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"CFD ANALYSIS OF THERMAL AND FLOW-INDUCED DAMAGE IN A PLATE HEAT EXCHANGER"

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ABSTRACT

Plate heat exchangers are widely used in power generation, refrigeration, chemical processing, food industries, and energy recovery systems because of their compact design and high heat transfer efficiency. However, exposure to high temperatures, pressure variations, turbulent fluid flow, and non-uniform thermal loading may cause plate deformation, thermal stress, flow induced vibration, fatigue, leakage, and structural failure. The present study investigates thermal and flow-induced damage in a plate heat exchanger using Computational Fluid Dynamics (CFD) and coupled thermo-structural analysis. A three-dimensional numerical model of the plate heat exchanger is developed to examine fluid-flow behaviour, temperature distribution, pressure drop, heat-transfer rate, and regions of excessive turbulence. The governing equations of mass, momentum, and energy conservation are solved under different operating conditions, including variations in inlet velocity, fluid temperature, pressure, and flow arrangement. The temperature and pressure fields obtained from the CFD analysis are transferred to a structural model to determine thermal deformation, equivalent stress, and critical damage-prone locations within the plates. Particular attention is given to plate contact regions, inlet and outlet ports, gasket areas, and highly corrugated sections where stress concentration and flow-induced forces are significant. The results help identify the operating conditions that may lead to plate fatigue, vibration, leakage, or permanent deformation. The study also evaluates the influence of plate geometry, flow rate, material properties, and thermal loading on the overall structural integrity of the heat exchanger. The findings can support the optimization of plate design, material selection, and operating parameters, thereby improving heat-transfer performance, durability, safety, and service life.

Key Words: *Computational Fluid Dynamics, Plate Heat Exchanger, Thermal Stress, Flow Induced Damage, Heat Transfer, Pressure Drop, Structural Deformation, Fluid–Structure Interaction..*

I. INTRODUCTION

Plate heat exchangers are among the most efficient heat transfer devices because of their large surface-area-to-volume ratio and highly turbulent flow passages. Corrugated plates promote turbulence even at relatively low Reynolds numbers, leading to high heat transfer coefficients. Consequently, PHEs are widely adopted in industries requiring compact and energy-efficient thermal systems.

Despite these advantages, the corrugated flow channels experience localized high-velocity regions, recirculation zones, and uneven thermal loading. These conditions generate thermal stresses and flow-induced mechanical stresses that may cause fatigue cracks, corrosion, gasket deterioration, and erosion. The long-term reliability of PHEs therefore depends on understanding the interaction between fluid flow and heat transfer.

Experimental evaluation of these phenomena is often expensive and limited by accessibility to internal flow channels. Computational Fluid Dynamics (CFD) offers an alternative by providing detailed information regarding velocity, pressure, turbulence, and temperature fields throughout the exchanger.

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The present work employs CFD to investigate thermal and flow-induced damage in a gasketed plate heat exchanger. Numerical simulations are carried out using ANSYS Fluent to predict heat transfer performance and identify critical regions subjected to excessive wall shear stress, pressure fluctuations, and thermal gradients.

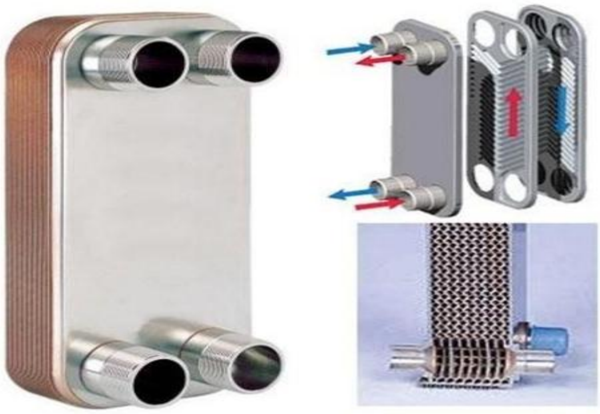

Figure.1 PHE Plate

II. Problem Statement

Increasing industrial demand for higher thermal efficiency has resulted in higher operating flow rates in plate heat exchangers. Although enhanced turbulence improves heat transfer, it also increases pressure losses, vibration, erosion, and fatigue damage. An integrated CFD study considering both thermal performance and structural degradation is therefore required.

III. Methodology

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START
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  ▼
Literature Review & Problem Identification
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  ▼
Selection of Plate Heat Exchanger Geometry
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  ▼
3D CAD Model Development (SolidWorks/CATIA)
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  ▼
Import Geometry into ANSYS Workbench
  |
  ▼
Mesh Generation & Mesh Independence Test
  |
  ▼
Define Material Properties
(Water & Stainless Steel SS316)
  |
  ▼
Apply Boundary Conditions
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IV. Results and Discussion

The air with moisture, its pressure is high and when it acts on the refrigerant tube, the erosion and stress will be high and if this happens continuously, the tube will puncture. Whereas if the air turbulence is high, the heat transfer will be high and the efficiency of the heat exchanger will increase and the high velocity is also not good for the tube and this is there as on that due to which even little moisture in the air is causing puncture of refrigerant tubes of PHE.

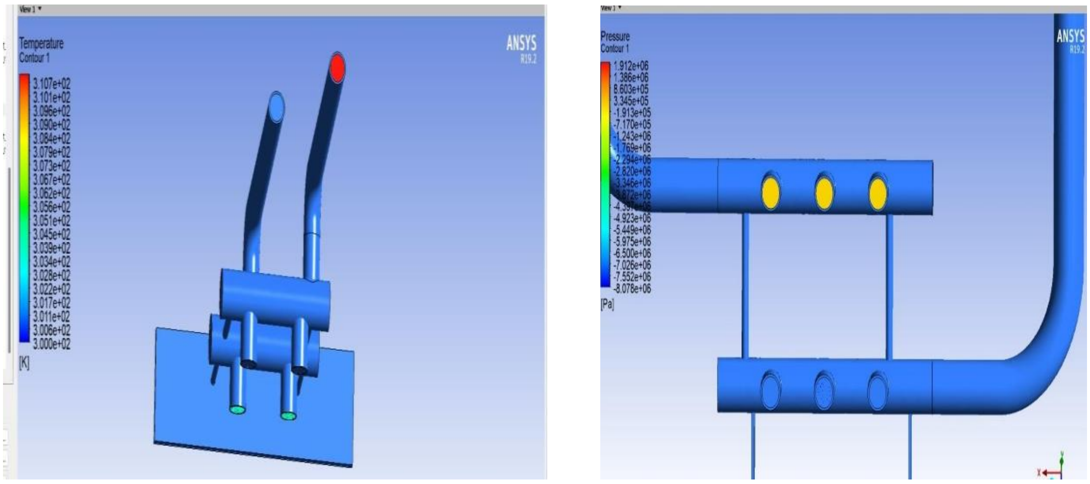

Figure 2(a) & (b) Temperature & Pressure contours

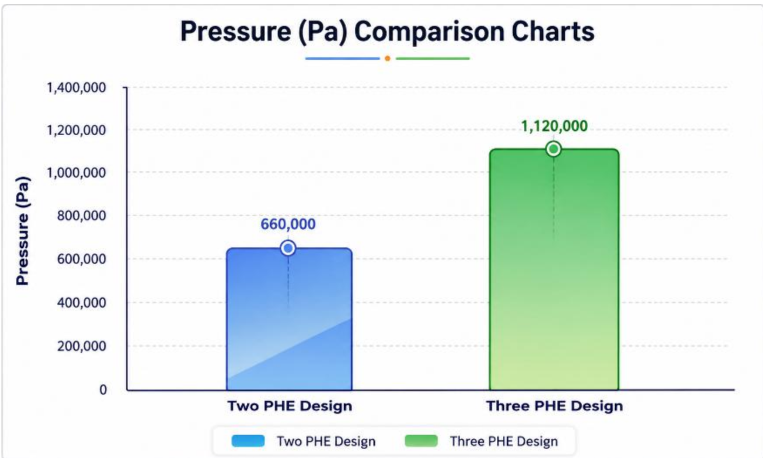

Figure.3 Pressure comparison charts

The Pressure (Pa) Comparison Chart presents the pressure distribution for two different PHE configurations: the Two PHE Design and the Three PHE Design. The two heat exchangers designs are shown on the x-axis, while the y-axis displays the pressure values in Pascals (Pa). Another significant element to study in heat exchangers is pressure since it has a direct impact on the fluid flow characteristics, pumping power needs, and the overall performance of the system.
The graph shows that the pressure of the Two PHE Design is about 670,000 Pa and the Three PHE Design is around 1,120,000 Pa. The large rise in pressure shows that the inclusion of the third plate provides a more complicated route for the flow to take, which leads to higher resistance to the passage of the fluid. The greater pressure is also related with increased turbulence which increases mixing of the fluid and accelerates the rate of heat transfer.
The Three PHE Design has a higher working pressure and hence a higher pumping power . However, it has a better thermal performance owing to better interaction of the fluids and a higher convective heat transfer coefficient . In comparison, the Two PHE Design has a reduced pressure drop, therefore being more energy-efficient, but a poorer heat transmission efficacy.

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Generally, the figure shows that the operating pressure and the heat transfer performance increase with the number of plates in the heat exchanger. Therefore, the Three PHE Design is more efficient in terms of thermal performance, but the greater pressure need has to be addressed in the system design to establish a compromise between heat transfer efficacy and pumping energy consumption.

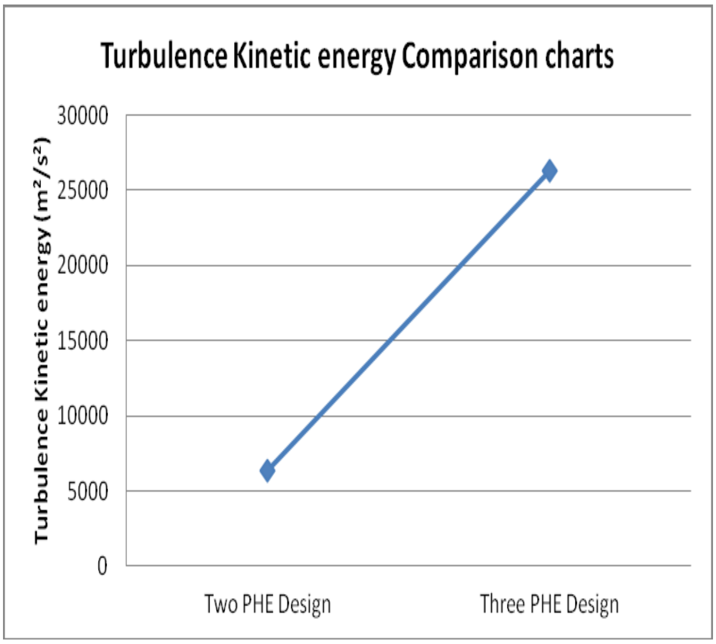

Figure.4 Turbulence kinetic energy comparison charts

The TKE Comparison Chart compares the turbulence kinetic energy produced in Two PHE Design and Three PHE Design. The x-axis displays the two alternative heat exchanger layouts, and the y-axis displays the turbulence kinetic energy in m^2/s^2, which is a measure of the intensity of turbulent fluid motion within the heat exchanger.

The graph shows that the Two PHE Design provides a turbulent kinetic energy of around 6,500 m^2/s^2, but the Three PHE Design yields a much greater value of nearly 26,000 m^2/s^2. This corresponds to a turbulent kinetic energy almost four times higher with the third plate added.

The increased turbulence in the Three PHE Design means the working fluid is mixed more vigorously, which improves convective heat transmission by thinning the thermal boundary layer. Better fluid mixing leads to a more uniform temperature distribution and a higher total heat transfer coefficient. Therefore, the Three PHE Design is projected to have greater heat exchanger efficiency and better thermal performance than the Two PHE Design.

However, increased turbulence is generally associated with a higher pressure drop, requiring additional pumping power. Therefore, while the Three PHE Design offers superior heat transfer characteristics, its hydraulic performance and energy consumption should also be considered during design optimization. Overall, the chart demonstrates that increasing the number of plates significantly enhances turbulence generation, making the Three PHE Design a more effective configuration for applications requiring high heat transfer efficiency.

V. CONCLUSION

CFD provides an effective tool for evaluating both thermal performance and flow-induced damage in plate heat exchangers. The coupled analysis enables visualization of velocity, pressure, temperature, and wall shear stress distributions that are difficult to obtain experimentally. Identifying critical regions susceptible to erosion, vibration, and thermal fatigue allows engineers to optimize plate geometry, corrugation patterns, and operating conditions. The proposed methodology can be extended to multi-pass, chevron-type, and nanofluid-based plate heat exchangers for enhanced performance and reliability.

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REFERENCES

[1] G. A. Longo, "Heat transfer and pressure drop characteristics of brazed plate heat exchangers," Experimental Heat Transfer, vol. 21, no. 2, pp. 87–102, 2008.
[2] T. S. Khan, M. S. Khan, M. C. Chyu, and Z. H. Ayub, "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, 2010.
[3] V. S. Gullapalli and B. Sundén, "A review of compact plate heat exchangers," Heat Transfer Engineering, vol. 30, no. 3, pp. 196–210, 2009.
[4] M. M. A. Bhutta, N. Hayat, M. H. Bashir, A. R. Khan, K. N. Ahmad, and S. Khan, "CFD applications in various heat exchangers design: A review," Renewable and Sustainable Energy Reviews, vol. 43, pp. 847–876, 2015.
[5] P. Pianko-Oprych and Z. Jaworski, "3D CFD fluid flow and thermal analyses of a new design of plate heat exchanger," Polish Journal of Chemical Technology, vol. 19, no. 1, pp. 20–28, 2017.
[6] E. Y. Rios-Iribe et al., "CFD simulation of non-Newtonian fluid flow and heat transfer in plate heat exchangers," Applied Thermal Engineering, vol. 108, pp. 138–148, 2016.
[7] R. S. Andhare, S. Shooshtari, M. Ohadi, and A. Dessiatoun, "Performance evaluation of manifold microchannel plate heat exchangers using experimental and CFD methods," Applied Thermal Engineering, vol. 103, pp. 397–410, 2016.
[8] V. Dvořák and T. Vít, "Numerical investigation of counter-flow plate heat exchanger," Energy Procedia, vol. 75, pp. 2784–2789, 2015.
[9] O. Giurgiu, A. Dobrovicescu, and M. Prisecaru, "CFD analysis of mini-channel plate heat exchangers," Energy Procedia, vol. 85, pp. 244–251, 2016.
[10] V. Patil, S. Patil, and R. Patil, "CFD analysis of plate heat exchanger," International Journal of Mechanical Engineering and Robotics Research, vol. 2, no. 4, pp. 321–329, 2013.
[11] D. B. Sapkal, V. S. Sapkal, and P. V. Walke, "Computer aided design and CFD analysis of plate heat exchanger," International Journal of Innovative and Emerging Research in Engineering, vol. 2, no. 4, pp. 1–8, 2015.
[12] R. K. Shah and D. P. Sekulić, Fundamentals of Heat Exchanger Design. New York, NY, USA: John Wiley & Sons, 2003.
[13] F. P. Incropera, D. P. DeWitt, T. L. Bergman, and A. S. Lavine, Fundamentals of Heat and Mass Transfer, 8th ed. Hoboken, NJ, USA: John Wiley & Sons, 2017.
[14] H. K. Versteeg and W. Malalasekera, An Introduction to Computational Fluid Dynamics: The Finite Volume Method, 2nd ed. Harlow, U.K.: Pearson Education, 2007.
[15] [15] J. D. Anderson, Computational Fluid Dynamics: The Basics with Applications. New York, NY, USA: McGraw-Hill, 1995.
[16] R. M. Manglik and A. E. Bergles, "Heat transfer and pressure drop correlations for the rectangular offset strip-fin compact heat exchanger," ASME Journal of Heat Transfer, vol. 117, no. 1, pp. 43–52, 1995.
[17] S. Kakaç and H. Liu, Heat Exchangers: Selection, Rating and Thermal Design, 2nd ed. Boca Raton, FL, USA: CRC Press, 2002.
[18] M. M. Abu-Khader, "Recent advances in plate heat exchanger technology," Renewable and Sustainable Energy Reviews, vol. 16, no. 4, pp. 1883–1891, 2012.
[19] H. Martin, "A theoretical approach to predict the performance of chevron-type plate heat exchangers," Chemical Engineering and Processing, vol. 35, no. 4, pp. 301–310, 1996.
[20] W. W. Focke, J. Zachariades, and I. Olivier, "The effect of corrugation geometry on the thermohydraulic performance of plate heat exchangers," International Journal of Heat and Mass Transfer, vol. 28, no. 8, pp. 1469–1479, 1985.
[21] A. Muley and R. M. Manglik, "Experimental study of turbulent flow heat transfer and pressure drop in a plate heat exchanger with chevron plates," ASME Journal of Heat Transfer, vol. 121, no. 1, pp. 110–117, 1999.

ISSN : 2455-9679
SJIF Impact Factor : 6.190

[22] D. Dović, B. Palm, and S. Švaic, "Generalized correlations for predicting heat transfer and pressure drop in plate heat exchangers," International Communications in Heat and Mass Transfer, vol. 36, no. 2, pp. 135–140, 2009.