CFD Letters

Journal homepage:
https://semarakilmu.com.my/journals/index.php/CFD_Letters/index
ISSN: 2180-1363

Numerical Analysis and Design for Thermal Efficiency Optimization using Al_2O_3 Nanofluids in Shell and Tube Heat Exchangers

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ARTICLE INFO

Article history:
Received 5 January 2024
Received in revised form 9 February 2024
Accepted 9 December 12 March 2024
Available online 30 June 2024

Keywords:
Nanofluids; Shell and tube heat exchangers; Computational fluid dynamics; heat transfer

ABSTRACT

In this study, the efficacy of aluminum oxide (Al_2O_3) nanofluids at a 2% concentration for enhancing heat transfer in shell and tube heat exchangers is evaluated. By employing SOLIDWORKS for the innovative design and Computational Fluid Dynamics (CFD) for simulation, an improvement in heat transfer efficiency over traditional hot water systems is identified. Emphasizing the unique properties of Al2O3 nanofluids in augmenting heat transfer rates, the role of advanced CAD and simulation tools in engineering practices is highlighted. Results confirm nanofluids' benefits in improving thermal management systems, indicating their potential to decrease energy consumption and operational costs. Furthermore, the exploration of a novel design for heat exchangers, inspired by but distinct from existing market standards, suggests new avenues for the application of nanofluids in various industrial settings, marking a step towards more energy-efficient technologies.

1. Introduction

Heat exchangers are pivotal in modern industries, particularly in power generation and petrochemical processing, where they efficiently transfer heat between fluids [1]. Recent advancements in heat transfer techniques have spotlighted nano-fluids, such as Al_2O_3 nano-fluids, for their improved thermal properties and potential in enhancing heat exchanger efficiency[2]. However, the implementation of nano-fluids faces challenges like particle aggregation and equipment wear, which are areas of active research [3]. This study emphasizes the need for energy-efficient systems, acknowledging the limitations of conventional fluids and underscoring the transformative potential of nano-fluids. Furthermore, it highlights the role of simulations in understanding the behaviour of nano-fluids within heat exchangers, thereby guiding their practical application and future experimental investigations [4].

Acknowledging the wealth of intensive research conducted in this domain, numerous previous studies have rigorously examined the impact and potential of nanofluids in improving the thermal performance of heat exchangers. In a recent experimental study, the thermal performance of single-pass solar collectors was significantly enhanced using high porosity metal foams. This approach

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https://doi.org/10.37934/cfdl.16.11.146160

increased the heat transmission efficiency of the absorber plates, particularly when the metal foam was positioned at a 45-degree tilt angle. The study's findings suggest that such innovative use of metal foams in solar collectors could lead to considerable improvements in thermal efficiency, potentially influencing future design and application of solar heating systems in various industrial context [5]. Previous research examined how different nano-fluids affected the efficiency of a baffled shell and tube heat exchanger. Using water as a base, the study tested nano-fluids like Al_2O_3, CuO, and TiO_2. The main finding was that as the volume concentration of these nano-fluids increased, the heat transfer rate also went up. Notably, Al_2O_3 had the best performance, suggesting it's the top choice for industries looking to boost their heat exchanger's efficiency with nano-fluids [6]. In addition to shell and tube configurations, nanofluids have shown viability in other heat exchanger types like hairpin designs. This past research, a comprehensive CFD analysis was conducted on a hairpin heat exchanger using different nano fluids. The primary objective was to understand the impact of various nanoparticles, specifically Titanium Carbide (TiC), Magnesium Oxide (MgO), and Silver, on the heat transfer rate. These nanoparticles were suspended in a base fluid in varying weight percentages ranging from 0.1% to 0.8%. The findings from the analysis were enlightening. It was observed that the heat transfer rate was notably enhanced with the addition of these nanoparticles [7]. Specialized exchangers aside, nanofluids also facilitate efficiency improvements in everyday applications using commonly available base fluids. In a past study, an analysis was conducted on the enhancement of the heat exchanger's performance through the application of Alumina (Al_2O_3) and Copper oxide (CuO) nanoparticles suspended in engine oil. It was demonstrated that the thermal conductivity of the working fluid is a critical determinant of a heat exchanger's efficiency. The introduction of nanoparticles, known for their superior thermal conductivity, was shown to significantly improve this efficiency [8]. Beyond engine oil nanofluids, additional research has explored aqueous nanofluid systems for heat transfer betterment. In the previous study, water-based nanofluids, with varying concentrations of Al2O3 nanoparticles, were examined for their heat transfer efficiency in comparison to pure water within the context of an automotive radiator's cooling system. It was observed that increments in the nanoparticle concentration led to corresponding enhancements in the heat transfer rate [9]. Alongside automotive applications, helical tube exchangers also stand to benefit from nanofluid integration as indicated by related research. In one of previous research, the thermal performance of helical tube heat exchangers was assessed, particularly with the introduction of Al_2O_3 nanofluids as a medium for enhancing heat transfer. Investigations were conducted to determine the impact of varying concentrations of Al_2O_3 nanofluids on the heat transfer characteristics [10]. Adding to the evidence around nanofluids, investigations into specialized nanofluid mixtures also confirm improved heat transfer in shell and tube configurations. [In a previous reaserch, attention was directed towards the advancement of heat transfer within shell and tube heat exchangers, achieved through the medium of nanofluid mixtures. The investigation discovered that a concoction comprising water, ethylene glycol, and copper oxide nanoparticles markedly bolstered the rate of heat transfer [11]. Further augmentations have been linked to the use of nanofluids containing novel nanoparticle types. In a past investigated research, emphasis was placed on the augmented heat transfer capabilities within shell and tube heat exchangers when Fe_3O_4-water nanofluids are employed. It was discovered that the suspension of Fe_3O_4 nanoparticles in water significantly bolstered the heat exchanger's thermal efficiency [12]. In a recent study, researchers explored the impact of TiO_2-water nanofluid on the efficiency of double-pipe heat exchangers. The study used different concentrations of TiO_2 nanoparticles in water to analyze their effect on thermal conductivity and viscosity. Findings revealed that adding TiO_2 nanoparticles to water significantly enhances its heat conductivity and viscosity, with the best results at a 0.3% nanoparticle concentration, where the heat transfer efficiency improved by up to 23%. This research suggests that using TiO_2-water nanofluid can be an effective approach to improve the performance and energy efficiency of double-pipe heat exchangers [13]. In a previous research paper, the thermal-hydraulic modeling of water/Al2O3 nanofluid as coolant in annular fuels for a typical VVER-1000 core was explored. The study focused on the use of nanofluid in enhancing the cooling efficiency within nuclear reactors, showing that the incorporation of Al_2O_3 nanoparticles significantly improves the heat transfer characteristics. This improvement suggests a promising avenue for increasing the safety and efficiency of nuclear power plants by leveraging the enhanced thermal properties of nanofluids [14]. In a recent scientific study, a 3-D CFD simulation was conducted to evaluate the impact of using Al_2O_3, Cu, CuO, and TiO_2 nanofluids in twisted tube heat exchangers. This research demonstrated a notable improvement in heat transfer efficiency and a modest increase in pressure drop with the use of nanofluids. Specifically, 0.1 vol% Cu and 0.15 vol% Al_2O_3 nanofluids were found to significantly enhance heat transfer rates in a 45 mm pitch tube, suggesting their potential in optimizing heat exchanger performance for industrial applications [15]. In another scientific paper, a numerical investigation focused on the thermal efficiency of shell and tube heat exchangers using twisted tubes and Al_2O_3 nanoparticles was conducted. Employing Computational Fluid Dynamics (CFD) with various turbulence models, this study revealed an increase in heat transfer efficiency by approximately 20% when utilizing twisted tubes compared to smooth tubes. Moreover, the addition of Al_2O_3 nanofluids led to an 8% increase in the heat transfer coefficient while simultaneously reducing the pressure drop by about 40%, showcasing the significant potential of nanofluids and twisted tubes in enhancing the performance and cost-efficiency of heat exchangers [16].

This research aims to explore the effects of Al_2O_3 nanofluids in heat exchangers with slightly modified designs created using SOLIDWORKS, under somewhat varied operational conditions. These nuanced design adjustments, alongside a detailed Computational Fluid Dynamics (CFD) analysis, are expected to provide insights into the performance of Al_2O_3 nanofluids in novel yet practical scenarios. By examining these new design dimensions and operational parameters, the study seeks to identify optimization strategies that could significantly improve the energy efficiency and operational effectiveness of heat exchangers, offering a fresh perspective on their application in industrial settings.

Research Gap: Despite the recognized effectiveness of nanofluids in improving heat transfer in shell and tube heat exchangers, the detailed impact of novel design modifications—particularly with the application of Al_2O_3 nanofluids under varied operational conditions—has not been thoroughly explored. This gap is addressed by investigating the influence of design adjustments on nanofluid performance, introducing innovative heat exchanger designs analyzed through Computational Fluid Dynamics (CFD) to enhance thermal efficiency and operational effectiveness, offering a fresh perspective on energy-efficient technologies.

The structure of this paper provides a comprehensive examination of the thermal efficiency optimization using Al_2O_3 nanofluids in shell and tube heat exchangers. It starts with a detailed introduction that outlines the research background, followed by a review of related literature. The methodology section describes the design and simulation strategies employed. This is succeeded by the presentation of results and a discussion of their implications. The paper concludes with a summary of key findings and recommendations for future research, emphasizing the potential of nanofluids in industrial applications for energy efficiency.

2. Methodology

This section outlines the structured approach used in investigating aluminum oxide nanofluids for their effectiveness in enhancing heat transfer in shell and tube exchangers. Starting with fundamental concepts of heat transfer, it then sheds light on the characteristics of nanofluids and their role in heat exchange. The focus shifts to detailing the simulation process, which includes custom CAD modeling of the heat exchanger and CFD analysis for quantifying improvements. The procedures, from preparing nanofluids to their comparative testing against standard water are designed to be clear and detailed. By the end, this section will provide a comprehensive understanding of the integrated approach used, employing SOLIDWORKS for optimizing and analyzing nanofluid performance in the specific heat exchanger system.

2.1 Heat Transfer Fundamentals

Heat transfer refers to the exchange of thermal energy driven by temperature differences. It governs the transport of heat between systems and their surroundings, underpinning applications from household appliances to industrial equipment. There exist three fundamental heat transfer modes - conduction, convection, and radiation [17]:

2.1.1 Conduction

In conduction, heat propagates through a medium due to molecular vibrations and free electron movements, without mass transfer. It can be calculated be equation below [17]:

$$q'' = -k\nabla T \tag{1}$$

Where q'' is the heat flux, k is the thermal conductivity, and ∇T is the temperature gradient.

2.1.2 Convection

Convection utilizes bulk fluid flow paired with conduction to exchange heat between a surface and the adjacent liquid or gas. It can be calculated be equation below [17]:

$$q'' = h(T_s - T_\infty) \tag{2}$$

Where h is the convection heat transfer coefficient, T_s is the surface temperature, and T_∞ is the ambient temperature.

2.1.3 Radiation

Unlike conduction and convection, radiative transfer occurs through electromagnetic waves, requiring no transport medium. All objects above 0 K emit thermal radiation with hotter matter releasing more intense radiation. It can be calculated be equation below [17]:

$$q'' = \epsilon\sigma T_s^4 \tag{3}$$

2.2 Heat Exchangers
2.2.1 Overview and types

Heat exchangers are devices engineered to transfer heat efficiently between two or more fluids at different temperatures. They have diverse applications spanning power generation, chemical processing, electronics cooling, HVAC systems, and refrigeration. Based on heat transfer mechanism, heat exchangers are categorized as direct contact where fluids mix directly and indirect contact where they exchange heat through a solid wall (see Figure 1). Main classifications by design are tubular (Figure 2), plate, and extended surface exchangers [18]. Key performance parameters for heat exchangers include overall heat transfer coefficient, log mean temperature difference (LMTD), heat transfer rate, and pressure drops. Enhancing efficiency must balance maximizing heat transfer with minimizing pumping power required [19]. Modern development efforts target more compact and high-performance designs. Extended surfaces, porous media inserts, and advanced working fluids like nanofluids have shown particular promise in this regard. By providing optimized heat transfer capabilities, heat exchangers continue to serve pivotal roles across industrial and commercial systems.

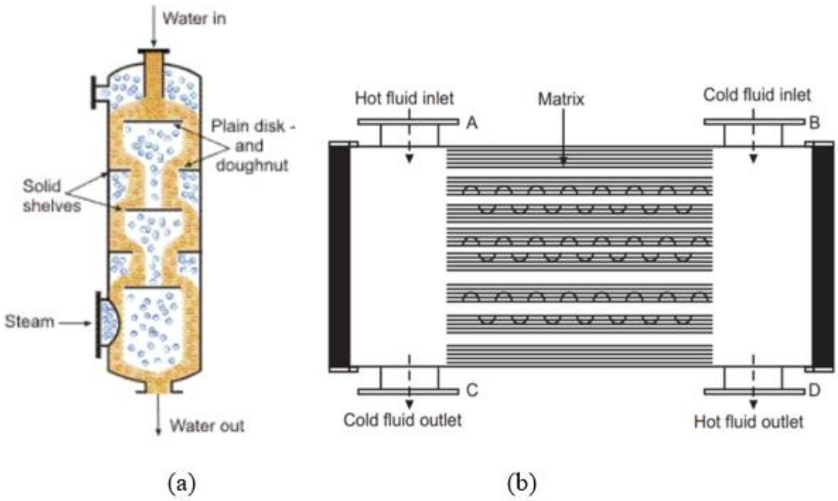


Fig. 1. (a) Direct contact heat exchanger (b) Indirect contact heat exchanger [20-21]

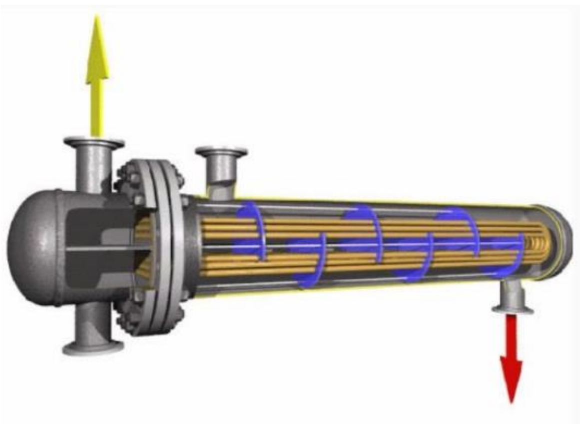


Fig. 2. Tubular heat exchanger [22]

2.2.2 Heat exchanger theoretical equations

a) For the condensing side (hot fluid)[18] :

$$Q_h = m_h \times \Delta h(h_i - h_o) \tag{4}$$

b) For the coolant side [18]:

$$Q_c = m_c \times c_p(T_{c2} - T_{c1}) \tag{5}$$

c) Basic Design Equation [18]:

$$Q = m \times Ao \times \Delta T_{lm} \tag{6}$$

Where Um is the mean overall heat transfer coefficient and ΔT_{lm} is the mean temperature difference, known as the log, mean temperature difference (LMTD) [18].

$$\Delta T_{lm} = \frac{\ln(\Delta T1/\Delta 12)}{\Delta T1 - \Delta T2} \tag{7}$$

d) Overall Heat Transfer Coefficient [18]:

$$\frac{1}{U_m} = \frac{1}{h_o} + R_{fo} + (\frac{A_i}{A_o})R_w + (\frac{A_i}{A_o})R_{fi} \tag{8}$$

This equation accounts for the individual heat transfer coefficients, wall resistances, and fouling resistances.

e) Incremental Heat Transfer in Specific Surface Area:

For any incremental surface area ΔA_i, the incremental heat transfer can be calculated by equation below [18].

$$\delta Q_i = U_i \times \Delta A_i \times (T_h - T_c)_i \tag{9}$$

This equation is used for a parallel-flow double-pipe heat exchanger.

f) Preliminary Estimation of Heat Exchanger Size [18]:

$$\delta Q_i = U_i \times \Delta A_i \times (T_h - T_c)_i \tag{10}$$

Where Ao is the outside heat transfer surface area based on the outside diameter of the tube.

2.2.3 Navier-Stokes equations

The Navier-Stokes equations, foundational to fluid dynamics, encapsulate the movement of fluids by outlining their velocity, pressure, and density. These equations are rooted in the conservation principles of mass, momentum, and energy, offering a robust mathematical model for fluid flow analysis across different scenarios. Within this framework, the continuity equation, integral to the Navier-Stokes equations, ensures mass conservation by equating mass rate changes within a fluid volume to the mass flow across its periphery, providing a precise mathematical depiction. t is represented as [23]:

i. Continuity equation

$$\frac{\partial \rho}{\partial t} + \mathrm{div}(\rho u) = 0 \tag{11}$$

Where ρ is the fluid density, it is time, u is the velocity vector, and div(ρu) represents the divergence of the mass flux.

The momentum equation captures the principle of momentum conservation, mapping out the relationship between the forces acting on a fluid and its resultant acceleration. This foundational relationship is mathematically articulated as follows [23]:

ii. Momentum equation

$$\frac{\partial(\rho u)}{\partial t} + div(\rho u \mathrm{u}) = -\frac{\partial p}{\partial x} + div(\mu \times \mathrm{grad}u) + S_{Mx} \quad \text{(x – direction)} \tag{12}$$

$$\frac{\partial(\rho v)}{\partial t} + div(\rho v \mathrm{u}) = -\frac{\partial p}{\partial y} + div(\mu \times \mathrm{grad}v) + S_{My} \quad \text{(y – direction)} \tag{13}$$

$$\frac{\partial(\rho w)}{\partial t} + div(\rho w \mathrm{u}) = -\frac{\partial p}{\partial z} + div(\mu \times \mathrm{grad}w) + S_{Mz} \quad \text{(z – direction)} \tag{14}$$

Where p is the pressure, μ is the dynamic viscosity, and u× grad$u$ represents the convection term and S_{Mx} This term includes any external forces acting on the fluid element in the x-direction. These forces could be due to applied body forces, such as gravity or electromagnetic forces.

The energy equation outlines the conservation of energy within a fluid, considering heat transfer, viscous dissipation, and the work performed by pressure forces. Mathematically, it is expressed as follows [23]:

iii. Energy equation

$$\frac{\partial(\rho i)}{\partial t} + div(\rho i \mathrm{u}) = -p div(\mathrm{u}) + div(k \times \mathrm{grad}T) + \Phi + S_i \tag{15}$$

where $div(\rho i\mathrm{u})$ convective transport of energy, $pdiv(\mathrm{u})$ work done by pressure forces on the fluid, T is the temperature, $div(k \times \mathrm{grad}T)$ divergence of the conductive heat flux vector, Φ heat source or sink within the fluid, S_i and any external sources or sinks of energy that are not due to heat transfer or pressure work.

2.3 Nanofluids in Heat Exchangers

Nano-fluids, particularly those infused with aluminum oxide (Al_2O_3) nanoparticles, represent a significant advancement in heat exchanger technology, enhancing thermal management and efficiency. These nano-fluids, merging traditional base fluids with nanoparticles, notably improve thermal conduction. Al_2O_3 is distinguished for its accessibility, cost-effectiveness, and substantial enhancement of the base fluid's thermal properties. The use of Al_2O_3 nano-fluids in heat exchangers not only promises improved efficiency but also potential reductions in size and operational costs, making them pivotal in the pursuit of energy-efficient and cost-effective thermal systems. This research will specifically focus on the application of Al_2O_3 nano-fluids, exploring their potential to revolutionize heat transfer efficiency in heat exchange [23-25].

2.3.1 Advantages of nanofluids in heat exchangers

Nanofluids, composed of solid nanosized particles dispersed in base fluids like water, mineral oil, or ethylene glycol, offer a promising avenue for enhancing heat transfer rates in thermal devices, including heat exchangers. Recent investigations into their physical properties have showcased their potential across various thermal engineering processes such as thermal management in fuel cells, power generation, refrigeration, and notably in the design of heat exchangers. Utilizing metallic and nonmetallic nanoparticles, such as SiO_2, Al_2O_3, Cu, CuO, Ag, and TiO_3, with diameters less than 100 nm, significantly impacts the thermal conductivity of nanofluids, thereby augmenting the overall performance of heat exchangers. Experimental and theoretical studies under diverse working conditions (varying flow regimes and temperatures) have enabled the determination of the thermophysical properties of nanofluids, considering different sizes, shapes, and types of particles. It has been observed that even a small addition of particle concentration to the base fluid results in substantial thermal improvement, allowing for more compact and lightweight heat exchanger structures due to the high thermal efficiency obtained by nanofluids [26].

2.3.2 Challenges of nanofluid-based heat transfer systems

While nanofluids present a significant enhancement in heat transfer efficiency, their application in heat exchangers is not without challenges. The preparation and utilization of nanofluids, such as Al_2O_3/water or mixtures with ethylene glycol, aiming to enhance the hydrothermal characteristics of plate-fin heat exchangers (PFHEs), demonstrate increased overall thermal performance and, in some cases, reduced pumping power. However, under turbulent flow conditions, the use of different nanomaterials has shown that while the heat transfer rate increases with the volume fraction of nanofluid, a decrease in nanoparticle diameter results in increased pressure drop. This highlights a critical trade-off between thermal enhancement and fluid dynamics within the heat exchanger. Moreover, comparisons of thermal enhancement across different nanofluids reveal variances in thermal conductivity and heat transfer enhancement values, indicating that the choice of nanofluid composition plays a crucial role in the system's efficiency and operational costs [26].

2.4 Shell and Tube Heat Exchanger Design and Simulation

In this part of the study, both the design and simulation of the shell and tube heat exchanger are conducted using SOLIDWORKS software. This comprehensive approach ensures a seamless integration of design parameters with simulation variables, allowing for a detailed examination of the heat exchanger's performance under various operating conditions. The simulations are carried out in 3D to accurately capture the complexities of fluid flow and heat transfer dynamics. However, for ease of analysis and clarity in presentation, results are displayed in 2D. This methodological choice underscores the sophisticated simulation capabilities of SOLIDWORKS, enabling a precise representation of the physical dimensions and configurations of the heat exchanger, while focusing on the effectiveness of Al_2O_3 nanofluids in enhancing heat transfer efficiency. The dual application of

SOLIDWORKS not only streamlines the design and simulation process but also provides valuable insights into nanofluid behavior, optimizing heat exchanger operations.

2.4.1 Shell and tube heat exchanger design

The Figure 3 below shows the final design of the heat exchanger that will be worked on, and SOLIDWORKS software was used to design it completely.

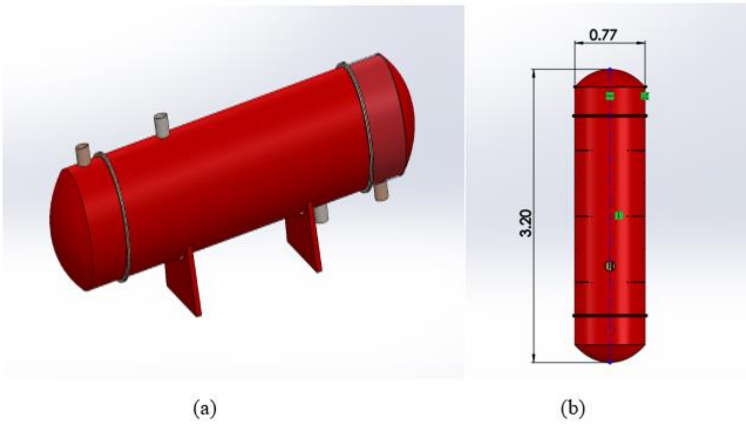


Fig. 3. Shell and tube heat exchanger 3D mode and its dimension

The dimensions selected for our heat exchanger design, while reflective of those available in the market, are intentionally adjusted to explore a new design experiment. This custom design is the basis for our CFD simulation analysis, focusing on the theoretical evaluation of heat transfer enhancements offered by Al_2O_3 nanofluids. Figure 4 shows Heat Exchanger Tube diameter. The table 1 below shows the main dimensions of shell and tube heat exchanger in this study.

Table 1
Dimensions of heat exchanger

Parameter	Value
Length	3.20 m
Width	0.77 m
Tube diameter	0.03 m

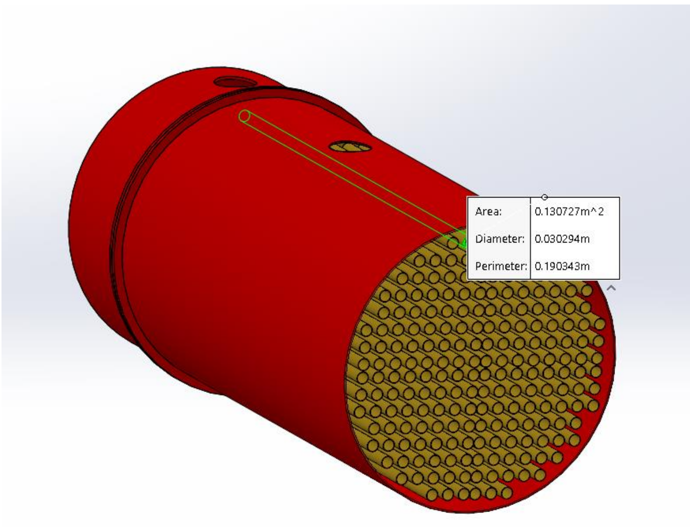


Fig. 4. Heat exchanger tube diameter

2.4.2 Shell and tube heat exchanger simulation

Flow Simulation in SOLIDWORKS will be used for conducting CFD analysis to study fluid dynamics and heat transfer. The process begins with meshing, where the model is divided into smaller segments for simpler calculations. The accompanying Figure 5 illustrates this meshing step as executed in SOLIDWORKS.

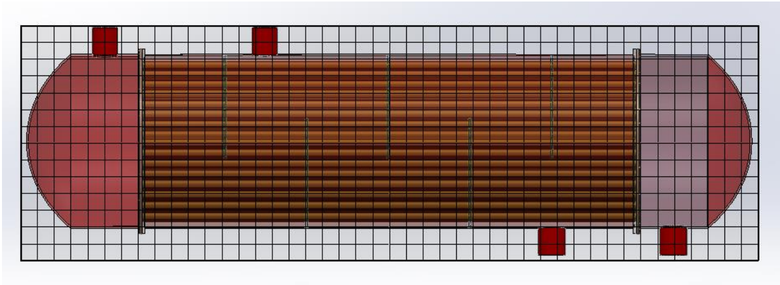


Fig. 5. Mesh result of heat exchanger

This study includes a case focusing on water-based nanofluids. The table 2 presented outlines various characteristics of Al_2O_3 nanofluids, with particular attention to the type with a 2% concentration rate, which is selected for this research. Figure 6 shows the boundary condition in this research.

Table 2
(Al_2O_3-water) Nanofluid mechanical properties [27]

Material	ρ kg/m3	Cp J/kg K	K W/m K	µ kg/m s
Pure water (c = 0%)	981.3	4189	0.643	0.000598
Al2O3	3600	765	36	-
Al2O3-water (c = 1%)	1007.4	4154.7	0.661	0.000612
Al2O3-water (c=2%)	1033.6	4120.5	0.68	0.000627
Al2O3-water (c =3%)	1059.8	4086.2	0.699	0.000642
Al2O3-water (c =4%)	1086	4052	0.719	0.000657

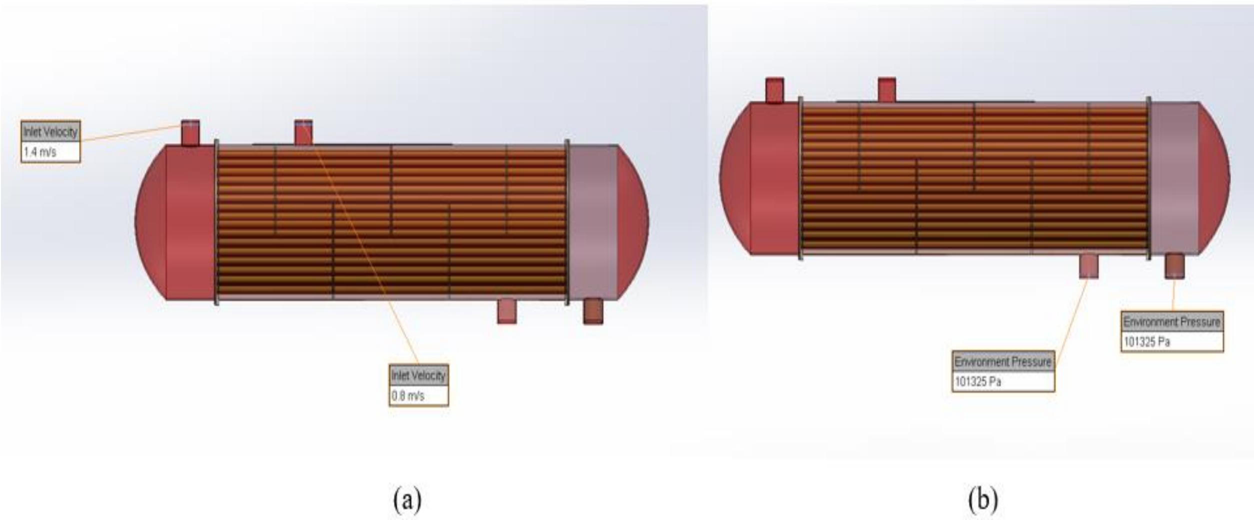


Fig. 6. (a) Boundary condition (Inlets velocity of each fluid) (b)Boundary condition (Outlets)

As observed in the table 3, the boundary conditions specified for the study involve setting a distinct inlet velocity for each fluid. Specifically, the cold water is introduced at a velocity of 1.5

meters per second and a temperature of 20°C. For the hot water (in the first case study) or water mixed with nanoparticles (in the second case study), the velocity is set at 0.8 meters per second with a temperature of 80°C. This detailed specification of boundary conditions is critical for accurately simulating the heat transfer characteristics under these defined operational parameters.

Table 3
Fluids velocities and temperatures in both cases

Fluid	**Velocity**	**Temperature**
Cold water	1.4 m/s	20 C
Hot water (1st case)	0.8 m/s	70 C
Hot fluid (Al2-O3-water (c=2%)) (2nd case)	0.8 m/s	70 C

The research comprises two distinct case studies. In the initial case, hot water is utilized to heat a separate stream of cold water. Here, the hot water is introduced via the shell, while the cold water flows through the tubes. After this process, the exit temperature of the initial cold water is determined. For the second case, the hot water is substituted with a fluid containing Aluminum Oxide (Al_2O_3) with a concentration of 2%. The outcomes from both scenarios will be analysed to discern the relative effectiveness of the two fluids in heat transfer applications.

3. Results and Discussion

In this section, the most important results reached will be presented, as the first case will be reviewed, which is using hot water to heat cold water. Then the other case will be reviewed, and a comparison will be made between them.

3.1 First Case Results

Figure 7-9 show the first case results of this research.

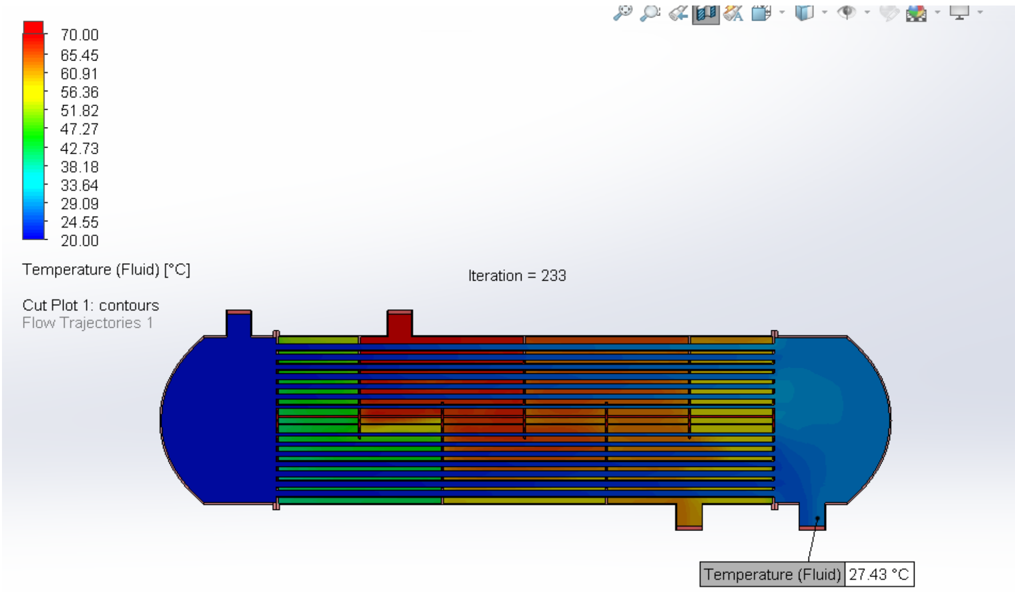
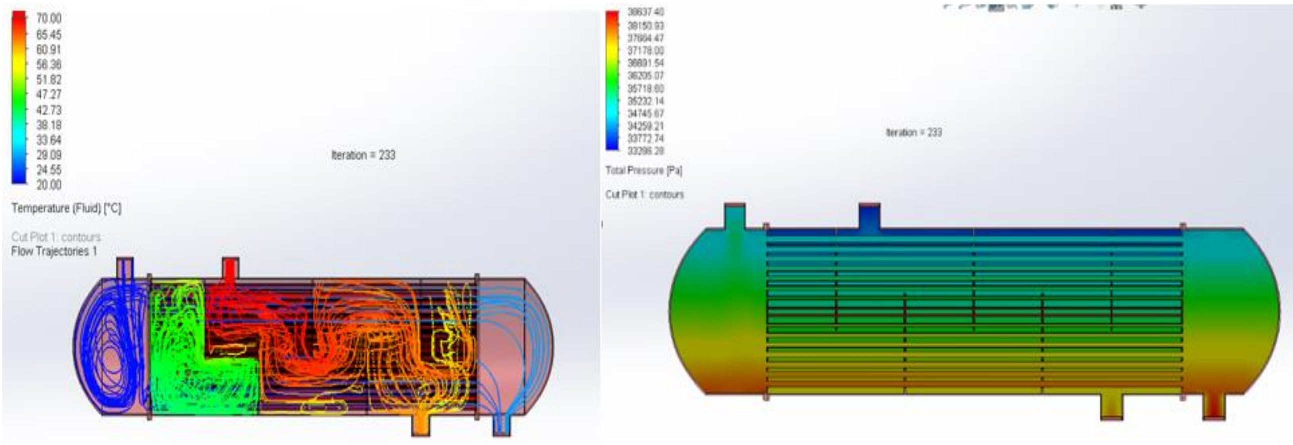


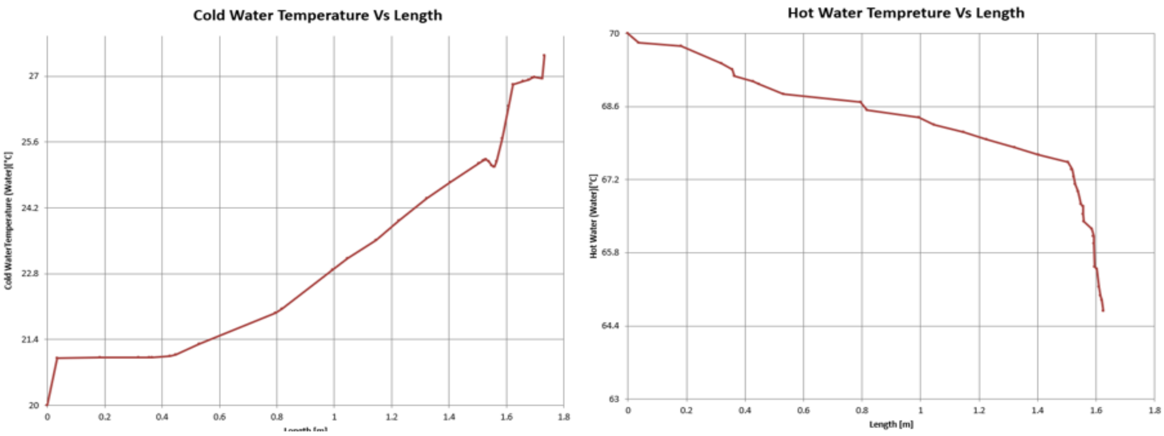
Fig. 7. Temperatures contours of first case analysis that clerify the outlet temperature

The outlet tempreture of cold water in first case is 27.43 ℃ after heating.



(a) (b)

Fig. 8. (a) Flow trajectories of first case analysis (b) Pressure conours of first case analysis



(a) (b)

Fig. 9. (a) Tempreture curve of cold water in first case (b) Tempreture curve of hot water in first case

3.2 Second Case Results

Figure 10-12 show the first case results of this research.

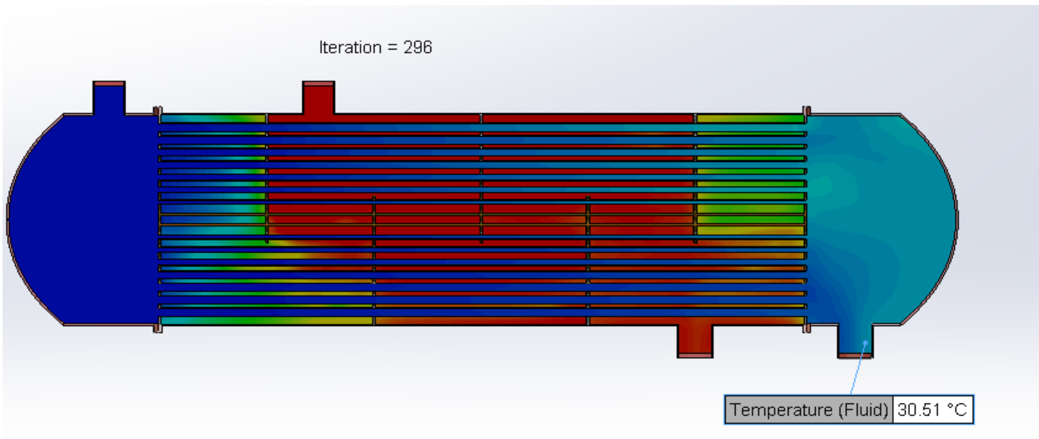


Fig. 10. Tempretures contours of second case analysis that clerify the outlet tempreture

The outlet tempreture of cold water in second case is $\mathbf{30.51}$ ℃ after heating

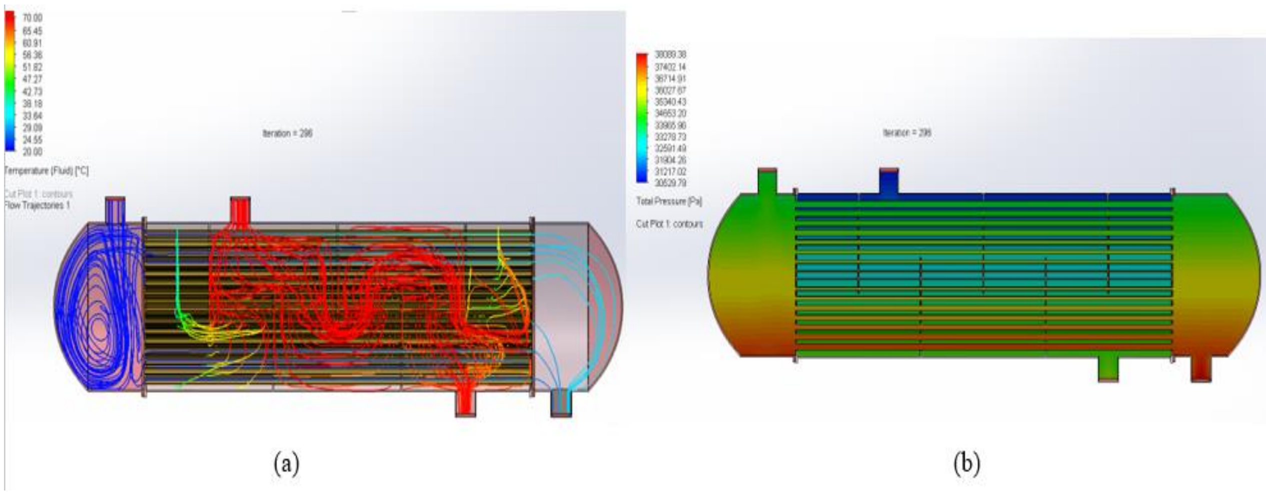


Fig. 11. (a) Flow trajectories of second case analysis (b) Pressure conours of second case analysis

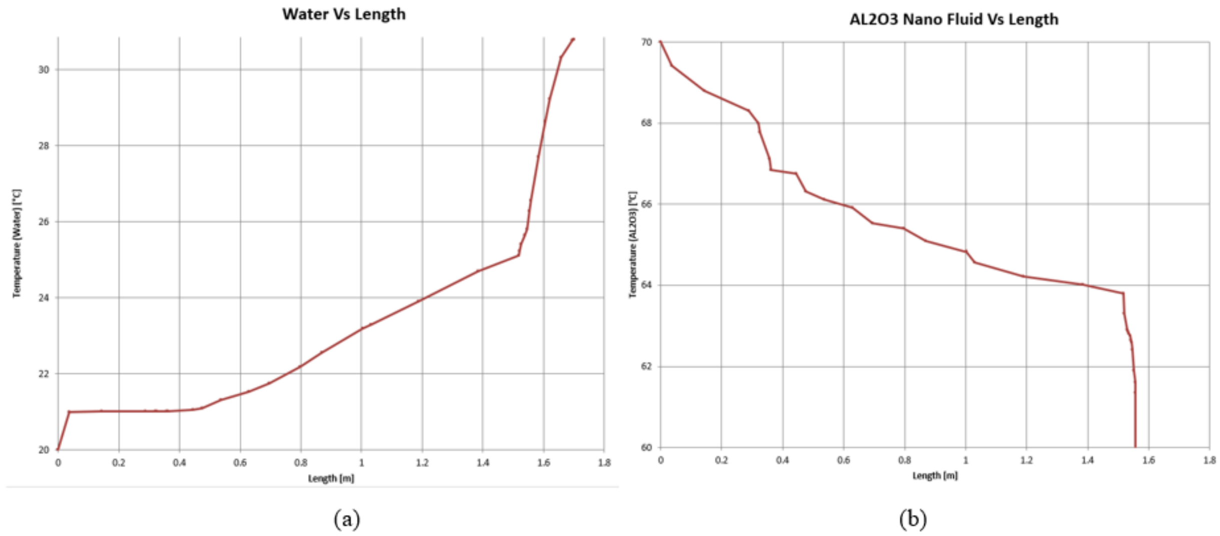


Fig. 12. (a) Tempreture curve of cold water in second case (b) Tempreture curve of hot(al2-o3,c=2% nano-fluid) in second case

$$\text{Percentage Improvement} = \left(\frac{30.51 - 27.43}{27.43}\right) \times 100 = \mathbf{11.23}\%$$

3.3 Discussion

Heat transfer optimization is an essential research domain in thermal fluid systems. This paper investigates two methods of heat transfer to determine the more efficient approach. The first method utilizes hot water within a shell to heat cold water flowing through an internal tube bundle. This configuration mimics standard industry heat exchanger setups. Analysis outcomes demonstrate the cold-water outlet temperature rises to 27.43°C after undergoing the heating process. Temperature distribution and flow trajectories visually showcase the thermal diffusion within this system. The captured pressure variation further validates observed energy transport phenomena. Plots of the hot and cold fluid temperature changes along the heat exchanger length provide additional verification of the calculated heat absorption. The second approach substitutes hot water with a specially formulated 2% volume concentration nanofluid comprising water and Al2O3 nanoparticles. Owing to enhanced thermophysical properties, this nanofluid demonstrates superior heat transfer potential. Accordingly, elevated outlet temperatures are witnessed in the cold water, rising to 30.51°C, which represents an improvement of approximately 11.23% over the traditional hot water method. More uniform thermal diffusion transpires with accelerated heating dynamics, distinguishable across temperature and flow visualizations for the nanofluid system. Gradual pressure evolutions supplement these findings. Upon comparison, the analysis definitively ascertains the nanofluid outperforms conventional hot water for heating purposes, attributed to the nanoparticles within the nanofluid intensifying thermal conduction. Besides greater outlet temperatures, faster and more consistent heating manifest across assessed parameters. These insights around leveraging nanofluids provide valuable inputs for creating next-generation heat transfer systems. The improved efficiency metrics point to possibilities for miniaturization and adapting towards waste heat recovery. Furthermore, opportunities exist in integrating emerging computational tools to optimize nanofluid applications within modular and reconfigurable heat exchanger architectures.

4. Conclusions

This study focused on heat transfer and the use of heat exchangers, specifically employing SOLIDWORKS for design and testing, including the introduction of a somewhat new dimensions within market standards for the heat exchanger design. A major finding was that Nano fluid Al2O3 at a 2% concentration was more effective in transferring heat than regular hot water, showing an enhancement in heat transfer efficiency by approximately 11.23%. This research underscores the significance of CAD tools like SOLIDWORKS in streamlining the design and simulation process in engineering. Looking ahead, it's essential to explore different concentrations of nanofluids, test various heat exchanger designs, and conduct real-world condition studies. Further steps include investigating other nano-fluid types, employing AI for design enhancements, and assessing the environmental and economic impacts of nano-fluid usage, particularly in conjunction with renewable energy sources, to evaluate their long-term heat transfer effectiveness.

Acknowledgement
This research was not funded by any grant.

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