluated boiling and condensation heat transfer correlations for modeling plate heat exchangers, emphasizing the difficulties in predicting two-phase events. Research, including [21] and [25], specifically examined condensation and evaporation heat transfer, together with pressure drop, for the refrigerant R-134a in plate heat exchangers (PHEs). [10] also examined computational techniques for single- and two-phase flow in plate heat exchangers.

Models and Simulations

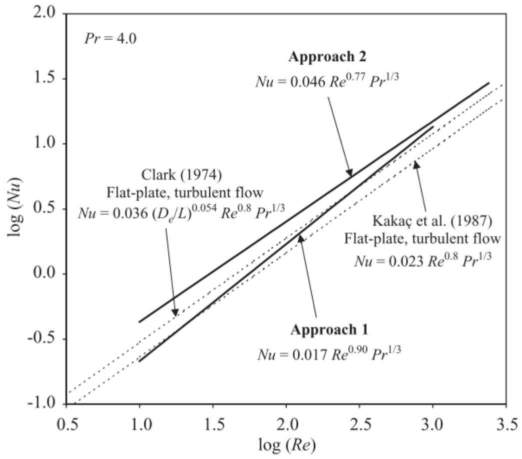
The creation of analytical models and numerical simulations is essential for forecasting PHE performance and refining designs without resorting to costly and time-intensive trials.



. [4] **Figure 1**: Chevron-type plate heat exchangers



[24] Figure 2: Experimental comparison of the performances of three different plates



[26] Figure 3 Model for PHEs with generalized configurations

Thermal and Hydraulic Models:

Diverse mathematical models have been created to forecast the overall heat transfer coefficient (U), pressure drop (ΔP), and effectiveness (ε) of plate heat exchangers (PHEs). [27] introduced a model for PHEs with generalized configurations, subsequently thermally confirmed by [26]; refer to Figure 3. These models facilitate the examination of PHE performance across diverse operating situations.

Dynamics and Control:

Comprehending PHE dynamics is essential for applications that require precise control. Reference [28] examined the dynamics of plate heat exchangers under flow fluctuations, whereas reference [13] explored their dynamic modeling and control, emphasizing the adaptability of PHEs to fluctuating load conditions.

Advanced CFD Simulations:

CFD simulations are increasingly employed to provide a comprehensive understanding of heat transfer and fluid flow phenomena within PHEs. [29] Performed an experimental and numerical investigation on heat transport in a plate heat exchanger, demonstrating strong concordance between the two methodologies.

DESIGN OPTIMIZATION

The optimization of PHE design seeks to maximize thermal efficiency while minimizing pressure loss, ensuring a compact size and reduced manufacturing expenses.

Optimization Methods:

Genetic algorithms and various optimization techniques have been extensively utilized in the analysis of heat exchangers. Reference [30] used a genetic algorithm to optimize the second law of thermodynamics for the design of a crossflow plate-fin heat exchanger, with the objective of minimizing entropy generation. Reference [31] examined the optimal design of plate heat exchangers, both with and without pressure drop criteria, emphasizing the adaptability of optimization goals. Reference [19] examined the optimal design of plate heat exchangers, highlighting the need to balance thermal performance and pressure drop.

Multi-Objective Functions:

Optimization of plate heat exchangers often involves multiple, and sometimes conflicting, objective functions. Reference [26] investigated the optimal design configuration of plate heat exchangers by considering various constraints and objectives. Similarly, [6] explored the optimal design of a plate heat exchanger with undulated surfaces, aiming to achieve improved performance under specific limitations.

Heat Exchanger Network Optimization:

Process heat exchangers are often integrated into extensive heat exchanger networks. Reference [32] examined the design and optimization of plate heat exchanger networks, demonstrating how PHEs can be effectively integrated into complex systems to achieve efficient energy recovery.

Nanofluids and Advanced Working Fluids

The application of nanofluids, which are suspensions of nanoparticles in a base fluid, has emerged as a promising approach to improving the heat transfer efficiency of PHEs.

Enhanced Heat Transfer Coefficient:

Experimental evidence established the influence of nanofluids on the thermophysical properties and heat-transfer characteristics of a plate heat exchanger, indicating substantial improvements. [33] examined the effectiveness of nanofluids as coolants in PHEs, concluding that nanofluids enhance performance. Several review studies, including [15], have examined the use of nanofluids in PHEs and emphasized their potential to improve performance. [34] evaluated the efficacy of plate heat exchangers utilizing various nanofluids, offering insights for nanofluid selection.

Thermophysical and Flow Characteristics:

Although nanofluids can improve heat transmission, studies also indicate a corresponding rise in viscosity and the possibility of greater pressure drop ([14]). [16] examined the efficacy of a plate heat exchanger with different nanofluids, demonstrating the compromise between improved heat transmission and elevated pressure drop.

Working Fluids for Specific Applications:

In addition to nanofluids, recent research has investigated the application of alternative advanced working fluids. Reference [35] analyzed the impact of supercritical Organic Rankine Cycle parameters on plate heat exchanger design, underscoring the importance of PHEs in renewable energy systems. Similarly, [17] conducted an experimental investigation into the single-phase heat transfer and pressure drop of refrigerants in a plate heat exchanger with channels filled with metal foam, demonstrating a novel approach to enhance performance.

Innovative Materials and Configurations

Advancements in PHE materials and configurations persist, with the objective of improving performance, durability, and specialized applications.

USE OF NEW MATERIALS:

Alongside conventional stainless steel, novel materials with superior thermal conductivity, enhanced corrosion resistance, and improved mechanical strength are currently under investigation. Although the provided publications do not specifically address these novel materials, the review by [1] extensively discusses recent advancements, which often encompass material innovations.

Micro and Flat Plate Configurations:

The configurations of PHEs are also undergoing continuous development. Reference [23] investigated heat transfer improvement in a modified flat plate heat exchanger, representing a variant of the conventional PHE design. Similarly, [22] provided a comprehensive analysis of heat transfer enhancement methods in

PHEs, covering advancements in geometry and configuration.

Additive Manufacturing (3D Printing): While none of the referenced articles explicitly address 3D printing for PHEs, this represents a rapidly emerging area of research. Additive manufacturing techniques enable the fabrication of intricate plate geometries that are unattainable with conventional methods, thereby enhancing efficiency and reducing unit size. This approach presents a promising direction for future investigation.

CRITICAL REVIEW OF SELECTED ARTICLES

This is a critical analysis of selected articles from your specified list, emphasizing their contributions and distinct viewpoints.

[14] The effects of nanofluid on thermophysical properties and heat transfer characteristics of a plate heat exchanger.

Main Objective: To experimentally investigate the effect of using nanofluids (specifically TiO_2/water and Al_2 O_3/water) on the thermophysical properties and heat transfer characteristics of a PHE.

Methodology: Experiments were conducted on a PHE by varying nanofluid concentration and flow rate. Data on heat transfer and pressure drop were subsequently collected and analyzed.

Key Findings: The utilization of nanofluids has been shown to significantly enhance the heat transfer coefficient, with improvements of up to 30% for TiO_2 nanofluids and 20% for Al_2O_3. However, an increase in viscosity and a corresponding reduction in pressure were also observed.

Strengths & Weaknesses: The strength of this research lies in its use of direct experimental data to demonstrate the potential of nanofluids. A possible limitation, however, is the lack of long-term analysis on nanofluid stability and fouling effects, which are critical for industrial applications.

Contribution: This study provides robust experimental evidence that nanofluids can improve the thermal performance of PHEs, thereby encouraging further research in this domain.

[26] Thermal model validation of plate heat exchangers with generalized configurations.

Main Objective: To authenticate a previously established thermal model for plate heat exchangers with generalized configurations utilizing experimental data.

Methodology: The thermal model presented in [27] was corroborated with experimental data acquired from commercial PHEs across diverse operating circumstances.

Key Findings: The model demonstrated good accuracy in predicting the thermal performance of PHEs across various configurations, confirming its reliability for design and analytical purposes.

Strengths & Weaknesses: The principal strength lies in the rigorous validation of the model against empirical data, providing a robust foundation for its application in design. Nonetheless, a limitation arises from the scope of the “generalized” configurations considered, which may not adequately capture the full range of possible PHE variants.

Contribution: Offers a validated and reliable modeling tool for PHE simulation and design, reducing the need for extensive experimentation.

[30] Second-Law-Based Optimization of Crossflow Plate-Fin Heat Exchanger Design Using a Genetic Algorithm

Main Objective: The study aimed to optimize the design of a crossflow plate-fin heat exchanger using an evolutionary method grounded in the second law of thermodynamics, with a specific focus on minimizing entropy generation.

Methodology: A thermodynamic model was developed and a genetic algorithm was employed to optimize the heat exchanger design, with the minimization of entropy production defined as the objective function.

Key Findings: Demonstrated that second law-based optimization can lead to more thermodynamically efficient designs, optimizing not only heat transfer but also overall energy utilization.

Strengths & Weaknesses: The use of an advanced optimization approach based on genetic algorithms and the second law of thermodynamics represents a major strength. However, this research focuses on plate-fin heat exchangers rather than standard PHEs, which differ in channel geometry, thereby limiting the direct generalizability of the findings to PHE applications.

Contribution: Shows the significant potential of thermodynamics-based optimization methods to improve the energy efficiency of heat exchanger designs.

[1] Plate heat exchangers: Recent advances.

Main Objective: To present a comprehensive review of recent advancements in PHE research and applications.

Methodology: A review article synthesizing findings from various research publications on different aspects of PHEs.

Key Findings: Highlighted the advantages of PHEs over other heat exchanger types, discussed new applications, and identified ongoing research areas such as heat transfer enhancement, fouling reduction, and the use of nanofluids.

Strengths & Weaknesses: The main strength of this work is its broad scope and systematic review, which provide a comprehensive overview of the field. However, a potential weakness is the limited in-depth technical detail on individual studies, which is inherent to its nature as a review.

Contribution: Serves as an important reference for researchers and practitioners to understand the state of the art and future directions of PHE research.

[2] Plate heat exchanger design for utilising waste heat from the drying process exhaust gases.

Main Objective: To design a PHE for waste heat utilization from drying process exhaust gases, emphasizing sustainability and energy efficiency aspects.

Methodology: Conducted a case study on PHE design for a specific application, considering exhaust gas characteristics and process requirements. Employed a modeling and optimization approach.

Key Findings: Demonstrated the feasibility and effectiveness of using PHEs for waste heat recovery in the industrial sector, contributing to energy efficiency and sustainability.

Strengths & Weaknesses: The focus on practical application and industrial relevance (waste heat recovery) is a key strength. It may be limited to a specific case study, meaning generalization to other applications requires further validation.

Contribution: Emphasizes the critical role of PHEs in sustainability efforts and industrial energy recovery.

CONCLUSION

Plate heat exchangers (PHEs) are essential elements in contemporary industry, with continuous research aimed at improving their efficiency, compactness, and dependability. Substantial advancements have been made in ideal plate shape, precise simulation modeling, nanofluid applications, and sophisticated design optimization techniques. PHEs have proven effective in various applications, such as waste heat recovery and renewable energy systems [2], [1].

Nonetheless, some significant challenges and prospective avenues for future research can be discerned:

More Accurate Two-Phase Flow Modeling:

While progress has been made [3], [20], predicting heat transfer and pressure drop in two-phase flows (e.g., evaporation and condensation) within PHEs remains complex. Further research is needed to develop more robust and generalized correlations and models for various refrigerants and operating conditions.

Fouling Reduction and Durability Enhancement:

Fouling, or the accumulation of deposits on plate surfaces, remains a critical issue that can significantly degrade PHE performance over time. Future research should focus on developing innovative anti-fouling strategies, anti-fouling surface materials, or more efficient and economical cleaning technologies.

Advanced Material Development:

Exploring new materials for plates and gaskets with improved corrosion resistance, higher mechanical strength, and enhanced thermal conductivity under extreme operating conditions will be highly valuable. In addition, the potential application of non-metallic materials for specific operational contexts also warrants further investigation.

Additive Manufacturing (3D Printing) for Complex Geometries:

The application of additive manufacturing in PHE plate production offers opportunities to develop highly complex and unconventional channel geometries (e.g., lattice structures and multi-scale designs). Such innovations have the potential to revolutionize heat transfer enhancement and pressure drop reduction; however, extensive research is still required in areas such as manufacturing processes, material compatibility, and performance validation.

Smart and Adaptive Control Systems:

Developing PHEs that can dynamically adapt to changing load conditions and working fluid characteristics through the integration of sensors, actuators, and intelligent control algorithms can improve overall operational efficiency and system reliability [13].

Lifecycle-Based Optimization and Sustainability:

Future research should increasingly consider sustainability aspects, such as lifecycle assessment (LCA) to evaluate the environmental impact of PHEs, the use of recycled materials, and design for ease of recycling at the end of their service life.

Applications in Extreme Environments:

Developing PHEs that can operate efficiently and reliably at extreme temperatures, pressures, or corrosive conditions will expand the scope of PHE applications to more challenging industrial sectors.

With continued innovation in materials, design, and manufacturing techniques, as well as a deeper understanding of heat transfer and fluid flow phenomena, plate heat exchangers will continue to play a central role in advancing energy efficiency and sustainability across various industrial sectors.

ACKNOWLEDGMENTS

The author gratefully acknowledges the guidance and support provided by Professor Azridjal Aziz, as well as the facilities made available by the University of Riau. Appreciation is also extended to colleagues and collaborators whose assistance and encouragement contributed significantly to the successful completion of this research.

AUTHOR CONTRIBUTIONS

Emil Mahfuzi conducted the literature review, developed the conceptual framework, performed the data analysis, and prepared the initial draft of the manuscript. Professor Azridjal Aziz supervised the research, contributed to the development of the methodology, provided critical revisions, and approved the final version of the manuscript.

FUNDING

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

REFERENCES

[1] M. M. Abu-Khader, “Plate heat exchangers: Recent advances,” *Renew. Sustain. Energy Rev.*, vol. 16, no. 4, hal. 1883–1891, 2012.

[2] O. Arsenyeva, J. J. Klemeš, P. Kapustenko, O. Fedorenko, S. Kusakov, dan D. Kobylnik, “Plate heat exchanger design for the utilisation of waste heat from exhaust gases of drying process,” *Energy*, vol. 233, 2021.

[3] R. Eldeeb, V. Aute, dan R. Radermacher, “A survey of correlations for heat transfer and pressure drop for evaporation and condensation in plate heat exchangers,” *Int. J. Refrig.*, vol. 65, hal. 12–26, 2016.

[4] H. Martin, “A theoretical approach to predict the performance of chevron-type plate heat exchangers,” *Chem. Eng. Process. Process Intensif.*, vol. 35, no. 4, hal. 301–310, 1996.

[5] A. Durmuş, H. Benli, I. Kurtbaş, dan H. Gül, “Investigation of heat transfer and pressure drop in plate heat exchangers having different surface profiles,” *Int. J. Heat Mass Transf.*, vol. 52, no. 5–6, hal. 1451–1457, 2009.

[6] A. G. Kanaris, A. A. Mouza, dan S. V. Paras, “Optimal design of a plate heat exchanger with undulated surfaces,” *Int. J. Therm. Sci.*, vol. 48, no. 6, hal. 1184–1195, 2009.

[7] T. S. Khan, M. S. Khan, M. C. Chyu, dan Z. H. Ayub, “Experimental investigation of single phase convective heat transfer coefficient in a corrugated plate heat exchanger for multiple plate configurations,” *Appl. Therm. Eng.*, vol. 30, no. 8–9, hal. 1058–1065, 2010.

[8] S. Al zahrani, M. S. Islam, dan S. C. Saha, “Heat transfer enhancement investigation in a novel flat plate heat exchanger,” *Int. J. Therm. Sci.*, vol. 161, no. November 2019, hal. 106763, 2021.

[9] J. A. W. Gut, R. Fernandes, J. M. Pinto, dan C. C. Tadini, “Thermal model validation of plate heat exchangers with generalized configurations,” *Chem. Eng. Sci.*, vol. 59, no. 21, hal. 4591–4600, 2004.

[10] B. Palm dan J. Claesson, “Plate heat exchangers: Calculation methods for singleand two-phase flow,” *Heat Transf. Eng.*, vol. 27, no. 4, hal. 88–98, 2006.

[11] I. Gherasim, M. Taws, N. Galanis, dan C. T. Nguyen, “Heat transfer and fluid flow in a plate heat exchanger part I. Experimental investigation,” *Int. J. Therm. Sci.*, vol. 50, no. 8, hal. 1492–1498, 2011.

[12] Y. N. Wang *et al.*, “A Study on 3D Numerical Model for Plate Heat Exchanger,” *Procedia Eng.*, vol. 174, hal. 188–194, 2017.

[13] S. K. Al-Dawery, A. M. Alrahawi, dan K. M. Al-Zobai, “Dynamic modeling and control of plate heat exchanger,” *Int. J. Heat Mass Transf.*, vol. 55, no. 23–24, hal. 6873–6880, 2012.

[14] F. S. Javadi *et al.*, “The effects of nanofluid on thermophysical properties and heat transfer characteristics of a plate heat exchanger,” *Int. Commun. Heat Mass Transf.*, vol. 44, hal. 58–63, 2013.

[15] V. Kumar, A. K. Tiwari, dan S. K. Ghosh, “Application of nanofluids in plate heat exchanger: A review,” *Energy Convers. Manag.*, vol. 105, hal. 1017–1036, 2015.

[16] D. Zheng, J. Wang, Z. Chen, J. Baleta, dan B. Sundén, “Performance analysis of a plate heat exchanger using various nanofluids,” *Int. J. Heat Mass Transf.*, vol. 158, 2020.

[17] G. Bamorovat Abadi, C. Moon, dan K. C. Kim, “Experimental study on single-phase heat transfer and pressure drop of refrigerants in a plate heat exchanger with metal-foam-filled channels,” *Appl. Therm. Eng.*, vol. 102, no. February 1999, hal. 423–431, 2016.

[18] S. Jin dan P. Hrnjak, “Effect of end plates on heat transfer of plate heat exchanger,” *Int. J. Heat Mass Transf.*, vol.

108, hal. 740–748, 2017.

[19] F. A. S. Mota, M. A. S. S. Ravagnani, dan E. P. Carvalho, “Optimal design of plate heat exchangers,” *Appl. Therm. Eng.*, vol. 63, no. 1, hal. 33–39, 2014.

[20] J. R. García-Cascales, F. Vera-García, J. M. Corberán-Salvador, dan J. Gonzálvez-Maciá, “Assessment of boiling and condensation heat transfer correlations in the modelling of plate heat exchangers,” *Int. J. Refrig.*, vol. 30, no. 6, hal. 1029–1041, 2007.

[21] Y. Y. Yan, H. C. Lio, dan T. F. Lin, “Condensation heat transfer and pressure drop of refrigerant R-134a in a plate heat exchanger,” *Int. J. Heat Mass Transf.*, vol. 42, no. 6, hal. 993–1006, 1999.

[22] J. Zhang, X. Zhu, M. E. Mondejar, dan F. Haglind, “A review of heat transfer enhancement techniques in plate heat exchangers,” *Renew. Sustain. Energy Rev.*, vol. 101, no. November 2018, hal. 305–328, 2019.

[23] S. Al zahrani, M. S. Islam, dan S. C. Saha, “Heat transfer enhancement of modified flat plate heat exchanger,” *Appl. Therm. Eng.*, vol. 186, no. December 2020, hal. 116533, 2021.

[24] C. Gulenoglu, F. Akturk, S. Aradag, N. Sezer Uzol, dan S. Kakac, “Experimental comparison of performances of three different plates for gasketed plate heat exchangers,” *Int. J. Therm. Sci.*, vol. 75, hal. 249–256, 2014.

[25] Y. Y. Yam, T. F. Lin, dan B. C. Yang, “Evaporation heat transfer and pressure drop of refrigerant R134a in a plate heat exchanger,” *Proc. ASME Turbo Expo*, vol. 121, no. February 1999, 1997.

[26] J. A. W. Gut dan J. M. Pinto, “Optimal configuration design for plate heat exchangers,” *Int. J. Heat Mass Transf.*, vol. 47, no. 22, hal. 4833–4848, 2004.

[27] J. A. W. Gut dan J. M. Pinto, “Modeling of plate heat exchangers with generalized configurations,” *Int. J. Heat Mass Transf.*, vol. 46, no. 14, hal. 2571–2585, 2003.

[28] A. K. Dwivedi dan S. K. Das, “Dynamics of plate heat exchangers subject to flow variations,” *Int. J. Heat Mass Transf.*, vol. 50, no. 13–14, hal. 2733–2743, 2007.

[29] F. C. C. Galeazzo, R. Y. Miura, J. A. W. Gut, dan C. C. Tadini, “Experimental and numerical heat transfer in a plate heat exchanger,” *Chem. Eng. Sci.*, vol. 61, no. 21, hal. 7133–7138, 2006.

[30] M. Mishra, P. K. Das, dan S. Sarangi, “Second law based optimisation of crossflow plate-fin heat exchanger design using genetic algorithm,” *Appl. Therm. Eng.*, vol. 29, no. 14–15, hal. 2983–2989, 2009.

[31] G. T. Polley, L. Wang, dan B. Sundén, “Optimal design of plate heat exchangers with and without pressure drop specification (By L. Wang and B. Sundén) [1] (multiple letters),” *Appl. Therm. Eng.*, vol. 23, no. 16, hal. 2147–2148, 2003.

[32] K. Xu, R. Smith, dan N. Zhang, *Design and optimization of plate heat exchanger networks*, vol. 40. Elsevier Masson SAS, 2017.

[33] M. N. Pantzali, A. A. Mouza, dan S. V. Paras, “Investigating the efficacy of nanofluids as coolants in plate heat exchangers (PHE),” *Chem. Eng. Sci.*, vol. 64, no. 14, hal. 3290–3300, 2009.

[34] A. K. Tiwari, P. Ghosh, dan J. Sarkar, “Performance comparison of the plate heat exchanger using different nanofluids,” *Exp. Therm. Fluid Sci.*, vol. 49, hal. 141–151, 2013.

[35] S. Karellas, A. Schuster, dan A. D. Leontaritis, “Influence of supercritical ORC parameters on plate heat exchanger design,” *Appl. Therm. Eng.*, vol. 33–34, no. 1, hal. 70–76, 2012.