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NUMERICAL INVESTIGATION AND OPTIMIZATION OF NOVEL FOUR LAYERSMICRO CHANNEL HEAT EXCHANGER COUPLED WITH NANO-FLUID USING TWO-PHASE APPROACH

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Abstract: **Ansys fluent is utilized to conduct an analysis of a four-layer micro channel heat exchanger (MCHE) operating in a counter-flow configuration, employing the Eulerian multiphase model. The primary focus of this research is to evaluate the thermohydraulic performance of the MCHE when utilizing a water-Al_2O_3 nanofluid and a Phase Change Material (PCM). The study examines the influence of nanoparticle and PCM volume fractions on the overall heat transfer coefficient. It is observed that due to its phase change properties, PCM exhibits a higher heat transfer coefficient compared to nanofluid. While nanofluids enhance thermal conductivity, they also increase viscosity, resulting in a lower overall heat transfer coefficient compared to pure PCM. The velocity, temperature, volume fraction, pressure, and density distributions provide insights into the flow, heat transfer, mixing, and dispersion characteristics of the MCHE. As the PCM volume fraction increases, the pressure drop across the MCHE decreases, leading to reduced pumping power requirements and improved energy efficiency.**

Keywords: **Phase change material, nanoparticle, heat exchanger, heat transfer, nanofluids**

I. INTRODUCTION

Heat exchangers play a crucial role in various industrial applications, including power generation, air conditioning, and refrigeration. The development of microchannel heat exchangers with their superior thermal properties, compact dimensions, and low fluid volume has sparked interest in using nanofluids as the heat transfer medium. Recent studies have explored innovative microchannel heat exchangers, such as the manifold-MCHE designed for aerospace applications by Zhang et al. (2018), as well as the utilization of air and refrigeration R245fa for two-phase cooling in microchannel heat exchangers, as investigated by Kwon et al. (2019a).

Mazaheri et al. (2021) conducted a study on a heat exchanger with a length of 100 mm and a width of 50 mm. The heat exchanger consisted of six, ten, and fourteen channels with varying widths, while maintaining a constant fluid flow height of 0.55 mm. The layers of the microchannel heat exchanger were 1.15 mm thick and constructed of aluminium with a thermal conductivity of 202 W/mK. The research focused on understanding the two-phase flow behavior of nanofluids in a four-layer microchannel heat exchanger to gain insights into the heat transfer mechanism and identify areas for further improvement. The findings of this study contribute to the design and optimization of microchannel heat exchangers for a wide range of industrial applications (Mazaheri et al., 2021).

Although nanofluids have demonstrated potential in enhancing heat transfer efficiency in microchannel heat exchangers, there are certain limitations and challenges associated with their use. Long-term stability is a concern as nanoparticles tend to agglomerate or settle over time, leading to the loss of their desired thermal properties. This agglomeration can obstruct the fluid flow, resulting in reduced heat transfer efficiency and increased pressure drop within the microchannels. Another issue is the potential erosion or fouling of microchannel surfaces caused by nanoparticles. Some nanoparticles possess abrasive characteristics that can cause erosion, leading to material degradation and decreased lifespan of the heat exchanger. Additionally, particle deposition on the channel walls can lead to fouling, diminishing heat transfer effectiveness and necessitating frequent cleaning or maintenance.

Moreover, in comparison to nanofluids, the incorporation of phase change materials (PCMs) in microchannel heat exchangers offers distinct advantages. PCMs have the ability to store and release thermal energy during phase transitions, significantly enhancing the heat transfer capacity of the system. This characteristic enables PCMs to absorb large amounts of heat during the phase change process, resulting in smoother temperature transitions and improved overall thermal performance of the heat exchanger.

Unlike nanofluids, which are prone to agglomeration and settling of nanoparticles, PCMs possess inherent stability. Once properly enclosed or integrated into the microchannel heat exchanger, PCMs maintain their thermal properties and are not affected by particle agglomeration or settling. Furthermore, the use of PCMs in microchannel heat exchangers reduces the risk of erosion or fouling on the channel surfaces. Since PCMs undergo phase change within the microchannels, they do not introduce abrasive nanoparticles that could cause erosion or deposition, thereby minimizing material degradation and the need for frequent maintenance.

Additionally, PCM-based systems offer a more compact solution compared to nanofluid-based systems. PCMs have a high latent heat of fusion, allowing for a greater energy storage capacity in a smaller volume compared to nanofluids. This compactness is particularly advantageous in applications with limited space or when considering the overall size and weight of the heat exchanger system. Moreover, the use of PCMs in microchannel heat exchangers can lead to cost savings. While the manufacturing and integration of nanofluids can be complex and expensive, PCMs are often commercially available at affordable prices, making them a more economically viable option for various industrial applications.

(Mazaheri et al., 2021) conducted research to explore the benefits of integrating phase change materials (PCMs) in microchannel heat exchangers (MCHEs). The objective of the study was to examine potential enhancements in heat transfer efficiency, energy storage capacity, and overall system effectiveness by investigating the performance of a four-layer MCHE combined with PCM, highlighting the advantages that PCM offers over nanofluids.

The researchers focused on leveraging PCMs in MCHEs to increase heat capacity and energy storage capabilities. PCMs possess the ability to store and release thermal energy during phase change, significantly enhancing the heat transport capability of the system. However, the utilization of PCMs in MCHEs presents challenges, such as the need for effective thermal management and control in order to optimize their performance in conjunction with nanofluids.

In this study, a two-phase approach was adopted to evaluate the performance of a unique four-layer MCHE integrated with both a nanofluid and PCM. The two-phase method treats the interactions between the fluid and PCM as distinct phases. The optimization process involved manipulating design parameters, such as channel dimensions, layer thickness, PCM concentration, and flow rate, to enhance heat transfer performance while minimizing pressure loss. By investigating the combined utilization of PCM and nanofluid in the MCHE, the study aimed to uncover strategies for improving heat transfer efficiency and energy storage capacity, ultimately enhancing the overall performance of microchannel heat exchangers in various industrial applications.

II. MATERIALS AND METHODOLOGY

Several studies have been conducted on the use of nanofluids in MCHEs. The capability of a counterflow MCHE for heat transmission, for example, was statistically tested by researchers employing a water-based Al_2O_3nanofluid. They discovered that when nanoparticle concentration grew, so did the heat transfer coefficient and pressure decrease. (Jung & Park, 2021) investigated the functioning of a microchannel heat sink employing an Al_2O_3-water nanofluid and discovered that the heat transfer coefficient was 18% larger than that of pure water. He investigated how the concentration of nanoparticles affects heat transfer efficiency in a microchannel heat sink based on an Al_2O_3-water nanofluid. They discovered that when the concentration of nanoparticles grew, so did the pressure and the heat transfer coefficient.

Mazaheri et al. (2021) used a two-phase technique to investigate numerical modelling and optimisation of a unique four-layer MCHE coupled with nanofluid. The MCHE's four layers of parallel microchannels were separated by rectangular fins, and two-phase nanofluid flowed through them. The scientists employed computational fluid dynamics (CFD) to examine the MCHE's thermal and fluid flow behaviour and tweak its design parameters for optimal thermal performance. According to the modelling results, the two-phase flow of nanofluid considerably improved the thermal performance of the MCHE, with a heat transfer coefficient that was 1.8 times greater than that of the base fluid alone. Furthermore, the authors discovered that increasing the nanofluid volume percentage and mass flux could improve the thermal performance of the MCHE even further. According to (Kwon et al., 2019b), in terms of heat transfer coefficient, a four-layer MCHE coupled with nanofluid employing a two-phase technique surpasses base fluids.

Several more research have investigated the use of nanofluids in MCHEs. The influence of an Al_2O_3-water nanofluid on the thermal performance of a two-layer MCHE with rectangular microchannels was examined by (H. Wu & Zhang, 2021). The researchers discovered that using nanofluid significantly enhanced the heat transfer coefficient when compared to using merely the base fluid. The use of an Al_2O_3-water nanofluid in a CFD analysis of the thermal performance of a microchannel heat sink boosted the heat transfer coefficient and decreased the thermal resistance of the heat sink (Mashayekhi et al., 2018).

Researchers have spent the last few years focusing on developing unique designs to increase the performance of MCHEs. For example, (Y. Wu et al., 2023) developed and tested a 3D-printed MCHE with a wavy channel architecture. They used a water-based Al_2O_3 nanofluid. When compared to the standard straight-channel design, they discovered that the heat transfer coefficient and thermal efficiency increased by 25% and 20%, respectively.

Numerous numerical and experimental research on the usefulness of MCHEs in transmitting heat utilising nanofluids have also recently been done. For example, the heat transmission capabilities of a counterflow MCHE using a CuO/water nanofluid were experimentally investigated. They discovered that as compared to pure water, the thermal efficiency rose by up to 16% and the heat transfer coefficient increased by up to 37%. The heat transmission properties of a serpentine microchannel were statistically examined using an Al_2O_3/water nanofluid. They discovered that as compared to pure water, the heat transfer coefficient rose by up to 56% (Nakhchi & Esfahani, 2021).

Several research have also been undertaken to evaluate how flow rate, channel design, and nanoparticle concentration affect how well MCHEs employ nanofluids to transmit heat. Mohamadian et al. (Mohamadian, 2018) used a CuO/water nanofluid to study the impact of flow rate and channel geometry on the effectiveness of heat transmission in a wavy channel MCHE.

Aside from nanofluids, researchers have investigated the impacts of employing PCM in MCHEs. (Ma et al., 2023) investigated the impact of various geometric parameters on the performance of an MCHE paired with a PCM. They discovered that widening and narrowing the channel increased the overall heat transfer coefficient while decreasing the temperature differential in the PCM. (Ma et al., 2023) discovered that increasing the PCM thickness increased the heat transfer rate and increased the device's thermal storage capacity in numerical simulations of an MCHE with a PCM.

Numerical simulations and actual studies were carried out to investigate the use of PCMs in MCHEs. (Ma et al., 2023) developed an MCHE with a paraffin wax PCM and tested its thermal performance. They discovered that as compared to a typical MCHE without PCM, the heat transfer coefficient was increased by up to 47%. (Ma et al., 2023) discovered that in testing on an MCHE with a PCM, the device's heat storage capacity might be enhanced by up to 22% when compared to a regular MCHE.

Several researchers have also looked into MCHE optimization approaches in conjunction with PCMs. (Ma et al., 2023) used a genetic algorithm to optimize the design of an MCHE with a PCM. They discovered that the perfect design enhanced thermal storage capacity by 23% when compared to a standard MCHE. (SUBASI, 2022) used a multi-objective optimization technique to tune the shape and operational parameters of an MCHE coupled with a PCM. They discovered that the perfect design yielded a 37% increase in thermal storage capacity and a 26% decrease in pressure drop when compared to a standard MCHE.

III. EXPERIMENTAL SETUP

This CFD problem's physical domain is a four-layer microchannel heat exchanger with nanofluid as the working fluid. The heat exchanger is made up of multiple tiny tubes that are designed to maximise heat transmission between the fluid and its surroundings. The channels range in width from six to fourteen channels and have a height of 0.55 mm. The heat exchanger is 100 mm in length and 50 mm in breadth. In Solidworks, I created a microchannel heat exchanger and used two layers for CFD analysis.

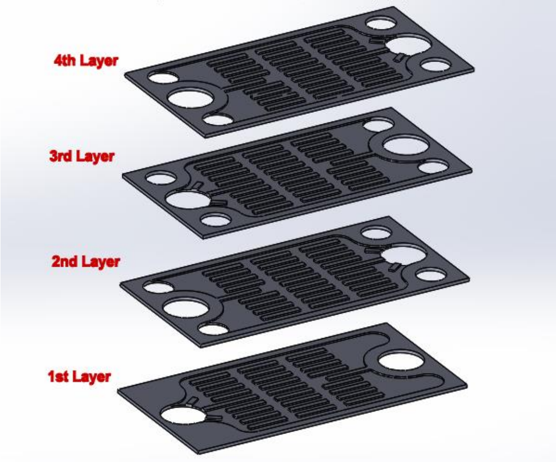

Figure 1: Exploded view in Solidworks of Microchannel heat Exchanger

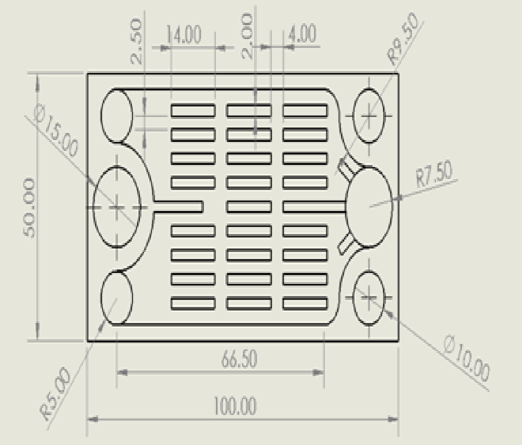

Figure 2: Dimension of single plate in mm

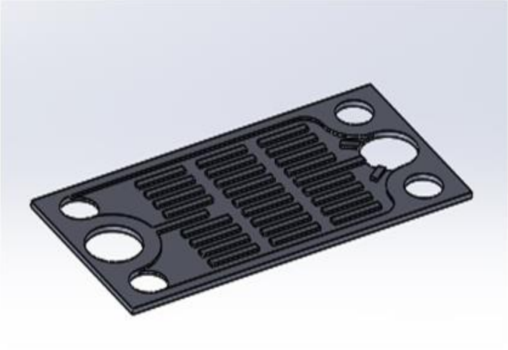

Figure 2: Single Plate 3D view

The heat exchanger is built of aluminium, a material with a thermal conductivity of 202 W/mK. In this CFD issue, the working fluid is nanofluid, which is a fluid containing nanoparticles that improve its thermal properties. The goal of this research is to analyse the two-phase flow behaviour of a nanofluid in a microchannel heat exchanger to optimise its flow and heat transfer characteristics and increase its energy efficiency.

The governing equations of fluid flow and heat transport are numerically solved using computational fluid dynamics (CFD) software to analyse the physical domain of this CFD problem. The simulations are built on a numerical grid, which divides the physical world into many microscopic cells. These cells are used to solve the fluid flow and heat transfer equations, which explain the behaviour of the nanofluid as it passes through the heat exchanger's microchannel. CFD analysis is performed on two levels in Ansys fluent for simplicity and to reduce computing time. The figure below depicts MCHE's fluid domain.

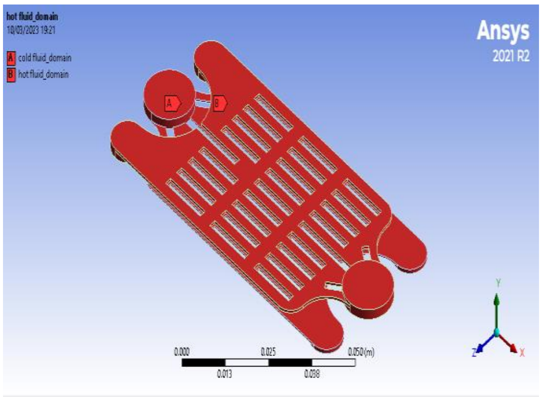

Figure 3:Fluid domains of MCHE

IV. BOUNDARY CONDITIONS

Boundary Conditions used in this Problem are following:

1.1 Inlet boundary conditions:

- Hot nanofluid enters from the bottom of the MCHE with a temperature of 350 K.
- Cold water enters from the top of the MCHE with a constant temperature of 290 K.
- The mass flow rate of the hot nanofluid/ PCM varies from 2.5×10^{-3} to 1.5×10^{-2} kg/s, while the mass flow rate of the cold water is invariant and equals to 5×10^{-3} kg/s.
- Number of Channel consider in this analysis is 10.

1.2 Outlet boundary conditions:

- The outlet temperature of the nanofluid/PCM and cold water were observed and analysed in the study.
- The pressure at the outlet is usually set to atmospheric pressure in CFD simulations.

1.3 Wall boundary conditions:

- The no-slip boundary condition applied at the walls, meaning that the velocity of the fluid at the wall is zero.
- The walls are assumed impermeable, meaning that there is no fluid flow through the walls.

V. RESULTS AND DISCUSSION

In computational fluid dynamics simulations, tetrahedral components are commonly used to discretize the physical domain. In order to balance accuracy and computational efficiency, a mesh with an element size of 1mm was employed in this study. Edge sizing technique was applied specifically to the inlets and outlets to enhance the accuracy of the simulation results. This approach involves refining the mesh near the boundaries of the domain where the fluid enters and exits.

In the Ansys parametric analysis, the number of divisions for edge sizing was considered as an input parameter to investigate the mesh/grid independence. As a result, a mesh with 155,649 elements and 44,547 nodes was determined when using 40 divisions for the edge size. This configuration aimed to ensure an adequate level of mesh resolution for capturing the desired flow behavior and achieving reliable simulation outcomes.

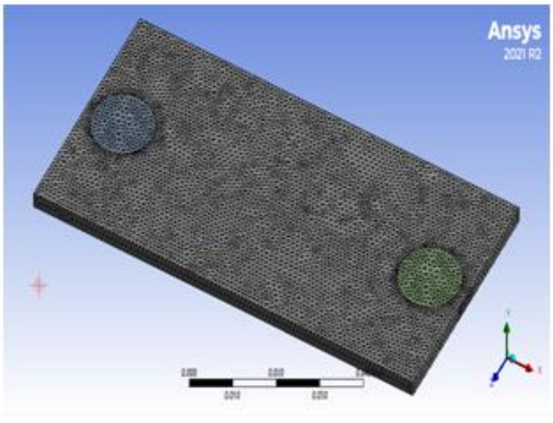

Figure 4:Mesh in Ansys

5.1 Mesh Quality:

In computational fluid dynamics (CFD) simulations, the quality of the mesh plays a crucial role in obtaining accurate and reliable results. Mesh quality can be evaluated based on various criteria, including aspect ratio, skewness, and orthogonal quality. These metrics provide quantitative measures of the geometric characteristics of the mesh elements. Mesh quality significantly influences the accuracy and convergence of the simulation outcomes. Therefore, it is important to assess the mesh quality carefully and refine the mesh if necessary to achieve the desired level of accuracy.

Orthogonal quality specifically refers to how closely the angles between adjacent mesh elements approach 90 degrees. High orthogonal quality is desirable in simulations as it contributes to improved accuracy, stability, and faster convergence rates. To assess the orthogonal quality of a mesh, metrics such as skewness angle, aspect ratio, and Jacobian determinant can be utilized.

In the case of the microchannel heat exchanger (MCHE) studied, the orthogonal quality of the mesh is presented. The minimum orthogonal quality value is 4.3216e-002, the maximum value is 0.98864, and the average value is 0.64688. These values provide insights into the overall quality of the mesh in terms of its angles and geometric characteristics. A higher average orthogonal quality value indicates a better alignment of mesh elements and suggests improved accuracy in the simulation results.

It is worth noting that maintaining a high-quality mesh with good orthogonal characteristics throughout the simulation domain is crucial for obtaining reliable and accurate CFD results.

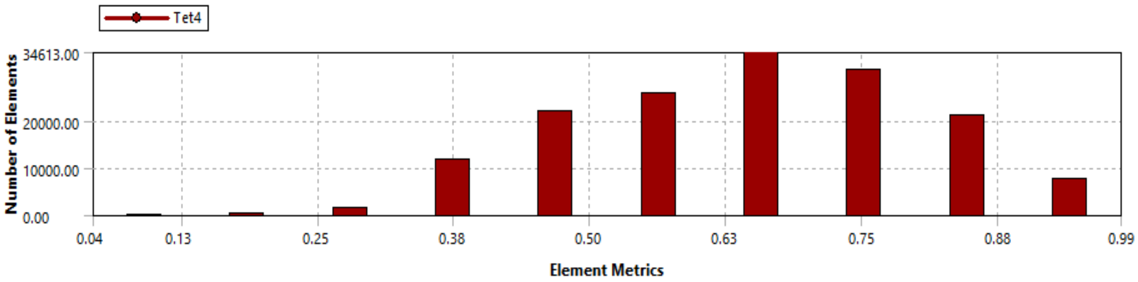

Figure 5:Mesh in Ansys

Skewness is a metric utilized in mesh generation to evaluate the quality of individual mesh elements. It quantifies the deviation of an element's shape from an ideal shape, such as a square or a hexagon. A higher skewness value indicates that an element's shape is distorted, which can result in numerical inaccuracies and instability during simulation. Various techniques can be employed to measure skewness, such as evaluating the angle between the element edges or calculating the ratio of the smallest to the longest edge length.Reducing skewness is a goal in mesh generation algorithms, as it contributes to improving the overall mesh quality. By minimizing skewness, the accuracy and reliability of the simulation results can be enhanced.

In the case of the microchannel heat exchanger (MCHE) analyzed, the skewness values of the mesh are presented. The minimum skewness value is 5.3495e-004, the maximum value is 0.95678, and the average value is 0.35217. These values provide insights into the extent of skewness exhibited by the individual mesh elements in the MCHE model. A lower average skewness value indicates a better alignment of the mesh elements with the desired shape, indicating improved quality and potentially more accurate simulation results.

It is important to note that minimizing skewness throughout the mesh is crucial for obtaining reliable and accurate computational fluid dynamics (CFD) simulations. By striving for a lower skewness value, the mesh quality can be improved, leading to more stable and accurate results.

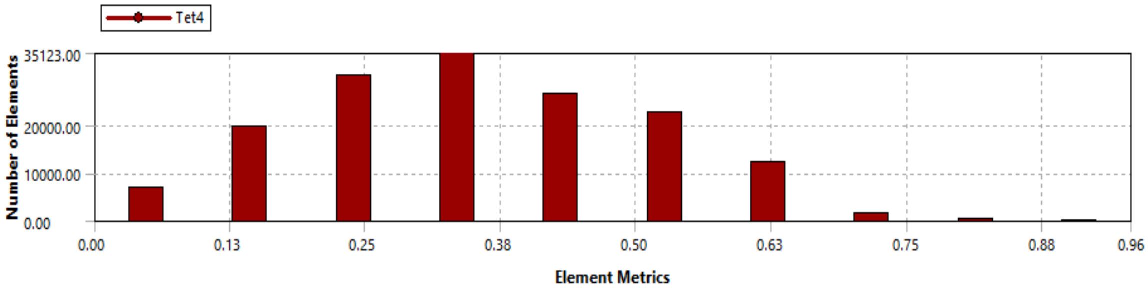

Figure 6:Skewness Graph

5.2 Grid/Mesh Independent Study:

Grid independence analysis is a crucial step in Computational Fluid Dynamics (CFD) analysis to ensure the accuracy and reliability of the results. It involves evaluating the solution using different grid sizes to determine the optimal grid size that yields a grid-independent solution. This analysis is performed by progressively increasing the grid density and conducting simulations to compare the results with a reference solution. A solution is considered grid independent if the results converge to a stable solution as the grid size decreases. Typically, the optimal grid size is the smallest size that achieves grid independence.

Having a grid-independent solution ensures that the results are not influenced by the grid size and provides confidence in the accuracy of the CFD analysis. In the conducted study, Ansys parametric analysis was employed to investigate mesh independence. The number of divisions was used as an input parameter, which influenced the number of nodes, elements, and the temperature of the hot fluid at the exit. Through this investigation, it was determined that the mesh with 325,256 elements produced the most accurate results.

By identifying the grid size that yields a grid-independent solution, the analysis becomes more reliable and trustworthy. It demonstrates that the results are not influenced by the mesh resolution and confirms the accuracy of the CFD simulations.

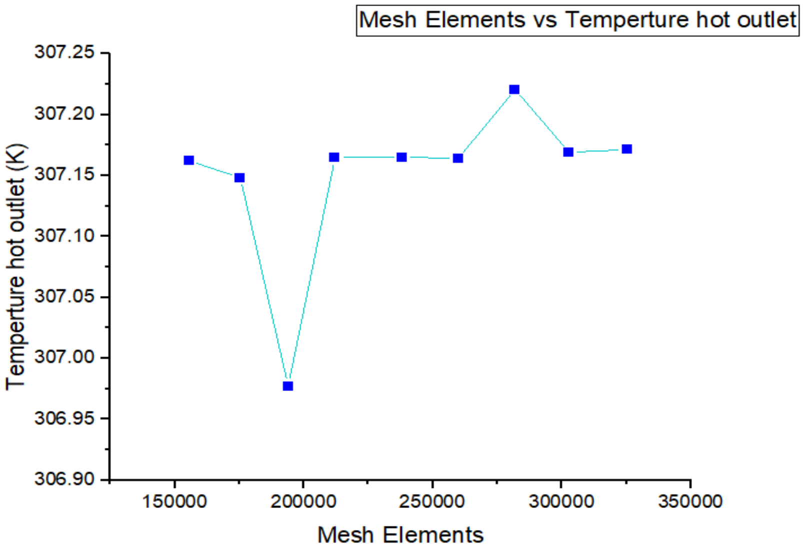

Figure 7:Mesh/Grid Independence graph

Ansys Fluent utilizes the Eulerian multiphase model to analyze the performance of a counter-flow four-layer Micro Channel Heat Exchanger (MCHE) using both Phase Change Material (PCM) and a water-Al2O3 nanofluid. The experiment focuses on evaluating the thermohydraulic characteristics of the MCHE. The nanofluid, consisting of water with Al2O3 nanoparticles, is supplied as the hot fluid at 350 K, while cold water enters at 290 K.

To investigate the influence of nanoparticle and PCM volume fractions, five different volume fractions ranging from 0% to 4% were considered. The mass flow rate of the nanofluid varied from 2.5 × 10−3 to 1.5 × 10−2 kg/s, while the mass flow rate of cold water remained constant at 5 × 10−3 kg/s. Ansys parametric analysis was conducted to assess the heat transfer rate (q), Log Mean Temperature Difference (LMTD), and the overall heat transfer coefficient for different volume fractions and mass flow rates. A similar procedure was employed to calculate the overall heat transfer coefficient for PCM.

Figure 9 illustrates the relationship between the overall heat transfer coefficient (U) of the MCHE and the mass flow rate of the nanofluid for various volume fractions. Figure 10 presents a graph depicting the mass flow rate versus the overall heat transfer coefficient for different PCM volume fractions. The results indicate that PCMs exhibit higher heat transfer coefficients compared to nanofluids due to their phase transition behavior, where they absorb or release significant amounts of heat during phase changes (e.g., solid to liquid or liquid to gas). This phase transition mechanism enables PCMs to efficiently store and release thermal energy, resulting in rapid heat transfer rates. Figures 9 and 10 demonstrate the increased heat transfer coefficients for PCM compared to nanofluid under the same volume fraction and mass flow rates.

In contrast, nanofluids are comprised of nanoparticles dispersed in a base fluid, altering its properties such as heat conductivity and viscosity. While nanofluids enhance the thermal conductivity of the base fluid, they also increase its viscosity, which can potentially reduce the overall heat transfer coefficient. Additionally, the behavior of nanoparticles in nanofluids can affect the heat transfer process. Nanoparticle agglomeration or settling can modify fluid flow properties and limit the overall heat transfer effectiveness, leading to a decreased heat transfer coefficient compared to pure PCM.

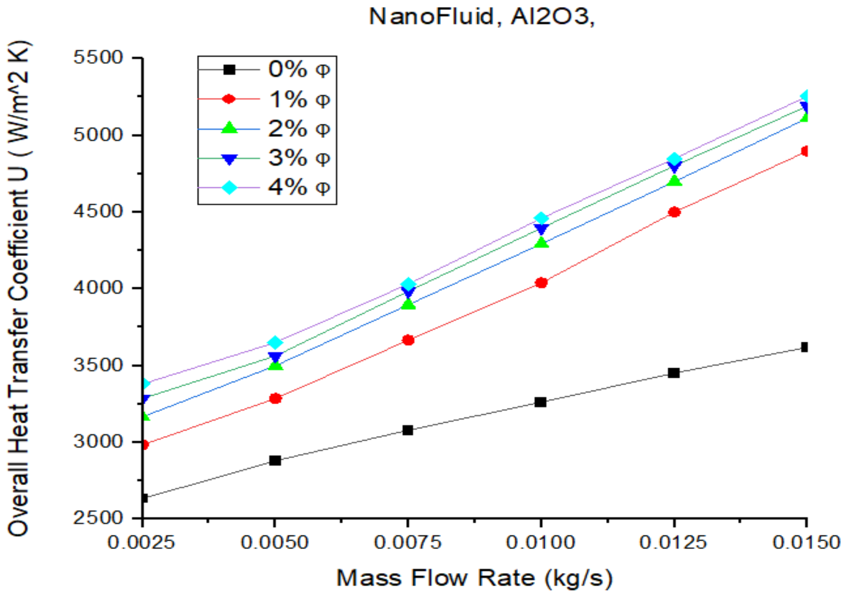

Figure 8: Graph between mass flow rate vs overall heat transfer coefficient for different volume fraction of nanofluid

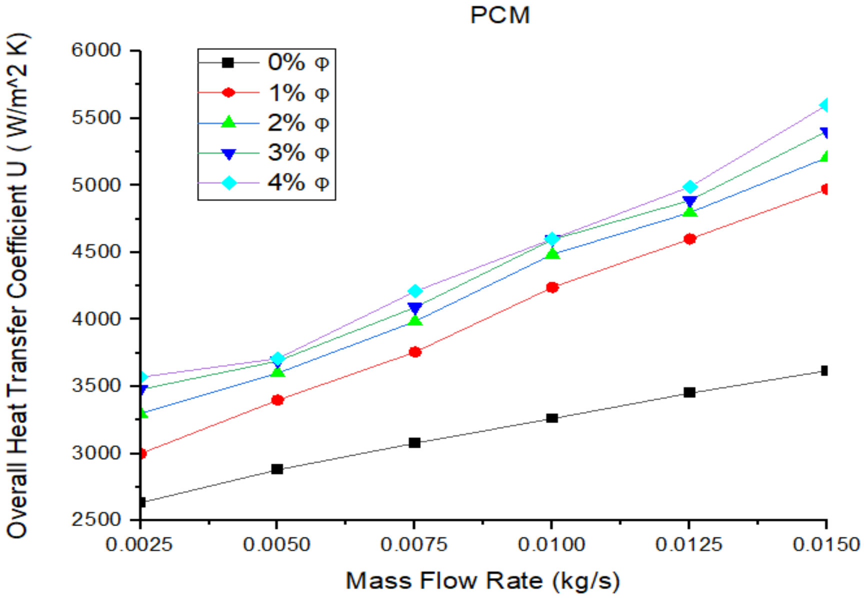

Figure 9: Graph between mass flow rate vs overall heat transfer coefficient for different volume fraction of pcm

The velocity distribution within the microchannels is a crucial aspect to examine when evaluating the flow behavior and heat transfer properties of the system. The researchers conducted a thorough analysis of flow patterns and identified regions with high and low velocities by examining velocity outlines. These contours visually depicted the velocity profile across the cross-sectional area of the microchannels. The data revealed that the velocity was highest towards the center of the channels and gradually decreased towards the channel sides. This velocity profile indicates the prevalence of forced convection and provides valuable insights into the fluid dynamics occurring within the microchannel heat exchanger. Figure 11 showcases the velocity streamline visualization of the microchannel heat exchanger, illustrating the flow patterns within the system.

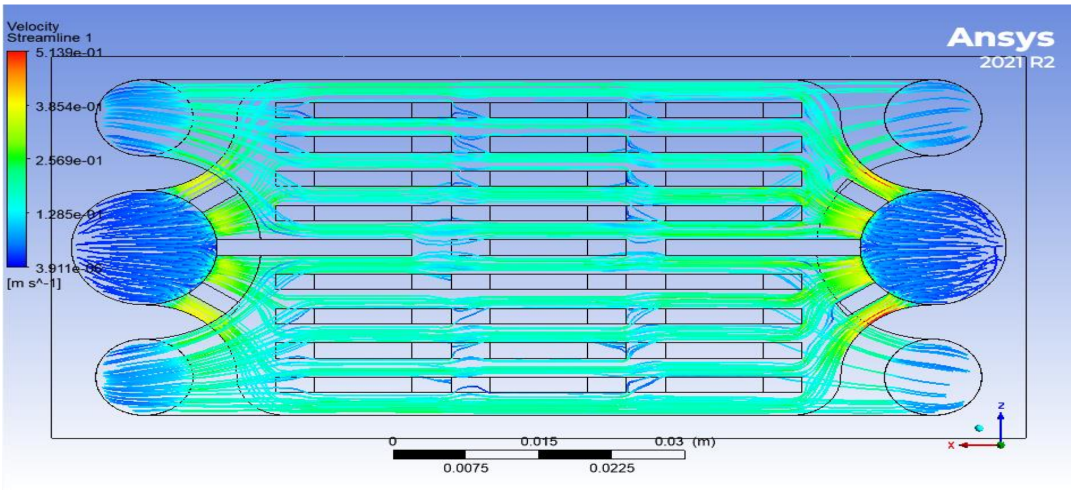

Figure 10: Velocity streamline

In assessing the heat transfer efficiency of a microchannel heat exchanger, the distribution of temperatures is a significant factor to consider. Temperature contours obtained from the study revealed variations in temperature across the microchannels. These contours allowed for the identification of regions with high and low temperatures, providing insights into the heat transfer patterns occurring within the system. The hot inlet exhibited a maximum temperature of 350 degrees Celsius, while the cold inlet had a minimum temperature of 290 degrees Celsius. Heat was transferred from the hot fluid to the cold fluid, resulting in an increase in temperature at the cold exit and a decrease in temperature at the hot outlet.

Figure 12 displays the temperature distribution as a contour plot for phase 1 (water), while Figure 13 represents the temperature contour for phase 2 (PCM). These temperature contours illustrate the PCM's capability to absorb and release thermal energy during phase change. The results indicated that the temperature was highest within the PCM zone during the phase transition process, ensuring efficient storage and transfer of thermal energy within the heat exchanger. Figures 14 and 15 depict the temperature contours for the hot and cold fluid domains, respectively. Additionally, Figure 16 showcases the temperature variation along the route line within the microchannel heat exchanger. These temperature contours provide valuable information about the thermal behavior and heat transfer characteristics of the system.

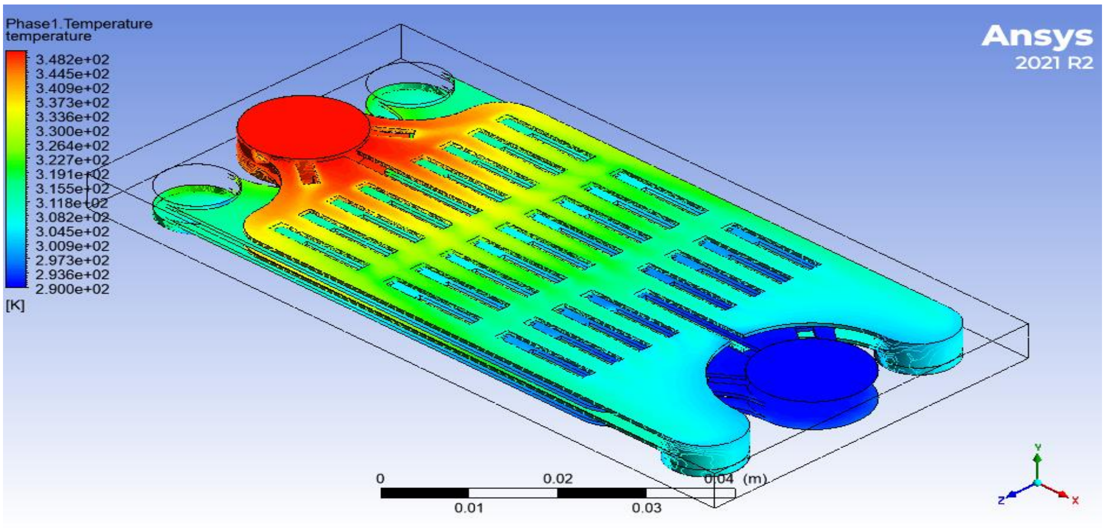

Figure 11: Phase 1(water) temperature contour

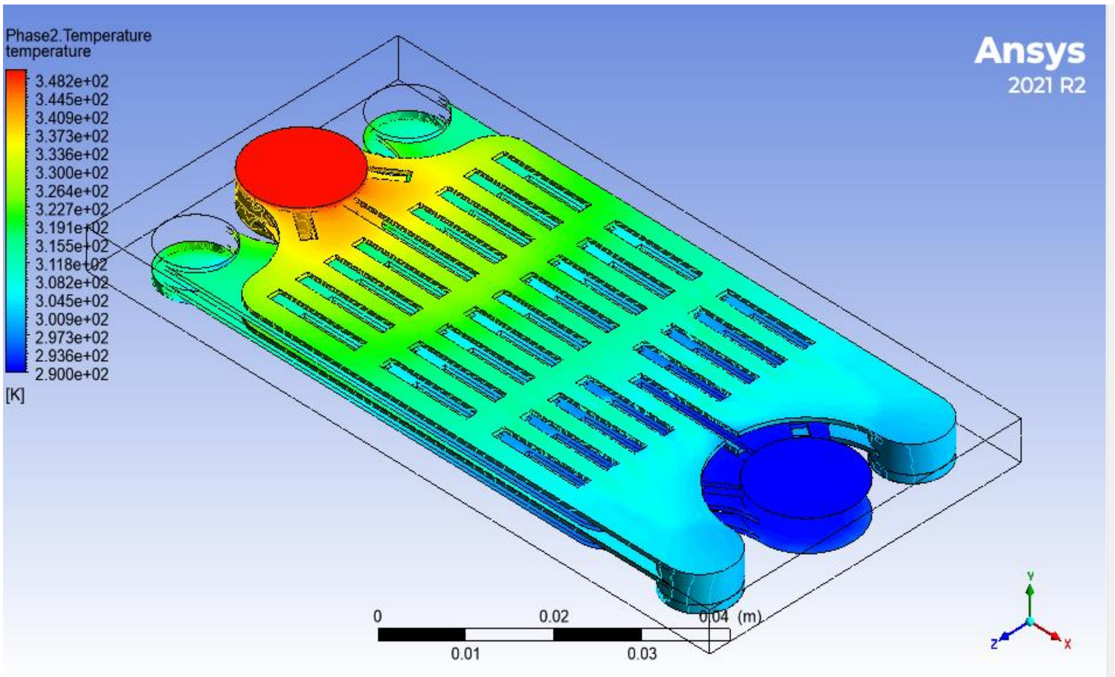

Figure 12: Phase2(pcm) temperature contour

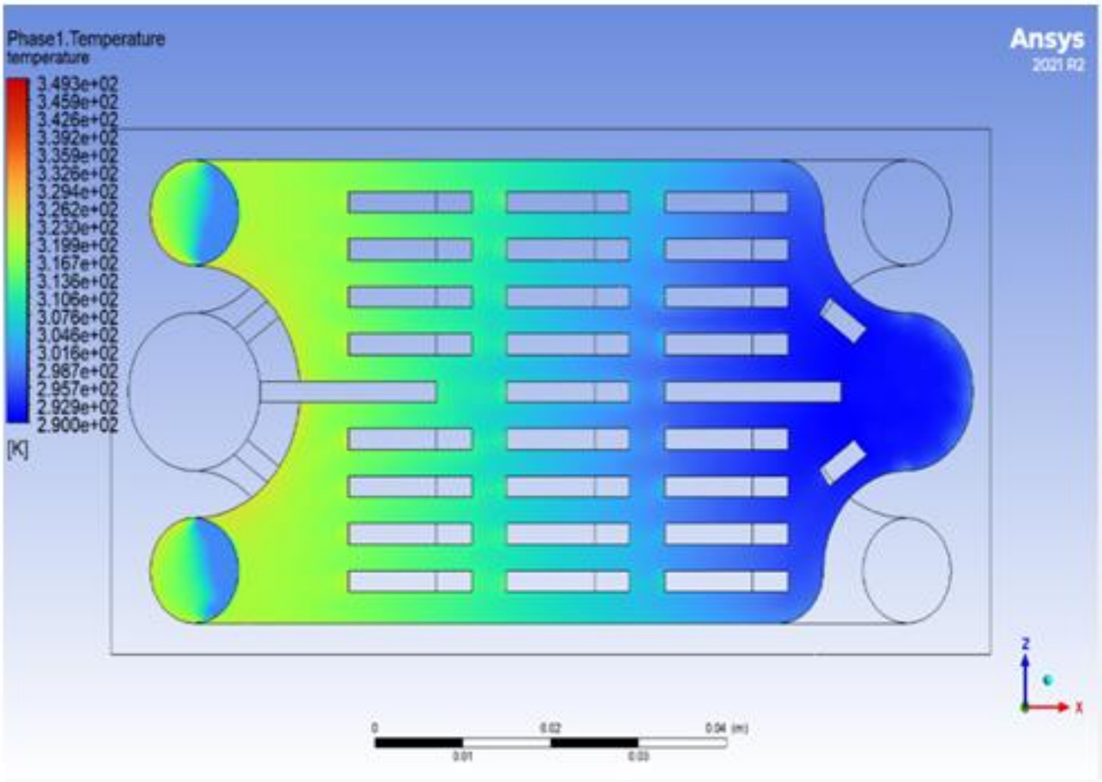

Figure 14: cold fluid domain temperature

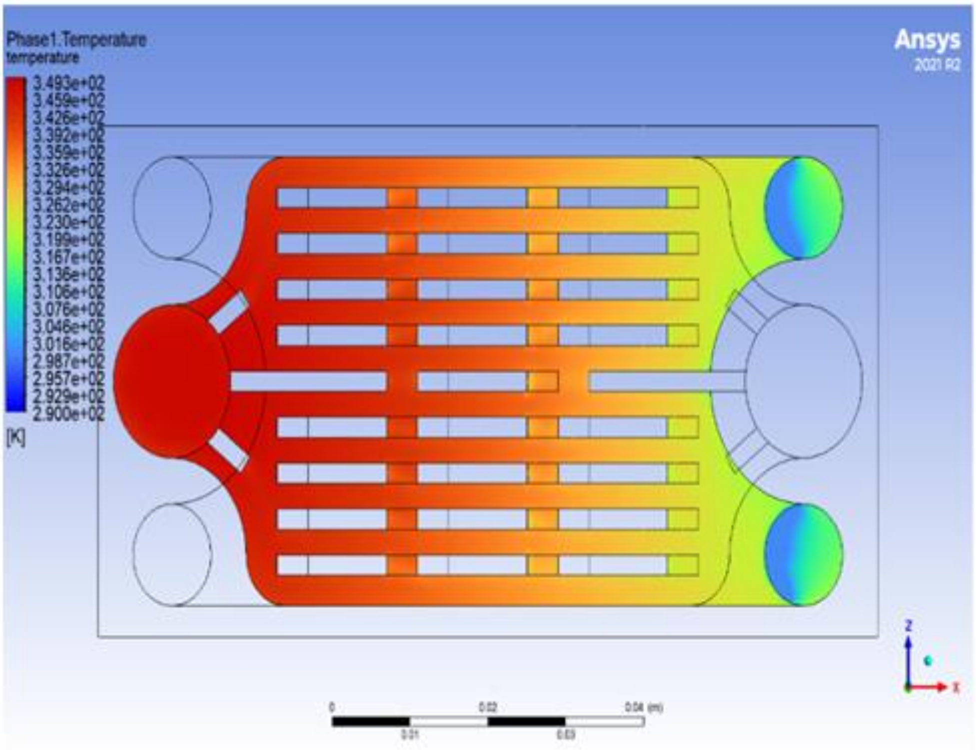

Figure 15: hot fluid domain temperature

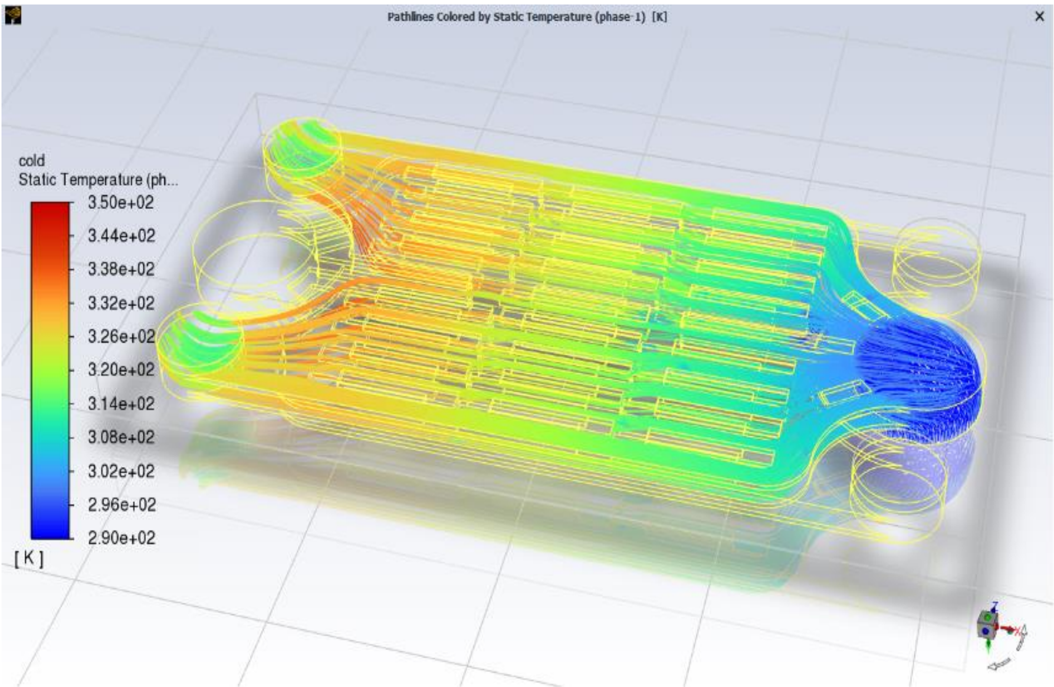

Figure 16 Temperature path line cold fluid domain

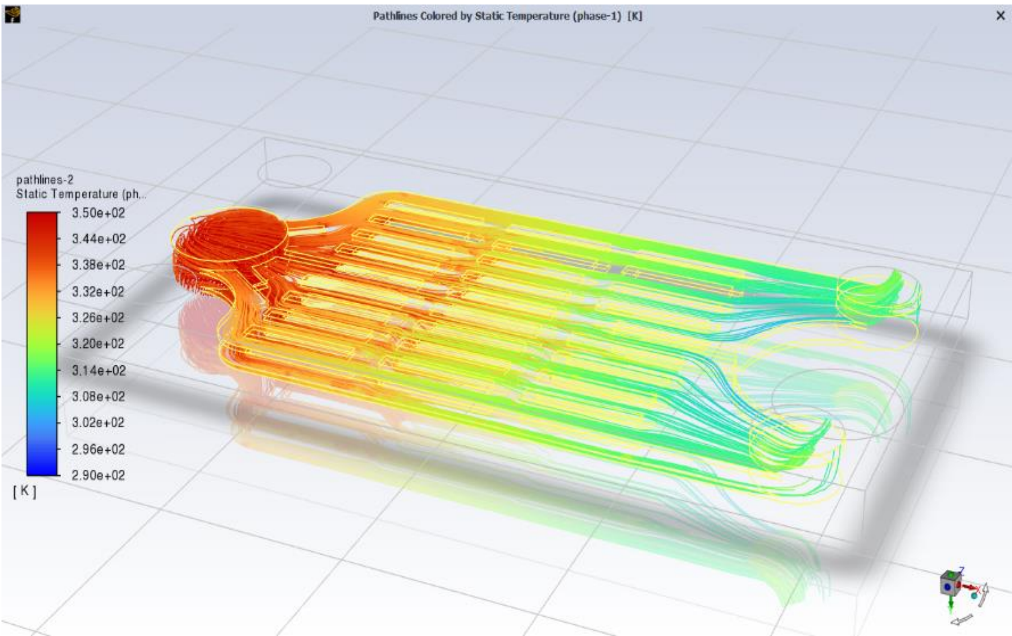

Figure 17 Temperature path lines hot fluid domain

The volume fraction contours displayed PCM concentrations in various regions, showing places with higher or lower particle concentrations. These contours aid in comprehending the mixing and dispersion properties of PCM particles or nanofluids, which are critical for optimising the thermal performance of the microchannel heat exchanger. Figure 18 depicts the volume percentage of pcm in the hot fluid domain as a contour.

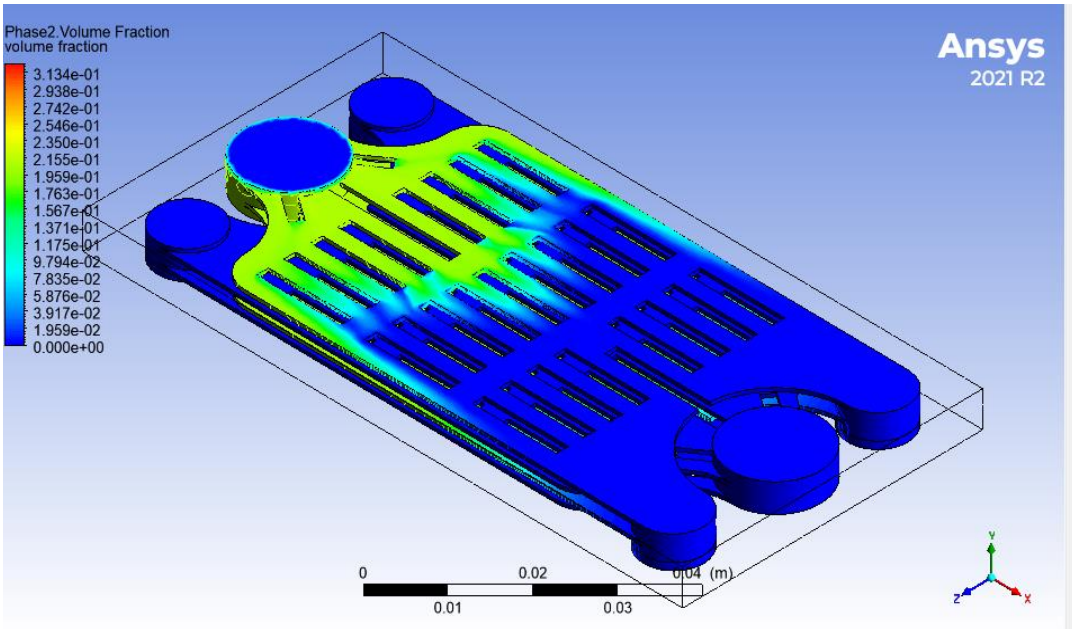

Figure 13: Volume fraction contour

Pressure contours depict the pressure change throughout the microchannels, revealing information about the system's pressure drop and flow resistance. We can discover high and low pressure zones, which indicate locations of higher flow resistance or potential pressure losses. These contours aided in the optimisation of the microchannel heat exchanger's design and flow characteristics, with the goal of minimising pressure drop while maximising heat transfer efficiency. Figure 19 depicts the pressure contour of the whole MCHE.

Figures 20 and 21 show pressure contours for the hot and cold fluid domains, respectively.

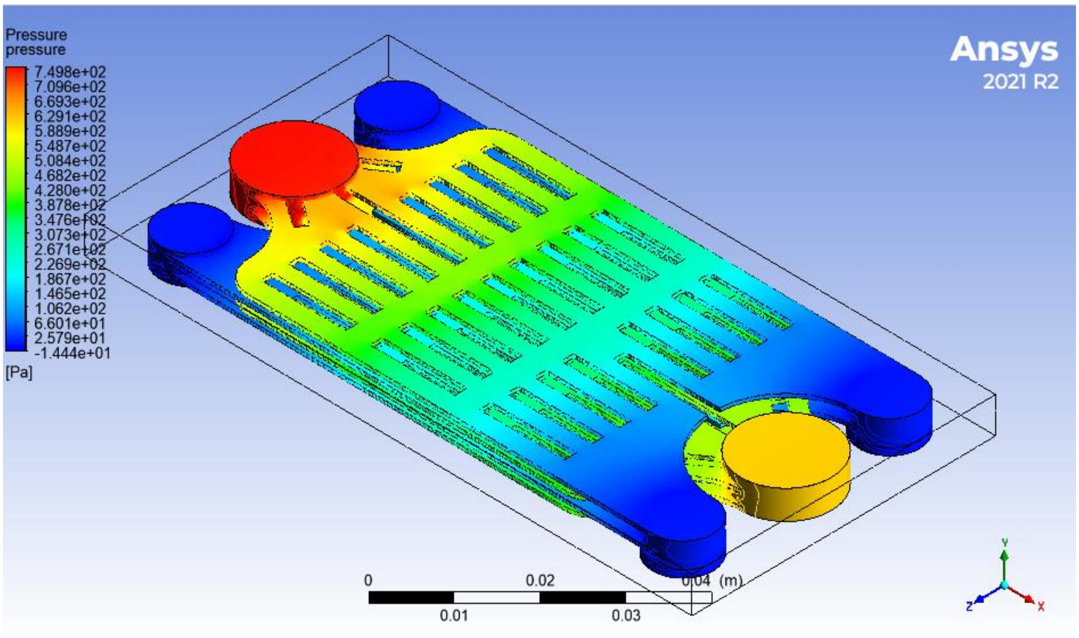

Figure 14: Pressure contour

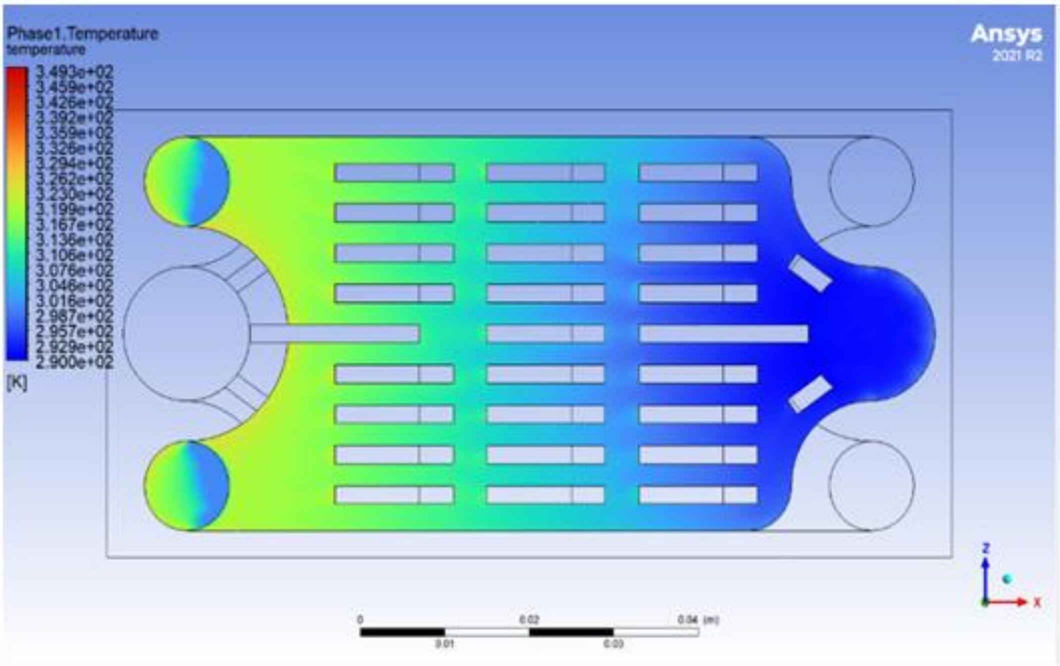

Figure 20: Cold fluid domain pressure

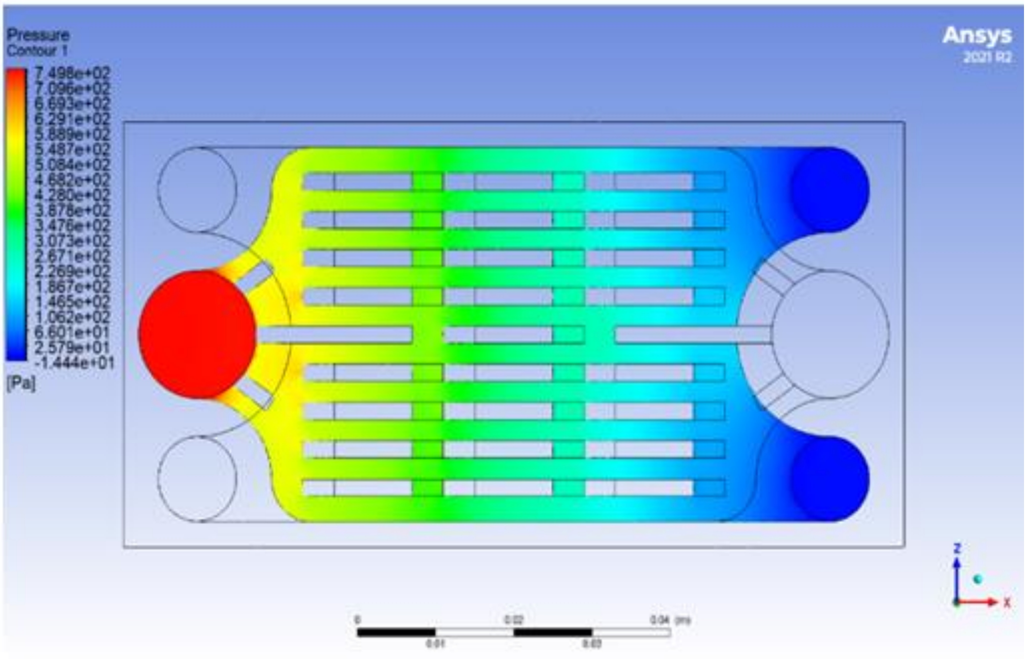

Figure 21: Hot fluid domain pressure

The density contours acquired from the research provided insights into fluid density fluctuations caused by the multiphase model. The density contours aided in understanding the flow patterns, pressure distribution, and heat transfer characteristics, allowing for a thorough investigation of the functioning of the microchannel heat exchanger. Figure 22 depicts the density contour.

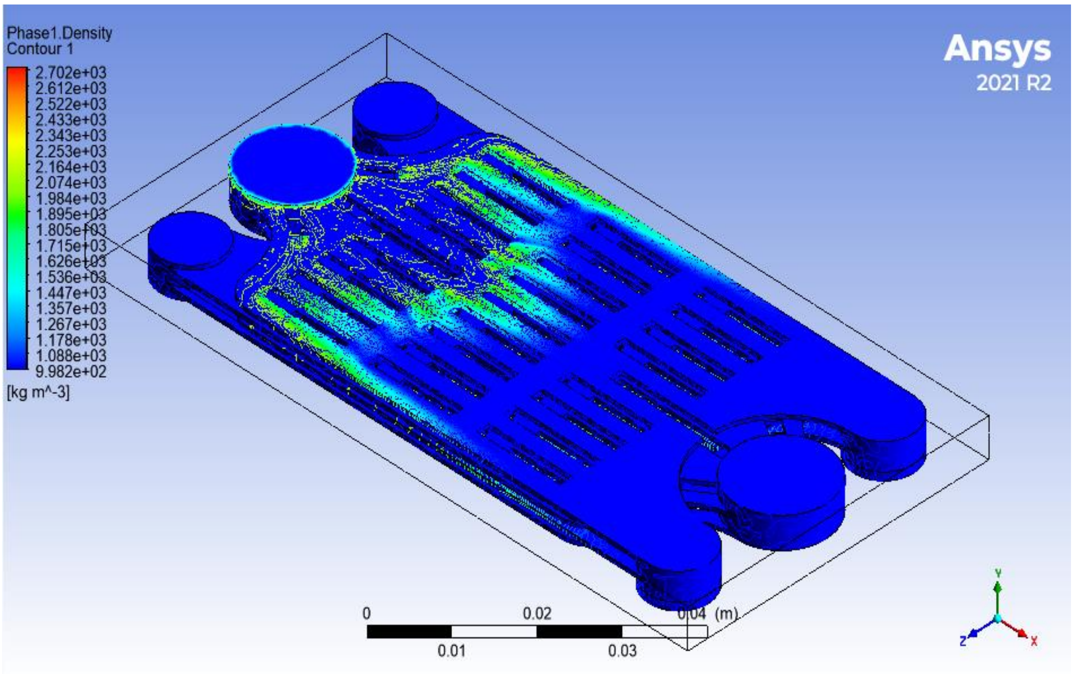

Figure 15: Density contour

The analysis of the microchannel heat exchanger (MCHE) with varying mass flow rates and volume percentages of PCM revealed that the pressure loss across the system increases with these alterations. Figure 23 demonstrates the relationship between pressure drop and mass flow rate for different PCM volume fractions (0%, 1%, 2%, 3%, and 4%). As expected, the pressure drop rises with higher mass flow rates.

However, the addition of PCM has a significant impact on reducing the pressure drop compared to the MCHE without PCM. This is because PCM possesses higher thermal conductivity and specific heat capacity than the base fluid, enabling improved heat transmission and reduced flow resistance. Consequently, at a given mass flow rate, the pressure drop is lower in the MCHE with PCM than in the MCHE without PCM.

Furthermore, the pressure drop decreases as the volume fraction of PCM increases at a given mass flow rate. This behavior can be attributed to the decreasing viscosity of the fluid with increasing PCM concentration. A lower viscosity results in reduced flow resistance, leading to lower pressure drops.

Overall, these findings indicate that the addition of PCM to the MCHE can effectively reduce pressure drop and subsequently decrease the power requirements for pumping. This improvement in energy efficiency demonstrates the potential of PCM to enhance the overall performance of the system.

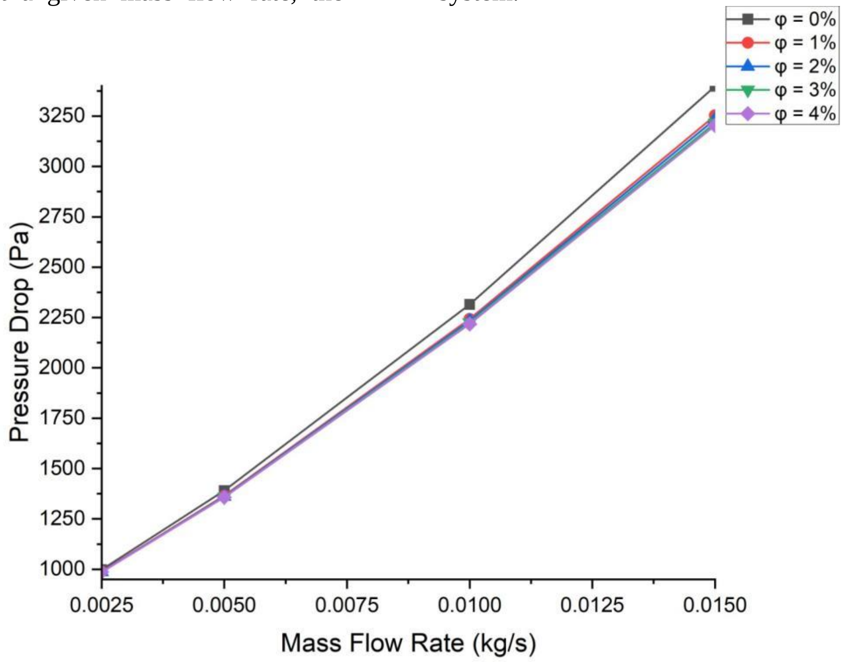

Figure 16: Pressure drop vs mass flow rate for different volume fraction of pcm

VI. CONCLUSION

The analysis conducted on the counter-flow four-layer Micro Channel Heat Exchanger (MCHE) using the Eulerian multiphase model in Ansys Fluent provided valuable insights into its thermohydraulic performance when operating with a water-Al2O3 nanofluid and Phase Change Material (PCM). The key findings of the study can be summarized as follows:

i. PCM exhibits a higher heat transfer coefficient compared to nanofluids due to its ability to undergo phase change, efficiently storing and releasing thermal energy. The phase transition process in PCM enables faster heat transfer rates, resulting in larger heat transfer coefficients.
ii. Nanofluids, while improving the thermal conductivity of the base fluid, tend to increase viscosity, which can lead to a drop in the overall heat transfer coefficient.
iii. The behavior of nanoparticles within nanofluids, such as agglomeration or settling, can also affect heat transfer effectiveness, resulting in a reduced heat transfer coefficient compared to pure PCM.
iv. The velocity distribution analysis revealed that forced convection dominates within the microchannels of the MCHE, with higher velocities observed near the channel center and gradually decreasing towards the channel sides. This understanding of fluid dynamics is crucial for optimizing the design and performance of the MCHE.
v. The temperature distribution study demonstrated the PCM's capability to absorb and release thermal energy

during phase change. The PCM region exhibited the highest temperature during the phase transition process, ensuring efficient thermal energy storage and transfer.

vi. Volume fraction contours provided insights into the concentration and dispersion properties of PCMs or nanofluids, which are essential for optimizing the MCHE's thermal performance.

vii. Pressure contours revealed pressure changes in the microchannels, indicating flow resistance and potential pressure losses. Optimizing the MCHE's design and flow characteristics based on pressure contours can reduce pressure drop and enhance heat transfer efficiency.

viii. Density contours helped in understanding fluid density fluctuations caused by the multiphase model, contributing to the analysis of flow patterns, pressure distribution, and heat transfer characteristics within the MCHE.

ix. Including PCM in the MCHE was found to reduce pressure drop, resulting in decreased pumping power requirements and increased energy efficiency. The findings contribute to increased efficiency, improved performance, and energy savings in MCHE applications.

VII. REFERENCES

[1]. Jung, S. Y., & Park, H. (2021). Experimental investigation of heat transfer of Al2O3 nanofluid in a microchannel heat sink. International Journal of Heat and Mass Transfer, 179, 121729. https://doi.org/10.1016/j.ijheatmasstransfer.2021.121729

[2]. Kwon, B., Maniscalco, N. I., Jacobi, A. M., & King, W. P. (2019a). High power density two-phase cooling in microchannel heat exchangers. Applied Thermal Engineering, 148, 1271–1277. https://doi.org/10.1016/j.applthermaleng.2018.11.123

[3]. Kwon, B., Maniscalco, N. I., Jacobi, A. M., & King, W. P. (2019b). High power density two-phase cooling in microchannel heat exchangers. Applied Thermal Engineering, 148, 1271–1277. https://doi.org/10.1016/j.applthermaleng.2018.11.123

[4]. Ma, F., Zhu, T., Zhang, Y., Lu, X., Zhang, W., & Ma, F. (2023). A Review on Heat Transfer Enhancement of Phase Change Materials Using Fin Tubes. Energies, 16(1), 545. https://doi.org/10.3390/en16010545

[5]. Mashayekhi, R., Khodabandeh, E., Akbari, O. A., Toghraie, D., Bahiraei, M., & Gholami, M. (2018). CFD analysis of thermal and hydrodynamic characteristics of hybrid nanofluid in a new designed sinusoidal double-layered microchannel heat sink. Journal of Thermal Analysis and Calorimetry, 134(3), 2305–2315. https://doi.org/10.1007/s10973-018-7671-3

[6]. Mazaheri, N., Bahiraei, M., & Razi, S. (2021). Two-phase analysis of nanofluid flow within an innovative four-layer microchannel heat exchanger: Focusing on energy efficiency principle. Powder Technology, 383, 484–497. https://doi.org/10.1016/j.powtec.2021.01.045

[7]. Mohammadian, E. , S. M. B. , & T. M. R. (2018). Numerical investigation on thermal performance of wavy channel microchannel heat exchanger using CuO/water nanofluid. . Journal of Thermal Analysis and Calorimetry, 553–566.

[8]. Nakhchi, M. E., & Esfahani, J. A. (2021). Numerical investigation of turbulent CuO–water nanofluid inside heat exchanger enhanced with double V-cut twisted tapes. Journal of Thermal Analysis and Calorimetry, 145(5), 2535–2545. https://doi.org/10.1007/s10973-020-09788-4

[9]. SUBASI, A. (2022). Mini-channel heat exchanger optimization using genetic algorithm and multiple-criteria decision making. Journal of Thermal Engineering, 8(1), 29–37. https://doi.org/10.18186/thermal.1066993

[10]. Wu, H., & Zhang, S. (2021). Numerical Study on the Fluid Flow and Heat Transfer Characteristics of Al2O3-Water Nanofluids in Microchannels of Different Aspect Ratio. Micromachines, 12(8), 868. https://doi.org/10.3390/mi12080868

[11]. Wu, Y., Zhi, C., Wang, Z., Chen, Y., Wang, C., Chen, Q., Tan, G., & Ming, T. (2023). Enhanced thermal and mechanical performance of 3D architected micro-channel heat exchangers. Heliyon, 9(3), e13902. https://doi.org/10.1016/j.heliyon.2023.e13902

[12]. Zhang, X., Tiwari, R., Shooshtari, A. H., & Ohadi, M. M. (2018). An additively manufactured metallic manifold-microchannel heat exchanger for high temperature applications. Applied Thermal Engineering, 143, 899–908. https://doi.org/10.1016/j.applthermaleng.2018.08.032

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