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Design And Analysis Of Double Helical Coil Heat Exchanger Using Al_2O_3 Nanofluid

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ABSTRACT

A Double Helical Coil Heat Exchanger (DHCHE) using nanofluids is an advanced thermal system designed to enhance heat transfer performance by combining the benefits of helical geometry and high-conductivity working fluids. The helical coil structure induces secondary flow patterns, known as Dean vortices, which improve fluid mixing and significantly increase the heat transfer rate compared to conventional straight tube heat exchangers.

In this study, nanofluids such as Al_2O_3 dispersed in base fluids like water are utilized to further enhance thermal conductivity. The presence of nanoparticles increases the heat transfer coefficient, leading to improved thermal efficiency of the heat exchanger. Key performance parameters, including temperature distribution, pressure drop, Nusselt number, and overall heat transfer coefficient, are analyzed to evaluate system effectiveness.

The results demonstrate that the use of nanofluids in a helical coil heat exchanger considerably improves heat transfer performance while maintaining a compact design. Although an increase in pressure drop is observed due to both the helical curvature and nanoparticle addition, the overall thermal enhancement outweighs this drawback. This makes nanofluid-based double helical coil heat exchangers highly suitable for applications in power plants, chemical industries, refrigeration systems, and energy-efficient heat recovery processes [1] .

Keywords: double helical coil, pressure drop, nanofluids, enhance heat transfer .

INTRODUCTION

Heat exchangers are essential components in many engineering systems, playing a crucial role in transferring heat between two or more fluids without mixing them. They are widely used in industries such as power generation, chemical processing, refrigeration, air conditioning, automotive engineering, and energy systems. With the growing demand for energy efficiency and compact thermal systems, conventional heat exchangers often face limitations in terms of size, heat transfer rate, and performance. This has led to the development of advanced heat exchanger designs, among which the Double Helical Coil Heat Exchanger (DHCHE) has gained significant attention.

A double helical coil heat exchanger consists of two tubes wound in a spiral or helical shape, usually placed inside a cylindrical shell. One fluid flows through the helical coil while another fluid flows over it, enabling heat exchange between them. The curvature of the coil introduces centrifugal forces that generate secondary flow patterns known as Dean vortices. These vortices enhance fluid mixing, disrupt boundary layers, and significantly improve the heat transfer coefficient compared to straight tube heat exchangers. As a result, helical coil heat exchangers offer higher thermal efficiency, compact design, and better performance in handling high-pressure and high-temperature applications.

Despite these advantages, there is a continuous need to further improve heat transfer efficiency, especially in modern industrial systems where energy conservation is critical. One of the most promising approaches to enhance heat transfer is the use of nanofluids. Nanofluids are engineered fluids that contain nanoparticles (typically less than 100 nm in size) such as aluminium oxide (Al_2O_3))and carbon-based materials dispersed in a base fluid like water, ethylene glycol, or oil. These nanoparticles possess high thermal conductivity, which significantly improves the overall thermal properties of the fluid.

The integration of nanofluids into helical coil heat exchangers represents a powerful combination for enhancing thermal performance. The improved thermal conductivity of nanofluids, along with the enhanced mixing due to the helical coil geometry, results in a substantial increase in heat transfer rate. Additionally, nanofluids can alter properties such as viscosity, density, and specific heat capacity, which influence the flow behaviour and heat transfer characteristics within the exchanger.

However, the use of nanofluids also introduces certain challenges. The addition of nanoparticles can increase the viscosity of the fluid, leading to higher pressure drop and pumping power requirements. Stability of the nanofluid, particle agglomeration, and potential erosion or clogging of the tubes are also important considerations. Therefore, a detailed analysis of thermal performance, fluid flow behavior, and system efficiency is necessary to optimize the design and operation of helical coil heat exchangers using nanofluids.

This study focuses on the design, analysis, and performance evaluation of a helical coil heat exchanger utilizing nanofluids. It aims to investigate key parameters such as temperature distribution, heat transfer coefficient, Nusselt number, and pressure drop under different operating conditions. The objective is to demonstrate how nanofluids can significantly enhance the efficiency of helical coil heat exchangers and contribute to the development of energy-efficient thermal systems.

Thus, the objectives of this study are:

- To design and develop a helical coil heat exchanger for efficient heat transfer applications.
- To enhance heat transfer performance by using nanofluids such as Al_2O_3.
- To analyze thermal characteristics like temperature distribution, Nusselt number, and heat transfer coefficient.
- To evaluate the pressure drop and flow behavior of nanofluids inside the helical coil.
- To compare the performance of nanofluids with conventional fluids and determine overall system efficiency [2]

2. METHODOLOGY

2.1 DESIGN OF DOUBLE HEAT EXCHANGER

The design of a Double Helical Coil Heat Exchanger (DHCHE) using nanofluids involves a systematic approach to ensure efficient heat transfer between hot and cold fluids. Initially, the design requirements such as the desired heat transfer rate, inlet and outlet temperatures, mass flow rates, and operating conditions are determined. Based on these requirements, suitable materials like copper, stainless steel, or aluminium are selected considering their thermal conductivity, strength, and corrosion resistance. The geometric parameters of the heat exchanger, including tube diameter, coil diameter, pitch, number of turns, and total coil length, are then defined to achieve a compact and efficient configuration.[3]

2.2 MATERIAL SELECTION

Common materials:

- Al_2O_3

Selection based on:

- Thermal conductivity
- Corrosion resistance
- Cost and availability

2.3 GEOMETRICAL PARAMETERS

- Tube inner diameter (di)
- Tube outer diameter (do)
- Coil diameter (Dc)
- Pitch (p) – distance between two turns
- Number of turns (N)
- Coil length (L)

2.3 PREPARATION OF NANOFLUIDS

The preparation of nanofluids is a crucial step in enhancing the heat transfer performance of a double helical coil heat exchanger. Nanofluids are formed by dispersing nanosized particles, typically less than 100 nm, into a base fluid such as water, ethylene glycol, or oil. Common nanoparticles used include aluminium oxide (Al_2O_3) which possess high thermal conductivity. The most widely used method for preparing nanofluids is the two-step method, where nanoparticles are first synthesized separately and then mixed into the base fluid.

In this process, a measured quantity of nanoparticles is added to the base fluid based on the desired concentration, usually expressed in volume fraction or weight percentage. The mixture is then subjected to mechanical stirring followed by ultrasonic agitation (sonication) to ensure uniform dispersion of particles and to break any agglomerations. In some cases, surfactants or stabilizing agents are added to improve the stability of the suspension and prevent particle settling over time. Proper preparation is essential to maintain a stable and homogeneous nanofluid, as instability can reduce thermal performance and affect experimental accuracy.[4]

2.4 SIMULATION

Simulation of a double helical coil heat exchanger using nanofluids is carried out to analyse and predict the thermal and flow behaviour of the system under different operating conditions. Computational Fluid Dynamics (CFD) tools such as ANSYS Fluent are commonly used to model the heat exchanger and study parameters like temperature distribution, velocity profile, pressure drop, and heat transfer rate. Initially, a three-dimensional geometric model of the helical coil heat exchanger is created based on design specifications, including coil diameter, tube diameter, pitch, and number of turns. The geometry is then discretized into a fine mesh to ensure accurate numerical results.[5]

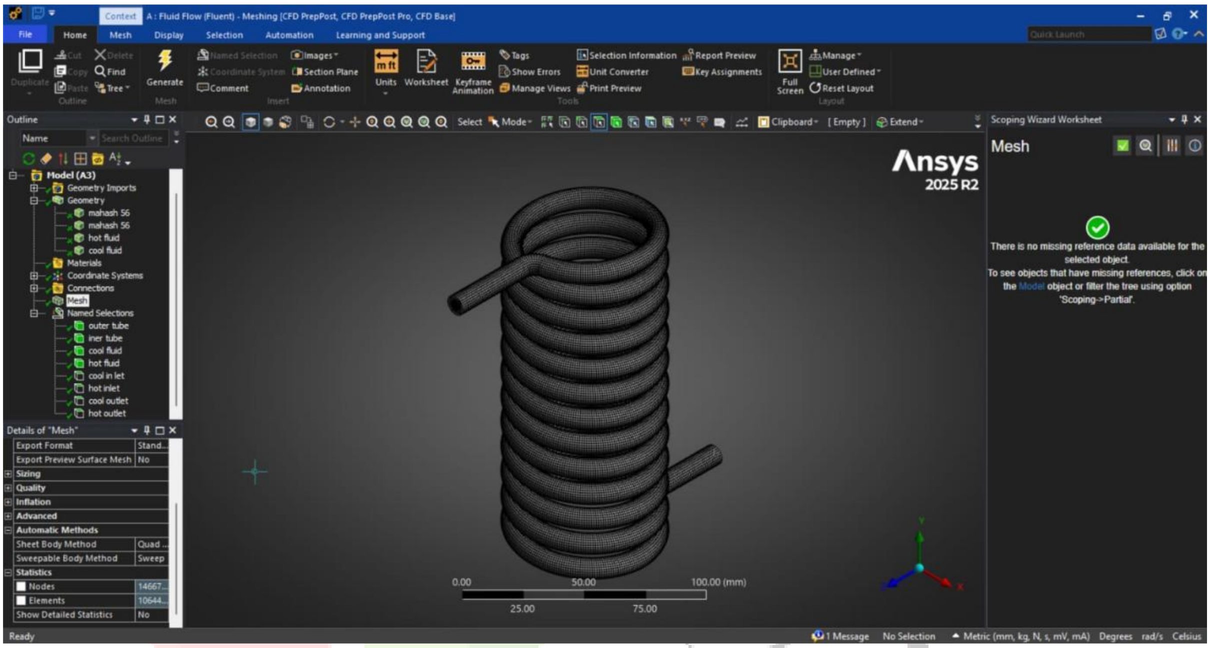
2.4.1 DESIGN

The design of a Double Helical Coil Heat Exchanger (DHCHE) using nanofluids focuses on achieving high heat transfer efficiency within a compact structure. The process begins with identifying the required heat duty, which depends on the inlet and outlet temperatures, mass flow rates, and properties of the working fluids. Based on these requirements, suitable materials such as copper or stainless steel are selected due to their good thermal conductivity and corrosion resistance.

The geometric configuration of the helical coil is then determined, including parameters like tube diameter, coil diameter, pitch, and number of turns, which directly influence the heat transfer performance and pressure drop.[6]

2.4.2 MESHING

Mesh generation is a critical step in the simulation of a helical coil heat exchanger using nanofluids, as it directly affects the accuracy and convergence of the computational results. In this process, the three-dimensional geometry of the helical coil and surrounding fluid domain is divided into a large number of small elements or control volumes. Due to the complex curved geometry of the helical coil, a fine and well-structured mesh is required, especially near the tube walls where heat transfer and fluid flow gradients are significant as show in figure 1. [7]



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Details of "Mesh"

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Figure 1. Mesh

2.5 TESTING PROCEDURE

VELOCITY

In a double helical coil heat exchanger, **velocity** refers to the speed at which a fluid flows through the coiled tube or the surrounding shell, and it is a key factor influencing overall thermal performance. As the velocity of the fluid increases, the flow becomes more turbulent, which enhances mixing and significantly improves heat transfer between the hot and cold fluids. This is especially important in helical coils because the curved geometry generates secondary flows known as Dean vortices, which further promote efficient heat transfer even at moderate velocities. However, increasing velocity also leads to a higher pressure drop due to increased frictional resistance, requiring greater pumping power. Therefore, an optimal velocity must be selected to achieve a balance between improved heat transfer and acceptable energy consumption. Typically, fluid velocity in such systems ranges from about 0.5 to 3 m/s, depending on the fluid properties, tube dimensions, and operating conditions.

TEMPARATURE

In a helical coil heat exchanger, **temperature** is the primary driving force for heat transfer between two fluids. Heat flows from the fluid at a higher temperature to the one at a lower temperature through the coil wall. The efficiency of this heat transfer depends on the temperature difference between the hot and cold fluids, commonly referred to as the temperature gradient. As fluids move along the helical coil, their temperatures continuously change—hot fluid loses heat and cools down, while cold fluid gains heat and warms up. The curved geometry of the coil enhances mixing due to secondary flows, which helps maintain a more uniform temperature distribution and improves heat transfer performance. However, very high temperatures can affect material strength and fluid properties, while low temperature differences can reduce heat transfer efficiency. Therefore, careful control of inlet and outlet temperatures is essential for optimal operation of a helical coil heat exchanger.

HEAT TRANSFER

In a helical coil heat exchanger, **heat transfer** occurs when thermal energy flows from a hot fluid to a cold fluid through the wall of the coiled tube. This process is mainly governed by the temperature difference between the two fluids and is enhanced by the unique helical geometry of the coil. As the fluid flows through the curved tube, it experiences centrifugal forces that generate secondary flows known as Dean vortices. These vortices improve mixing within the fluid, reduce thermal resistance, and significantly increase the rate of heat transfer compared to straight tubes. Heat transfer in such systems takes place through three modes: conduction across the tube wall, and convection within both the inner and outer fluids. The overall heat transfer rate depends on factors such as fluid velocity, properties of the fluid (like viscosity and thermal conductivity), coil dimensions, and flow conditions. Higher flow velocities and the use of advanced fluids like nanofluids can further enhance heat transfer, although they may also increase pressure drop. Therefore, an optimal balance of operating conditions is essential to achieve efficient thermal performance in a helical coil heat exchanger [8]

2.6 DATA ANALYSIS

Heat transfer in a double helical coil heat exchanger using nanofluids is significantly enhanced due to the combined effects of coil geometry and improved fluid properties. In this system, heat is transferred from the hot fluid to the cold fluid through the wall of the helical tube by means of conduction and convection. The helical shape of the coil induces centrifugal forces as the fluid flows through it, resulting in secondary flow patterns known as Dean vortices. These vortices increase fluid mixing.

NUSSELT NUMBER

The Nusselt number is a dimensionless parameter used to evaluate the heat transfer performance in a helical coil heat exchanger, especially when nanofluids are employed. It represents the ratio of convective heat transfer to conductive heat transfer across the fluid. A higher Nusselt number indicates more effective convective heat transfer, which is desirable for improving the efficiency of the heat exchanger.

$$Nu=hD/k$$

In a helical coil heat exchanger, the Nusselt number is significantly influenced by the curvature of the coil, which induces secondary flows known as Dean vortices. These flows enhance fluid mixing and reduce the thermal boundary layer thickness, leading to an increase in the convective heat transfer coefficient. When nanofluids are used, the Nusselt number further increases due to the higher thermal conductivity of the fluid and the enhanced energy transport caused by the Brownian motion of nanoparticles.

COIL LENGTH CALCULATION

The coil length is an important design parameter in a helical coil heat exchanger, as it determines the total heat transfer area available for effective heat exchange between fluids. The length of the helical coil depends on the coil diameter and the number of turns in the coil. It is calculated based on the geometry of the helix, ensuring that the required heat transfer area is achieved for the desired thermal performance.

$$NL=\pi DcN$$

In this relation, the total length of the coil is directly proportional to the coil diameter and the number of turns. Increasing either the coil diameter or the number of turns results in a longer coil, which increases the surface area available for heat transfer. This, in turn, enhances the overall heat transfer rate of the exchanger. However, a longer coil also leads to higher pressure drop due to increased flow resistance, especially when nanofluids are used, as they generally have higher viscosity than conventional fluids.[9]

RESULTS AND DISCUSSIONS

In a **double helical coil heat exchanger using water as the working fluid**, the *results and discussion* typically focus on how water behaves in terms of heat transfer, flow characteristics, and overall system efficiency.

PRESSURE DROP

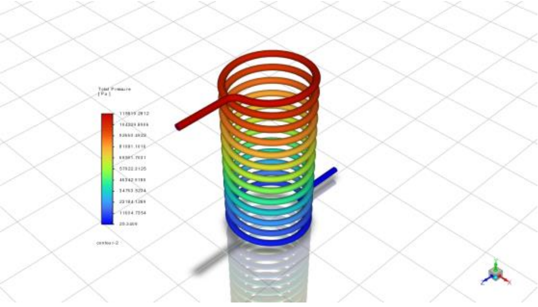


Figure 2. Pressure drops in DHCHE Water as a cooling medium variation

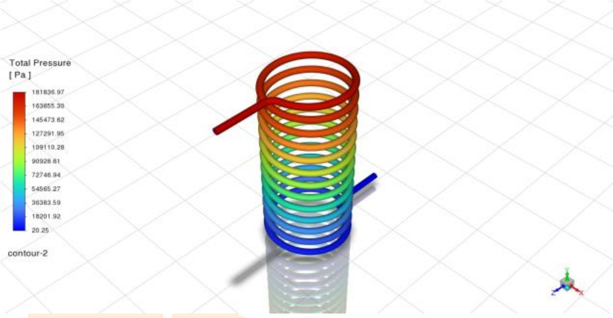


Figure 3. Pressure drops in DHCHE Al_2O_3 as a cooling medium variation

The comparison of **pressure drops** between as show in figure 2,3 cooling medium variation of water and Al_2O_3nanofluid at inlet velocities of **1, 1.5, and 2 m/s** shows that pressure increases with velocity for both fluids, while Al_2O_3exhibits a different hydraulic response due to the presence of nanoparticles. For water, the cold inlet total pressure rises from **64,344 Pa** at 1 m/s to **115,783 Pa** at 1.5 m/s. For Al_2O_3. the corresponding values are **39,880 Pa**, **106,811 Pa**, and **181,783 Pa** at 1, 1.5, and 2 m/s respectively. At lower velocity (1 m/s), water shows higher pressure than Al_2O_3, whereas at higher velocities Al_2O_3produces significantly larger pressure values. This behavior is mainly due to increased density and viscosity of the nanofluid, which raises flow resistance and momentum effects at higher Reynolds conditions. The results indicate that Al_2O_3 nanofluid can enhance thermal performance, but it also requires greater pumping power because of the higher pressure drop compared with water, especially at elevated flow velocities.

TEMPARATURE

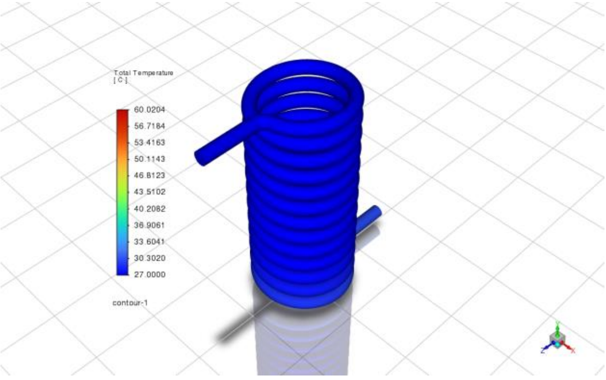


Figure 4. Temperature Variation of Water

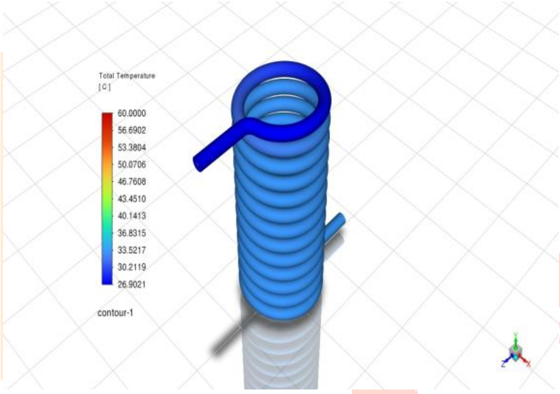
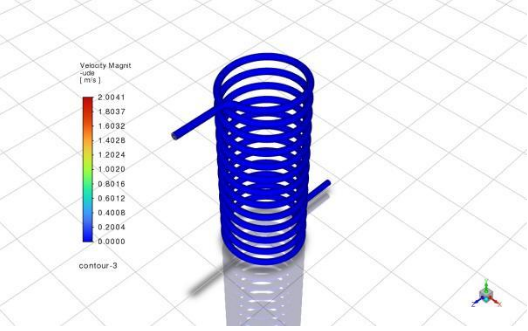


Figure 5. Temperature Variation in Al_2O_3

The comparison of **total temperature** between as show in figure 4,5 temperature variation of water and Al_2O_3 nanofluid at inlet velocities of **1, 1.5, and 2 m/s** indicates improved thermal performance for the nanofluid. For water, the cold outlet temperature changes from **32.61°C** at 1 m/s to **30.76°C** at 1.5 m/s, while the hot outlet remains near **27°C**, showing effective heat exchange. In contrast, Al_2O_3 nanofluid gives higher cold outlet temperatures of **34.03°C**, **34.06°C**, and **33.88°C** at 1, 1.5, and 2 m/s respectively, while the hot outlet temperatures remain around **32.4–32.6°C**. This shows that the nanofluid absorbs and retains more thermal energy because of its higher thermal conductivity and enhanced particle-fluid interaction. The water case shows a stronger reduction in outlet temperature with increasing velocity due to reduced residence time, whereas Al_2O_3 maintains more stable temperature values over the tested range. Overall, the results confirm that Al_2O_3 nanofluid provides superior heat transfer characteristics compared with water in the helical coil heat exchanger.

VELOCITY



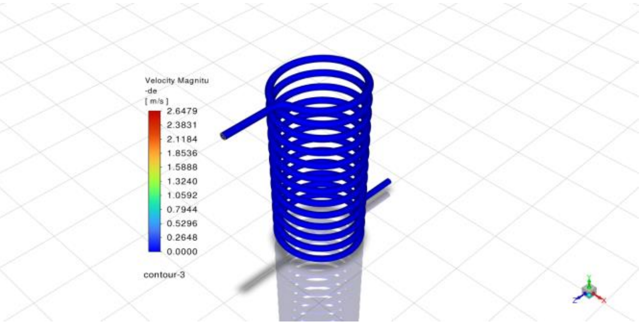


Figure 6. Velocity Distribution in Water **Figure 7. Velocity Distribution in Al_2O_3**

Based on the CFD results for water at 1 m/s, the **velocity magnitude** shows minor variation along the helical coil. The cold fluid velocity slightly decreases from **1 m/s to 0.973 m/s**, while the hot fluid increases from **0.7 m/s to 0.755 m/s**. This change is due to flow development and secondary motion caused by the coil curvature. The net velocity of **0.829 m/s** indicates stable and continuous flow. Overall, the results show uniform velocity distribution with effective mixing inside the coil as show in figure 6,7. [10]

COMPARISION OF WATER AND Al2O3

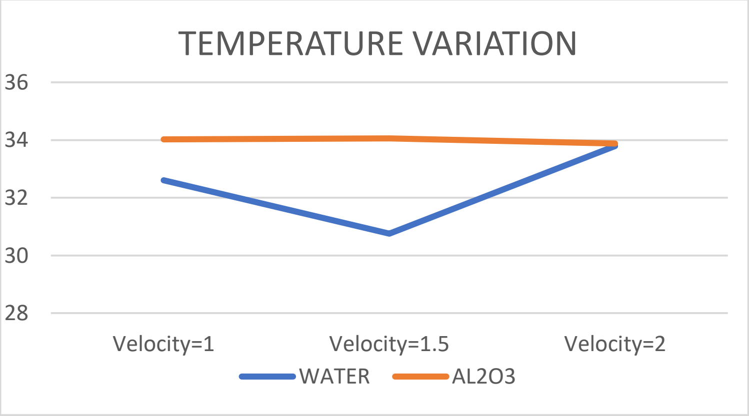


Figure 8. Comparison of temperature variation in DHCHE

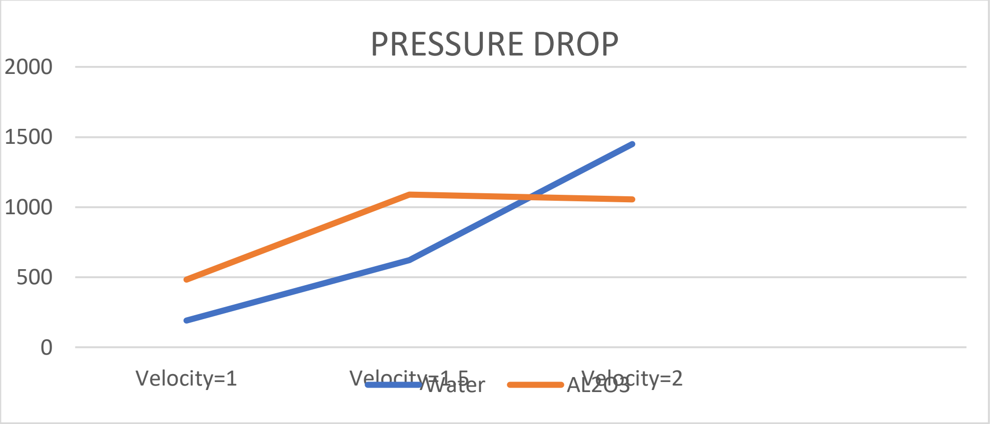


Figure 9. Comparison of Pressure drop in DHCHE

CONCLUSION

Based on the pressure versus velocity comparison graph for water in the helical coil heat exchanger, it is observed that pressure varies significantly with flow velocity. At the inlet velocity of **1 m/s**, the total pressure reaches the highest value, while pressure decreases at outlet regions due to frictional and flow resistance losses inside the coil. This indicates that as fluid moves through the helical path, energy losses occur because of curvature effects and turbulence generation. The graph confirms that water experiences noticeable pressure drop within the exchanger, which is an important factor in pump power requirement and system efficiency. Therefore, proper selection of operating velocity is necessary to achieve a balance between higher heat transfer performance and lower pressure loss in the helical coil heat exchanger.

REFERENCES

[1] S. K. Das, S. U. S. Choi, and H. E. Patel, “Heat transfer in nanofluids—A review,” *International Journal of Heat and Mass Transfer*, vol. 48, no. 12, pp. 240–250, 2005.

[2] M. Naphon and S. Wongwises, “A review of flow and heat transfer characteristics in curved tubes,” *Applied Thermal Engineering*, vol. 26, no. 8–9, pp. 845–854, 2006.

[3] S. K. Das, S. U. S. Choi, and H. E. Patel, “Heat transfer in nanofluids—A review,” *International Journal of Heat and Mass Transfer*, vol. 48, no. 12, pp. 240–250, 2005.

[4] W. Yu and H. Xie, “A review on nanofluids: Preparation, stability mechanisms, and applications,” *Renewable and Sustainable Energy Reviews*, vol. 43, pp. 590–606, 2015.

[5] S. M. Peyghambarzadeh et al., “Experimental study of heat transfer enhancement using nanofluids,” *Experimental Thermal and Fluid Science*, vol. 35, no. 7, pp. 1367–1374, 2011.

[6] R. K. Shah and D. P. Sekulic, *Fundamentals of Heat Exchanger Design*. Wiley, 2003.

[7] H. K. Versteeg and W. Malalasekera, *An Introduction to Computational Fluid Dynamics: The Finite Volume Method*. Pearson Education, 2007.

[8] F. P. Incropera, D. P. DeWitt, T. L. Bergman, and A. S. Lavine, *Fundamentals of Heat and Mass Transfer*. Wiley, 2007.

[9] F. P. Incropera, D. P. DeWitt, T. L. Bergman, and A. S. Lavine, *Fundamentals of Heat and Mass Transfer*. Wiley, 2007.

[10] J. P. Holman, *Heat Transfer*, 10th ed. McGraw-Hill, 2010.