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Numerical and CFD Analysis of Heat Transfer Enhancement Technique in Shell and Tube Heat Exchanger: A Review

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Abstract - *In heat exchangers enhanced with nanofluids, computational fluid dynamics (CFD) modelling has been thoroughly examined in this review work. Colloidal nanoparticle suspensions in base fluids known as nanofluids have drawn a lot of attention because of their potential to improve heat transfer characteristics. This research analyses the effects of nanofluid features, geometrical configurations, and operating circumstances on heat transfer and fluid flow characteristics using CFD models. The basic concepts of heat exchangers and nanofluids are first introduced, with an emphasis on the qualities of their thermal conductivity, viscosity, and convective heat transfer. In this review work, computational fluid dynamics (CFD) modelling has been comprehensively analyzed in heat exchangers augmented with nanofluids. The potential for colloidal nanoparticle suspensions in base fluids, sometimes known as nanofluids, to enhance heat transfer properties has attracted a lot of interest. Using CFD models, this study examines the effects of nanofluid properties, geometrical arrangements, and operating conditions on fluid flow characteristics and heat transmission. A focus on the properties of their thermal conductivity, viscosity, and convective heat transfer is placed at the outset of the introduction of the fundamental ideas of heat exchangers and nanofluids. The review also discusses issues with uncertainties in nanoparticle behavior, aggregation, and thermophoresis effects, as well as the shortcomings of CFD modelling of nanofluid heat exchangers. Current research and methods to solve these difficulties are discussed, providing information on potential outcomes. As a result of its thorough consolidation of the state of the art, this study will be an invaluable tool for scientists and engineers investigating CFD analysis in heat exchangers using nanofluids. It establishes the groundwork for upcoming advancements by synthesizing multiple discoveries, encouraging the development of highly effective and sustainable heat exchange systems for many industrial applications.*

Key Words: **Heat Exchanger, Nanofluid, Heat Transfer Rate, Convective Heat transfer Coefficient, CFD**

1.INTRODUCTION

Heat exchangers are essential parts in many different sectors because they are essential tools for effective heat transfer between fluids. Researchers are focusing on nanofluids as a possible way to improve their performance and meet the constantly growing need for energy efficiency. When introduced into traditional heat exchangers, nanofluids, colloidal suspensions of nanoparticles in base fluids, have exceptional thermal characteristics that can dramatically increase heat transfer rates. Computational fluid dynamics (CFD) has become a potent tool for simulating and enhancing the performance of intricate fluid flow and heat transport phenomena in recent years. Because they are necessary tools for efficient heat transfer between fluids, heat exchangers are crucial components in many different industries. Researchers are concentrating on nanofluids as a potential means to enhance their functionality and satisfy the continuously expanding need for energy efficiency. Nanofluids, colloidal suspensions of nanoparticles in base fluids, offer excellent thermal properties that can significantly boost heat transfer rates when added to conventional heat exchangers. In recent years, computational fluid dynamics (CFD) has developed into an effective tool for simulating and improving the performance of complex fluid flow and heat transport processes. The potential for nanofluids to completely alter heat transfer applications is highlighted in a succinct overview of these materials' special thermal properties. The introduction then emphasizes the growing use of CFD as a potent computational tool in heat transfer research and emphasizes its function in deciphering intricate heat exchanger-nanofluid interactions. The introduction sets the main goal of the review, which is to thoroughly assess the present literature on CFD modelling of heat exchangers with nanofluids, on top of this basis. This study intends to pinpoint knowledge gaps, difficulties, and potential research initiatives in the area by synthesizing and critically analyzing prior research. Overall, the goal of this review study is to be a useful resource for scientists, engineers, and other professionals working on heat exchangers with nanofluids. The combination of nanofluid technology and CFD modelling presents a fascinating potential to transform heat transfer systems, opening doors to new and more effective energy utilization in a variety of industries.

2. LITERATURE SURVEY

2.1 Nanofluid Application

One of the most extensively studied thermal processes in nanofluids [1-23] is convective heat transfer, which has a variety of engineering uses. Nanofluids should offer improved convective heat transfer coefficients because of the observed enhancement in thermal conductivity. Quantification of the impact of nanoparticles on heat transfer performance is, however, essentially necessary because the suspensions of nanoparticles in the base fluids also affect thermophysical properties other than thermal conductivity, such as the viscosity and the thermal capacity [24]. Godson et al. [24], Wang and Mujumdar [25], Duangthongsuk and Wongwises [26], Kakac- and Pramuanjaroenkij [27], Wen et al. [28], Mohammed et al. [29], Sarkar [30], Murshed et al. [31], Saidur et al. [32] and Vajjha and Das [33] published reviews of nanofluids for heat transfer applications. The obtained results make it abundantly evident that nanofluids have more potential for enhancing heat transfer and are ideally suited for use in various types of heat exchangers. Based on the literature that is currently accessible, this section describes the usage of nanofluids in heat exchangers utilized in industries, such as plate heat exchangers, shell-and-tube heat exchangers, compact heat exchangers, and double-pipe heat exchangers. A small plate heat exchanger with a modified surface was put to the test numerically and experimentally by Pantzali et al. [34] to see how nanofluids affected its performance. Their thermophysical analyses of the nanofluid (CuO in water, 4 vol%) show a considerable decrease in heat capacity and an increase in viscosity along with the increase in thermal conductivity. Additionally, it was noted that the heat transfer increase is greater at lower flow rates and that nanoparticle contribution is minimal at higher flow rates, when convection is the primary heat transport mode. The findings imply that for a given heat duty, a lower volumetric flow rate of nanofluid is needed than for water, resulting in a lower pressure drop and requiring less pumping power. Additionally, Pantzali et al. [35] conducted a plate heat investigation. exchangers (PHE) that use water and CuO nanoparticles as nanofluids cooling agents. To understand the flow inside the PHE, they used a combination of experimental analysis, CFD simulation, and nanofluid synthesis and measurement of their thermophysical properties. The plates have 2 mm-high corrugations in the shape of chevrons 8.6 mm for the wave length, measured normal to the crests. The Corrugations create a herringbone pattern with a 501-degree angle to the flow direction. Plates are set in succession with a pattern of corrugation with opposing directions. Using water as A heater regulates the temperature of the heated fluid, which is kept at about 50°C, while a high-accuracy valve controls its flow rate and a float-type flow metre measure it. Either The PHE's cooling liquid is either water or a nanofluid, with the with the goal of contrasting their output. A centrifugal pump circulates the cooling fluid while it is kept in a 5-l container.

Using another PHE that is comparable to this one and using tap water as the working fluid, its inlet temperature is kept at a consistent 30°C.

The measurements of the nanofluids' thermophysical properties led to the following conclusions: increased thermal conductivity, increased density, decreased heat capacity, increased viscosity, and perhaps non-Newtonian behaviour. The results of the experiments demonstrated that the efficiency of the nanofluid as a coolant was significantly influenced by the thermophysical characteristics and type of flow within the heat exchanger. It was determined that the usage of nanofluids in industrial heat exchangers, where vast volumes of nanofluids are needed and the flow is turbulent, appears impracticable. Mare' et al. [36] examined the thermal performance of two types of nanofluids (aqueous suspensions of carbon nanotubes and alumina oxides distributed in water) exchangers. The study's experimental setup consisted of schematically depicted the basic components of the testing setup were three buckles. three buckles (hot, middle, and cold), as well as two identical plates exchangers of heat. An UPS is installed in the middle buckle. 60 circulator Three speeds on the Grundfos ensure a flow rate. a flow metre that measures ultrasonic flow between 400 and 1000 l/h, and using four PT100 probes, four temperatures may be measured. (Tfe, Tfe, Tfs, Tce, Tcs). In the event that the results of the validation using the installation and the many nanofluids will circulate in this buckle. Kwon et al. [37] reported the results of experimental studies on the heat transfer properties and pressure drop of the ZnO and Al2O3 nanofluids in a plate heat exchanger. The range of volumetric flow rates and Reynolds numbers used in the experiment was 100–500. The heat exchanger's operating temperature ranged from 20 to 40 °C. The calculated convective heat transfer coefficient of the plate heat exchanger using the ZnO and Al2O3 nanofluids generated using a two-step process was based on the measured thermophysical parameters, such as thermal conductivity and kinematic viscosity. According to experimental findings, the overall heat transfer coefficient for 6 vol% Al2O3 increased to 30% since the nanofluids did not flow at the same rates at the specified viscosity and density. The performance did not, however, increase at a specific volumetric flow rate. The experimental findings regarding the efficiency of nanofluids appeared unimpressive when the nanofluids were added to the plate heat exchanger. According to Pandey and Nema [38], the investigation of convective heat transfer in a corrugated plate heat exchanger utilizing nanofluid, including aluminum oxide in water (as the base fluid), in various concentrations, and water in turbulent flow. Results indicated that with increasing Reynolds and Peclet numbers and decreasing nanofluid concentration, the heat transfer properties improve. The amount of pumping power needed increased with an increase in nanofluid concentration for a particular heat load. For flow rates of 2–5 lpm of hot and cold fluids, water outperformed the nanofluid in terms of power consumption and heat transfer rates. Furthermore, compared to water, the nanofluid required a lower flow rate but saw a greater pressure decrease. The maximum heat transfer rate was discovered with the lowest concentration of nanofluids, despite the fact that for a given pumping power the nanofluids could remove more heat than water could.

2.2 Shell and Tube Heat Exchanger

According to Khoddamrezaee et al. [39], the properties of Al2O3/ethylene glycol nanofluid and ethylene glycol fluid that flow via a rectangular configuration of tubes in a shell and tubes heat exchanger have been reported. We have calculated and compared the stagnation point, separation point, heat transfer coefficient, and shear stress in both nanofluid and pure fluid. The findings demonstrated that the use of nanofluids delayed the flow's stagnation and separation points, increased the amount of heat transfer coefficient, and raised shear stress, but that the influence of the latter might be overlooked in favor of the unexpected rise in heat transfer. An experimental examination was carried out by Farajollahi et al. [40] to investigate the heat transfer properties of nanofluids in a shell and tube heat exchanger. To examine the impacts of Peclet number, volume concentration of suspended particles, and particle type on the heat transfer properties, the nanofluids g-Al2O3/water and TiO2/water were utilized. Schematic representation of the experimental apparatus employed in this investigation was provided. Specifically, two flow loops—one for nanofluids and one for water—are involved. The test portion is a shell and tube heat exchanger with 16 tubes that have an outside diameter of 6.1 mm, a thickness of 1 mm, and a length of 815 mm. Water circulates inside the shell, which has an internal diameter of 55.6 mm. The baffle cut and baffle spacing are 25% and 50.8 mm, respectively, while the tube pitch is 8 mm. The following ranges were used for the experiments: The Peclet number ranged between 20,000 and 60,000, while the nanoparticle volume concentrations of g-Al2O3/water and TiO2/water nanofluids range between 0.3-2% and 0.15-0.75%, respectively. According to the findings, adding nanoparticles to the base fluid improves heat transfer efficiency and produces a heat transfer coefficient that is higher than the base fluid's at the same Peclet number. It was discovered that the Peclet number greatly affects the way nanofluids transport heat. Multi-walled carbon nanotube (MWNT)/water nanofluid heat transfer enhancement was experimentally studied by Lotfi et al. [41] in a horizontal shell and tube heat exchanger. The heat exchanger, through which nanofluid travels, serves as the test section. through 14 tubes, each 580 mm long and 7 mm internal diameter, using a 101 mm bore, the coolant passes through the shell side. inner circumference. The heat exchanger's inlet and outflow were four K type thermocouples are present. inaccuracy in measurement of K type thermocouples were used to gauge the temperatures of fluids. 70.1 1°C. This review delves into graphene nanoplatelets (GNP) nanofluids, highlighting their strong thermal properties and stability. The study compares various preparation methods and analyzes applications in heat exchange, solar collection, and heat pipes. It reveals the impact of functionalization on stability and heat transfer. Smaller particles and increased concentration boost performance, showing potential as a promising working fluid [42]. Amidst rapid industrial advancement and increased high-power devices, durability and efficiency challenges arise. Research focuses on efficient thermal management for these scenarios. Graphene nanomaterials, with high thermal conductivity, stand out as nanofluid candidates. Despite studies on graphene nanofluids, a comprehensive review on their thermal conductivity factors and applications, including economic and environmental aspects, is missing. This paper covers influencing factors like temperature, particle properties, and more. Applications span heat pipes, exchangers, and solar collectors, with economic and environmental considerations. The review highlights graphene nanomaterials' substantial impact on thermal conductivity and device performance, crucial for sustainable development and carbon neutrality goals [43]. Heat exchangers are vital in industries like thermal power, chemicals, and petroleum, facilitating heat exchange between fluids. Common models are less thermally efficient, prompting researchers to seek energy-efficient, miniaturized designs. Nanofluids, containing high thermal conductivity particles, offer a solution. Hybrid nanofluids, mixing nanoparticles into base fluids, amplify properties. This review explores hybrid nanofluids' potential in diverse heat exchangers, detailing synthesis methods, properties, and applications. Experimental and numerical studies' findings are reviewed, alongside prior research, to assess overall performance enhancements [44]. Nanofluids exhibit superior thermal and thermophysical traits, revolutionizing various industries with enhanced mass and heat transport. They curtail energy use, elevate fluid heat efficiency, and optimize equipment size in novel technologies. This paper reviews nanoparticles' impact on fluid properties and existing models for nanofluid thermal conductivity assessment. Results highlight heightened thermal conductivity with rising nanoparticle concentration and temperature. Particle shape also affects conductivity, with non-spherical particles demonstrating greater impact in ionic fluids than spherical counterparts. Investigations span temperatures of 10-250°C and concentrations of 0.01-50% [45].

3. FLUID FLOW FLUENT ANALYSIS

ANSYS Fluent is a widely used computational fluid dynamics (CFD) software that allows engineers and researchers to simulate and analyze fluid flow, heat transfer, and other related phenomena. When conducting a thermal analysis using ANSYS Fluent, several models, equations, and assumptions can be employed. Below, I'll outline some of the key aspects typically considered in a thermal analysis using ANSYS Fluent for a review paper

3.1 Continuity Equation

The continuity equation represents mass conservation and is given by:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0$$

Where,

ρ = density of the fluid

u = fluid velocity vector

∇ = del operator

3.2 Navier Stoke's Equation

The Navier-Stokes equations govern fluid motion and are given by:

$$\frac{\partial \rho u}{\partial t} + \nabla \cdot (\rho u u) = -\nabla P + \nabla \cdot \tau + \rho g$$

Where,

P is the pressure

τ is the stress tensor

g is the body force vector (e.g., gravitational force).

3.3 Energy Equation

The energy equation accounts for heat transfer and is given by:

$$\partial(\rho E)/\partial t + \nabla \cdot (\rho u E + q) = \nabla \cdot (k \nabla T) + Q$$

ρ represents the fluid density.

E is the total energy per unit mass, which includes internal energy, kinetic energy, and potential energy.

t is time.

u is the fluid velocity vector.

q is the heat flux vector, which represents the convective heat transfer.

k is the thermal conductivity of the fluid.

T is the temperature.

Q is the volumetric heat source/sink term.

3.4 Turbulence Model

In many cases, the flow might be turbulent. Several turbulence models can be used, such as:

Reynolds-Averaged Navier-Stokes (RANS) models: k-ε, k-ω SST, etc.

Large Eddy Simulation (LES).

Reynolds Stress Model (RSM).

3.5 Boundary Conditions

Appropriate boundary conditions must be set to define the flow and thermal behavior at the domain boundaries. Examples include:

Inlet velocity and temperature profiles.

Outlet pressure or mass flow rate boundary.

Wall boundary conditions (no-slip, wall temperature, heat flux, etc.).

3.6 Material Properties

Fluid properties like density ρ, Thermal Conductivity k, Specific Heat Capacity Cp, Dynamic Viscosity μ, Thermal Expansion Coefficient β, Prandtl Number Pr, Thermal Diffusivity α, Thermal Expansion Coefficient β.

4. CONCLUSION

In this review paper, we have explored the application of Computational Fluid Dynamics (CFD) in the analysis of shell and tube heat exchangers using nanofluids. The study of nanofluids, which are colloidal suspensions of nanoparticles in conventional base fluids, has gained significant attention in recent years due to their enhanced thermal properties. The incorporation of nanofluids in shell and tube heat exchangers presents a promising avenue for improving overall heat transfer efficiency and performance. Through an extensive review of the literature, we have observed that CFD simulations have proven to be a valuable tool in investigating the intricate fluid flow and heat transfer phenomena within shell and tube heat exchangers with nanofluids. The CFD simulations have provided crucial insights into the thermal behavior, pressure drop characteristics, and nanofluid distribution, which are otherwise challenging to obtain through experimental means alone.

The findings from various studies indicate that the incorporation of nanofluids can significantly enhance the heat transfer rate compared to conventional fluids. The increased thermal conductivity and convective heat transfer coefficient of nanofluids play a pivotal role in this enhancement. Moreover, researchers have also explored the influence of nanoparticle concentration, size, and base fluid properties on the overall heat transfer performance of the heat exchanger.

Despite the numerous advantages offered by nanofluids, challenges still exist, such as potential nanoparticle agglomeration, stability, and cost-effectiveness. CFD simulations have played a crucial role in addressing some of these challenges by providing valuable information on the flow behavior and particle distribution within the heat exchanger.

As we move forward, it is essential to continue advancing CFD techniques to accurately predict the behavior of nanofluids within complex heat exchanger geometries. Additionally, experimental validation of CFD results remains essential to ensure the reliability and accuracy of the simulations.

In conclusion, the combination of CFD analysis and nanofluids in shell and tube heat exchangers offers a promising pathway for enhancing heat transfer efficiency and exploring innovative designs. This research area holds great potential for numerous industrial applications, such as thermal management in electronics, renewable energy systems, and various other heat exchanger applications. By harnessing the capabilities of CFD simulations and continually exploring new nanofluid formulations, we can unlock the full potential of nanofluids and contribute to more efficient and sustainable heat exchange technologies in the future.

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