



Heat Transfer Improvement in Plate Heat Exchangers via Corrugated Geometries - A Review

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Abstract—In this Review paper discuss on the heat transfer in plate heat exchangers (PHEs) through the implementation of corrugated geometries using ANSYS software. Plate heat exchangers are widely used in industries due to their high heat transfer efficiency and compact design. The performance of triangular, sinusoidal, and rectangular corrugation patterns was analyzed under various Reynolds numbers to understand their effect on flow behavior, heat transfer rate, and pressure drop. Computational simulations were conducted using ANSYS Fluent to model the fluid flow and thermal characteristics within the corrugated channels. The results demonstrate that corrugated geometries significantly improve heat transfer by inducing turbulence, promoting fluid mixing, and increasing the effective surface area. Among the tested configurations, rectangular corrugations exhibited the highest heat transfer enhancement, while triangular and sinusoidal patterns provided moderate improvements with lower pressure drop penalties. The study highlights the potential of geometric modifications in optimizing plate heat exchanger performance and provides insights for the design of energy-efficient thermal systems.

Keywords— Heat Transfer Enhancement, Plate Heat Exchanger (PHE), Triangular, Sinusoidal, Rectangular Channels.

I. INTRODUCTION

It has been recognized that plate heat exchangers possess many unique characteristics, which are capable of recovering heat efficiently at low temperature differentials (as low as 1°C) because of the high turbulence even at low velocities. Enhanced surfaces yield higher heat transfer coefficient when compared to unenhanced surfaces. A surface can basically be enhanced in two ways, either active enhancement which requires deployment of external power which is obviously high in operational and capital cost thus commercially unviable, and passive enhancement which involves adding extended surfaces (e.g. fins), or employing interrupted surfaces (e.g. corrugations). The plate surface geometry is characterized by corrugation profile, corrugation inclination angle corrugation pitch (P) and corrugation height (h). The enhancement of heat transfer between corrugated plates is directly related to these features, which provide increased effective heat transfer area, disruption and reattachment of boundary

layers, swirl or vortex flow generation, and small hydraulic diameter flow channels.

The plate heat exchangers are most economical and efficient type of heat exchanger in the market. Due to its low cost, easy maintenance, flexibility, and high thermal efficiency. Those mechanisms are associated with friction expenditure which increases the pressure loss, flow separation, and reattachment processes. As the channel with complicated passage is formed as a result of the arrangement of the two plates, the breakup and reattachment of boundary layers together with vortices flows occurring in the passage

are the most affective contributes to the high heat transfer efficiency. The corrugation patterns induces turbulent flows at very low velocity of flow, it not only achieves unmatched efficiency, but also creates a self-cleaning effect that reducing fouling on surface of a heat exchanger plate [1]. The most common surface pattern used is the corrugated design.

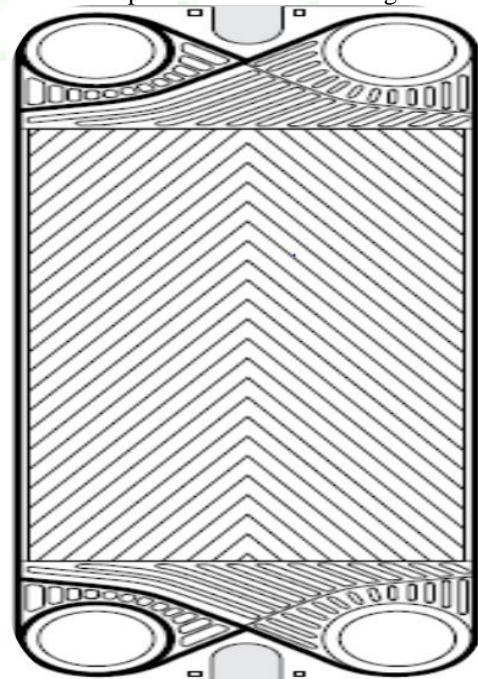


Fig. 1: Heat Exchanger Plates

Plate heat exchangers are usually designed to achieve turbulence across the total flow passage and increase heat transfer area in order to get the maximum possible heat transfer coefficient with the minimum pressure drop, and allow for reach close temperature difference. It means smaller heat transfer area, smaller size of heat exchangers, and sometimes less number of heat exchangers.

The corrugated plate heat exchangers have gasketed plates which are fixed between an upper carrying rod and a bottom guide rod. The plates are tightened and compressed to closed packing by means of tie bolts between a fixed frame part and a moveable frame part [1].

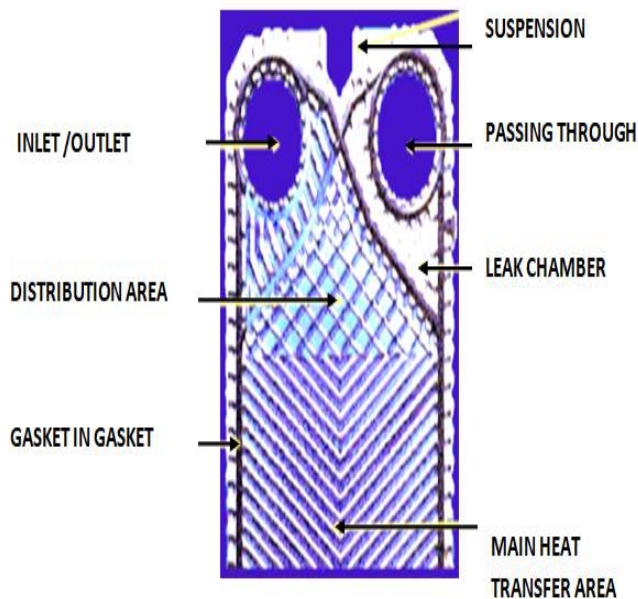


Fig 2. Main Component of Heat Exchanger Plate

II. LITERATURE REVIEW

The study carried out by Jain, S. Joshi, A. Bansal, and P. K. [2] titled 'Approach to Numerical Simulation of Small Sized Corrugated Plate Heat Exchangers' have experimental study of total heat transfer and fluid flow in a single pass counter flow plate heat exchanger with corrugated plates presented. Computational fluid dynamic analysis of small sized corrugated plate heat exchanger was conducted by taking the full geometry of the total heat transfer surface and realistic thermal and hydrodynamic boundary conditions. A cold water flow channel with two corrugated plates and two parts of hot channel on both side having flat boundaries was selected as the computational fluid domain. For Reynolds number range 400-1300 and Prandtl number range 4.4-6.3 heat transfer data and pressure drop data were collected experimentally for water. The work considered a cold channel (with two corrugated plates on either side) and two half hot channels on either side as the computational domain. The virtual flat boundaries of the outer half hot channel were treated as periodic surfaces to represent the complete heat exchanger. In applying the periodic boundary conditions, the pack was assumed to contain infinite plates (neglecting the end effects), although

the end effects may be significant if the number of plates is less than 50.

Shah, R. K. and Focke, W. W. [3]. has found for the selected geometry, 3-D, steady state numerical simulations were carried out using ANSYS WORKBENCH as the preprocessor for geometry creation and mesh generation and FLUENT 14 as the solver and postprocessor. The inputs to the simulation included the inlet velocities and temperatures of hot and cold fluids. The simulations predicted the heat transfer coefficient and pressure drop along with the velocity, pressure, and temperature distribution in the channels. The realizable $k-\epsilon$ turbulence model with non-equilibrium wall function was used.

Lee Y. S. Sun Y.M [4] has investigated the heat transfer characteristics of the corrugated channels in plate heat exchangers. A flow channel with wavy surfaces was constructed within which air was passed through. The temperature of the wall was maintained constant. Starting from the entrance, the air temperatures within two wavelengths were measured at about 300 locations. The Reynolds number of air was varied from 300-9000. Results show that both the average and local Nusselt number decreases with the distance from the entrance and is greater at sections near the crest.

Davidov, B. I. [5] has numerically investigated the two-dimensional time dependent fluid flow and heat transfer in two geometrical configurations for the unsteady regime with Reynolds number (175 to 200) for sinusoidal channel, and Reynolds number varying from 60 to 80 for the arc-shape channel. The results showed that as long as the heat transfer enhancement was high, the pressure loss was high too.

Harlow, F. H [7] studied numerically on the fully unsteady fluid flow and heat transfer in sine shaped wavy channels. Jones, W. P [8] considered the influence of the sinusoidal wavy-surface plate-fin geometry on hydrodynamic and thermal behaviors of laminar air flow under a constant wall temperature and through the range of Reynolds number from 10 to 1000. The predicted results were identical to the results of the above mentioned researches. The vortices which were responsible for enhancing of heat transfer increased as the Reynolds number increased and with sharp and sudden sinusoidal corrugation. These results were approved under the same conditions by Launder, B. E. and Sharma, B. I [9] but with viscous liquids (Prandtl number 5, 35, and 150).

Mansour, N. N. and Kim, J. Moin, P. [10] has investigated the same model but changing flow type to forced flow, and using both the constant wall temperature and constant wall heat flux as boundary conditions. However, the predicted flow phenomena were comparable, but the thermal performance with the constant heat flux was higher than that with constant temperature boundary condition. Under the same condition as above i.e. constant wall temperature and constant wall heat flux Morris,

It is observed by F. H. Whitman, [11] undertook a fully developed laminar water flow for sinusoidal channels of circular and semi-circular cross-section, and investigated the influence of Reynolds number ($5 < Re < 200$) and amplitude to half wavelength ratio ($0.222 < A/L < 0.667$) on

heat transfer enhancement and pressure drop. With varying the Reynolds number and amplitude to half wavelength ratio, the enhancement efficiency obtained with as large as 1.8, and 1.5 for the circular and semi-circular section respectively. The author found that the numerical results obtained show that the heat transfer performance can suitably be described by the field synergy principle.

The investigation of developing laminar forced convection and entropy generation in both double- and half-sine ducts subject to the variation of Reynolds number (86 to 2000) was numerically carried out by Incropera, F. P. DeWitt, D. P. [13]. investigated that the Nusselt number in double-sine ducts was higher than that in half-sine, whereas the entropy generation in half-sine duct was much higher in double-sine ducts.

Pham, M. V. [14] used the Large-eddy simulation together with dynamic modeling to examine 3D turbulent flow in wavy channels exposed to the variation of Reynolds number (750 to 4500), spacing ratio, and waviness aspect ratio. It was found that the spacing ratio played a key role to produce vortices, control turbulent kinetic energy. And also, the friction factor was highly sensitive to the variation of spacing ratio.

Ismail, S. L. [15] has studied the design data and flow patterns for three types of offset fins and sixteen types of wavy fins for a compact plate heat exchanger. This study addressed the quantification of geometry generating maldistribution. The type of flow inside the corrugated channel in the compact heat exchanger as function of Reynolds number is a significant issue.

Heggs, J and Walton, C. [17] has utilized the electrochemical mass transfer technique to calculate values of the local transfer coefficient for a corrugated plate heat exchanger channel, confirmed that the pure laminar flow did not exist for the tested Reynolds number range from 150 to 11,500. When the compact heat exchangers were used as reflux condenser, Drosos, E. I. P and Karabelas, A. [18] has suggested that the limit imposed by the onset of flooding, reduces the Reynolds number for less than 2000. Vlasogiannis, P [19] has experimentally tested a plate heat exchanger under two-phase flow conditions and visualized the flow regime, validated that the flow was turbulent for Re 650.

It is observed by Lioumbas, I.S [20] that the flow in narrow passages during counter-current gas-liquid flow, recommended that for gas Reynolds numbers in the range of 500–1300, the flow exhibited the basic features of turbulent flow.

III. CHALLENGES OF HEAT TRANSFER IMPROVEMENT

Improving heat transfer in engineering systems, such as heat exchangers, industrial boilers, and electronic cooling devices, presents several challenges. One major difficulty is balancing enhanced heat transfer with increased pressure drop, as techniques like adding fins, corrugations, or tabulators often improve thermal performance but also require more pumping power. Material limitations pose another challenge, since high-conductivity materials may be expensive, prone to corrosion, or unsuitable for certain

operating conditions. Additionally, optimizing complex geometries for turbulent or multiphase flows is computationally intensive and may not always translate from simulations to practical applications. Fouling and scaling on heat transfer surfaces further reduce efficiency over time, complicating maintenance and design. Lastly, economic and environmental considerations, such as energy consumption, manufacturing cost, and sustainability, impose constraints on the methods used to enhance heat transfer. Collectively, these factors make the improvement of heat transfer a multi-disciplinary and often trade-off-driven challenge.

Optimizing heat transfer improvement often involves trade-offs between efficiency, durability, and cost. For instance, adding fins, corrugations, or turbulators can significantly enhance convective heat transfer but may also accelerate fouling, erosion, or material fatigue, reducing the system's lifespan. Scale formation and surface deposits further complicate the process, as they reduce thermal performance and are difficult to remove in continuous operations. In micro-scale or compact systems, maintaining uniform temperature distribution while preventing hotspots presents additional challenges. Furthermore, accurately predicting the behavior of enhanced surfaces under transient or non-uniform flow conditions is difficult, requiring advanced computational models and experimental validation. These challenges highlight the need for an integrated approach that considers fluid dynamics, material science, manufacturing feasibility, and operational constraints to achieve practical and sustainable heat transfer enhancement.

IV. CONCLUSION

This review highlights the significant role of corrugated geometries in enhancing heat transfer performance in plate heat exchangers (PHEs). Studies consistently demonstrate that incorporating triangular, sinusoidal, and rectangular corrugations improves thermal performance by promoting turbulence, increasing fluid mixing, and disrupting boundary layers. Among these configurations, rectangular and triangular corrugations tend to offer higher heat transfer rates, while sinusoidal geometries provide a favorable balance between heat transfer enhancement and pressure drop.

The review also emphasizes the importance of optimizing parameters such as corrugation angle, pitch, and Reynolds number to achieve maximum thermal efficiency without incurring excessive pressure losses. Computational studies, particularly those using CFD tools like ANSYS, complement experimental findings by providing detailed insights into flow patterns, shear stress distribution, and local heat transfer characteristics.

References

- [1] Shah R.K., Sekulic D.P. (2003). Fundamentals of heat exchanger design, John Wiley & Sons, USA.
- [2] Fernandez-Seara J., Ufía F.J., Sieres J., Campo A.A. (2007). General review of the Wilson plot method and its modifications to determine convection coefficients in heat exchange devices, Applied

- Thermal Engineering, Vol. 27, No. 17-18, pp. 2745-2757, DOI: 10.1016/j.applthermaleng.2007.04.004.
- [3] Khan T.S., Khan M.S., Chyu M.C., Ayub Z.H. (2010). Experimental investigation of single phase convective heat transfer coefficient in a corrugated plate heat exchanger for multiple plate configurations, Applied Thermal Engineering, Vol. 30, No. 8-9, pp. 1058-1065, DOI: 10.1016/j.applthermaleng.2010.01.021.
- [4] Yaïci W., Ghorab M., Entchev E. (2016). 3D CFD study of the effect of inlet air flow maldistribution on plate-fin-tube heat exchanger design and thermal-hydraulic performance, International Journal of Heat and Mass Transfer, Vol. 101, pp. 527-541. DOI: 10.1016/j.ijheatmasstransfer.2016.05.063.
- [5] Hashmi A., Tahir F., Hameed U. (2012). Empirical Nusselt number correlation for single phase flow through a plate heat exchanger, Proceedings of the 9th WSEAS International Conference on Heat and Mass Transfer (HMT'12), Cambridge, MA, USA, pp. 25-2.
- [6] Muley A., Manglik R. (1999). Experimental study of turbulent flow heat transfer and pressure drop in a plate heat exchanger with chevron plates, Journal of heat transfer, Vol. 121, No. 1, pp. 110-117. DOI: 10.1115/1.2825923..
- [7] Akturk F., Gulben G., Aradag S., Uzol N.S., Kakac S. (2011). Experimental investigation of the characteristics of a chevron type gasketed-plate heat exchanger, International Advanced Technologies Symposium (IATS'11), pp. 16-18.
- [8] Turk C., Aradag S., Kakac S. (2016). Experimental analysis of a mixed-plate gasketed plate heat exchanger and artificial neural net estimations of the performance as an alternative to classical correlations, International Journal of Thermal Sciences, Vol. 109, pp. 263-269. DOI:10.1016/j.ijthermalsci.2016.06.016.
- [9] Quintero A.E., Vera M. (2017). Laminar counterflow parallel-plate heat exchangers: an exact solution including axial and transverse wall conduction effects, International Journal of Heat and Mass Transfer, Vol. 104, pp. 1229-1245. DOI:10.1016/j.ijheatmasstransfer.2016.09.025.
- [10] Kumar B., Singh S.N. (2015). Analytical studies on the hydraulic performance of chevron type plate heat exchanger, International Journal of Heat and Technology, Vol. 33, No. 1, pp. 17-24. DOI: 10.18280/ijht.330103.
- [11] Hazmi A.S.A., Maurad Z.A., Pauzi N.N.P.N., Idris Z. (2016). Rapid evaluation of plate heat exchanger performance and fouling analysis in epoxidation of oleochemical at pilot plant scale, International Journal of Heat and Technology, Vol. 34, No. 4, pp. 558-564. DOI: 10.18280/ijht.340402.
- [12] Doohan R.S., Kush P.K., Maheshwari G. (2016). Exergy based optimization and experimental evaluation of plate fin heat exchanger, Applied Thermal Engineering, Vol. 102, pp. 80-90. DOI: 10.1016/j.applthermaleng.2016.03.101.
- [13] Zhang Y., Jiang C., Yang Z., Zhang Y., Bai B. (2016). Numerical study on heat transfer enhancement in capsule-type plate heat exchangers, Applied Thermal Engineering, Vol. 108, pp. 1237-1242. DOI: 10.1016/j.applthermaleng.2016.08.033.
- [14] Khan T.S. (2011). Evaporation in flooded corrugated plate heat exchanger with ammonia and ammonia miscible oil, Ph.D. dissertation, Ghulam Ishaq Khan Institute of Engineering Sciences & Technology, Swabi.