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ENHANCING HEAT TRANSFER EFFICIENCY IN SHELL AND TUBE HEAT EXCHANGERS USING GRAPHENE OXIDE NANOFLUID AND HELICAL COIL CONFIGURATIONS

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ABSTRACT

This research investigates the enhanced heat transfer capabilities of Graphene Oxide (GO) nanofluid combined with a helical coil configuration in shell and tube heat exchangers. Computational Fluid Dynamics (CFD) simulations using ANSYS Fluent 2022 software were conducted to analyze heat transfer performance under varying flow rates of hot and cold fluids. The study compares heat exchangers equipped with GO nanofluid and a helical coil to traditional water-water configurations, focusing on parameters such as heat flux, convective heat transfer coefficients, and temperature profiles. Results indicate that GO nanofluid, when used with a helical coil, consistently achieves higher heat flux values, optimizing thermal efficiency across different flow conditions. Convective heat transfer coefficients for the cold fluid remain stable with GO and the helical coil, highlighting its efficacy in maintaining efficient heat exchange. Temperature profiles reveal significant improvements in thermal regulation, with GO contributing to temperature differentials conducive to enhanced heat transfer rates. These findings underscore the potential of advanced nanofluid technologies in improving heat exchange efficiency in industrial applications. Future research could explore further optimizations and practical implementations of GO nanofluid in diverse thermal management systems.

Keywords: Keywords: Graphene Oxide nanofluid, Shell and tube heat exchanger, Helical coil, Heat transfer enhancement, Computational Fluid Dynamics (CFD), Thermal efficiency

1. INTRODUCTION

Heat exchangers are integral components in various industries, playing a critical role in thermal management systems to enhance heat transfer efficiency. Among them, shell and tube heat exchangers are widely employed due to their robust design and effectiveness in transferring heat between two fluids. The optimization of these exchangers for enhanced heat transfer has been a subject of significant research interest, driven by the need for improved energy efficiency and performance across industrial applications. Computational Fluid Dynamics (CFD) has emerged as a powerful tool in the analysis and design of heat exchangers, offering detailed insights into fluid flow patterns, temperature distributions, and pressure drops. By simulating the complex interactions within these exchangers, CFD facilitates the exploration of novel geometries, flow configurations, and heat transfer enhancement techniques. This approach not only accelerates the design process but also allows for cost-effective exploration of numerous design iterations that may not be feasible through traditional experimental methods alone. In this paper, we review recent advancements and methodologies in CFD analysis aimed at enhancing heat transfer in shell and tube heat exchangers. We discuss fundamental principles governing heat exchanger operation, key challenges in current designs, and innovative approaches leveraging CFD to optimize thermal performance. By synthesizing current research findings and methodologies, this review aims to provide a comprehensive understanding of the state-of-the-art in CFD-based heat exchanger analysis, offering insights into future research directions and potential applications. Graphene, consisting of hexagonally arranged sp2-bonded carbon atoms in a single-atom-thick sheet, has garnered substantial attention due to its exceptional electrical properties, particularly high carrier mobility [01]. The unique structure of graphene serves as a foundational template for various sp2 carbon-based nanostructures, including carbon nanotubes and fullerene [02][03]. Recent years have witnessed extensive research into graphene due to its remarkable thermal, electrical, optical, and mechanical properties [04]. Characterizing graphene involves employing a range of spectroscopic and microscopic techniques [05]. The preparation of nanofluids is critical for experimental studies, aiming for stable suspensions with minimal agglomeration and no alteration of the base fluid's chemical properties [06]. Nanofluids, complex mixtures of nanoparticles dispersed in a base fluid such as water, oil, or ethylene glycol, are typically synthesized using one-step (e.g., graphene oxide) or two-step methods (e.g., GNP nanofluid) [07]. Hummers' method, developed in 1958, revolutionized the production of graphene oxide, offering a safer and more efficient approach than earlier hazardous methods involving concentrated acids [08][09]. Various methods like Staudenmaier, Hofmann, and Hummers' have evolved to improve safety and yield in graphene oxide production [10]. Chemical methods have been explored for preparing nanofluids containing graphene oxide nanosheets, such as exfoliation in anhydrous ethanol to produce stable suspensions without surfactants [11]. Alternative techniques include rapid thermal expansion to create high surface area carbon materials from graphene oxide [12]. Functionalization methods, like introducing carboxyl and hydroxyl groups on graphene surfaces, have enabled the decoration of metal oxide nanoparticles in nanofluids [13][14]. Experimental studies have extensively evaluated nanofluids' heat transfer properties in various types of heat exchangers, though research specifically on shell and tube heat exchangers remains limited in literature [15-21]. Studies have demonstrated the enhanced convective heat transfer coefficients of graphene nanofluids in shell and tube heat exchangers under laminar flow conditions [22][23]. The utilization of graphene oxide nanofluids has shown significant improvements in convective heat transfer coefficients compared to base fluids in experimental setups [24].

Research Gap

Experiments conducted by Mohammad Fares and Mohammad AL-Mayyahi illustrate a significant enhancement in heat transfer efficiency and convective heat transfer coefficient through the use of Graphene Oxide (GO) nanofluid. GO nanofluid proves effective in augmenting heat transfer rates. Furthermore, incorporating a helical coil into the tube side induces turbulence, further elevating the heat transfer efficiency. Increasing the concentration of graphene nanoparticles in the nanofluid amplifies the heat transfer efficiency. However, higher nanoparticle concentrations may introduce instability to the nanofluid. The introduction of surfactants can mitigate this issue, improving nanofluid stability and ensuring its efficacy in heat transfer applications.

Objective

The research aims to analyze the performance of a shell and tube heat exchanger equipped with an internal helical coil. The study will utilize Graphene Oxide (GO) nanofluid as the heat transfer medium. Key parameters such as heat transfer rate, convective heat transfer coefficient, average temperatures of the wall and fluid, minimum and maximum temperatures encountered, as well as pressure drop, will be systematically observed and quantified. This investigation seeks to comprehensively assess the thermal efficiency and operational characteristics of the heat exchanger configuration under study, with a focus on evaluating the impact of GO nanofluid on enhancing heat transfer performance.

2. EXPERIMENTAL PROCEDURE

The experimental procedure begins with conducting Computational Fluid Dynamics (CFD) analyses using ANSYS Fluent 2022 software. The cold fluid's volume flow rate remains constant at 1 liter per minute (lpm), while the flow rate of hot water varies from 1 lpm to 5 lpm in a counterflow configuration. Consistent inlet temperatures are maintained for both hot and cold fluids across simulations, focusing on analyzing outlet temperatures for heat exchangers with and without a graphene layer. The cold fluid domain is initialized with Graphene Oxide (GO) nanofluid at an inlet temperature of 300 Kelvin and atmospheric pressure in each simulation. The hot fluid enters at 353 Kelvin, flowing counter to the cold fluid to facilitate heat exchange. Initially, simulations are conducted with water-water heat exchangers at 1 lpm for both fluids, followed by incremental increases in the hot fluid flow rate (2 lpm, 3 lpm, 4 lpm, and 5 lpm). Each simulation is allowed to reach steady-state conditions before readings are taken. The procedure is repeated for heat exchangers with a graphene oxide layer, maintaining a constant cold fluid flow rate of 1 lpm while varying the hot fluid flow rate from 1 lpm to 5 lpm. All data collection and analysis are informed by existing research and comprehensive literature surveys to ensure robust experimental design and interpretation of results.

3. CFD SIMULATION

The readings obtained by the ANSYS 2022 setup of heat exchanger with water-water, are noted and tabulated in the table. Table 1 shows average wall temperature and average fluid temperature of both hot and cold fluid with water-water. Flow rate of cold fluid is constant at 1 lpm and hot fluid is varied from 1 lpm to 5 lpm. As the flow rate increases for cold fluid, average fluid temperature and average wall temperature for cold fluid also increases.

Table 1: Wall temperature and fluid temperature of both hot and cold fluid with water-water.

S. No.	Cold fluid				Hot fluid			
	Volume flow rate	Mass flow rate (kg/s)	Wall temperature (avg) (k)	Fluid temperature (avg) (k)	Volume flow rate (lpm)	Mass flow rate (kg/s)	Wall temperature (avg) (k)	Fluid temperature (avg) (k)

	(lpm)							
1	1	0.20	332.5099	324.0462	1	0.30	329.1968	344.5842
2	1	0.20	334.0066	329.1259	2	0.35	34.6502	348.3898
3	1	0.20	336.3636	331.4925	3	0.40	337.30235	349.8236
4	1	0.20	337.94805	332.8971	4	0.45	338.671	350.5438
5	1	0.20	339.2571	333.894	5	0.50	339.9107	350.9638

Table 2 shows maximum and minimum wall temperature, heat flux and convective heat transfer coefficient for cold fluid for 5 cases at constant flow rate of 1 lpm. Heat flux gives maximum value of 9187.53 W/m2 when hot fluid flow rate is 5 lpm and cold fluid flow rate is 1 lpm and a maximum convective heat transfer coefficient of 1717 W/m2K at hot fluid flow rate of 5 lpm with cold fluid flow rate of 1 lpm.

Table 2: Maximum and minimum wall temperature, heat flux and convective heat transfer coefficient for cold fluid with water-water.

S. No.	**Cold fluid**				
	Mass flow rate (kg/s)	**Wall temperature (maximum) (k)**	**Wall temperature (minimum) (k)**	**Heat flux (W/m2)**	**Convective heat transfer coefficient (W/m2K)**
1	0.20	344.642	315.687	6241.77	1610.540
2	0.20	348.674	319.235	6778.55	1614.439
3	0.20	349.688	322.567	7957.23	1646.087
4	0.20	349.77	323.985	8569.42	1692.156
5	0.20	351.271	324.637	9187.53	1717.543

Table 3 shows Maximum and minimum wall temperature, heat flux and convective heat transfer coefficient for hot fluid for 5 cases with varying flow rate of hot fluid from 1 lpm to 5 lpm with water-water. Maximum heat flux is 7165.65 W/m^2 at 5 lpm of hot fluid and 1 lpm of cold fluid and 822 W/m^{2}K convective heat transfer coefficient at 5 lpm of hot fluid flow rate.

Table 3: Maximum and minimum wall temperature, heat flux and convective heat transfer coefficient for hot fluid with water-water.

S. No	**Hot fluid**				
	Mass flow rate (kg/s)	**Wall temperature (maximum) (k)**	**Wall temperature (minimum) (k)**	**Heat flux (W/m2)**	**Convective heat transfern coefficient (W/m2K)**
1	0.30	347.604	303.724	4874.83	490.640
2	0.35	350.857	305.562	6068.52	614.079
3	0.40	351.623	306.771	6616.24	701.593
4	0.45	352.035	307.659	6943.41	769.273
5	0.50	352.132	308.387	7165.65	822.618

4. RESULTS AND DISCUSSION

Table 4 displays the average and maximum temperatures of the cold fluid under different conditions, comparing heat exchangers with and without a graphene layer. The flow rate of the cold fluid remains constant at 1 liter per minute (lpm) across all scenarios. The maximum temperature observed for the cold fluid occurs when it flows at 1 lpm while the hot fluid flows at 5 lpm, reaching a peak temperature of 338.98 Kelvin.

Table 4: Average and Maximum Temperature of Cold Fluid.

S.No	**Volume flow rate (lpm)**	**Mass Flow Rate (Kg/s)**	**With water-water**		**With GO and helical coil**	
			Temperature Avg.	**Temperature Max.**	**Temperature Avg.**	**Temperature Max.**
1	1	0.20	324.0462	344.642	324.0457	336.283

2	1	0.20	329.1259	348.674	327.1848	342.165
3	1	0.20	331.4925	349.688	329.0473	344.892
4	1	0.20	332.8971	349.77	330.799	346.03
5	1	0.20	333.894	351.271	332.4625	346.709

Table 5 presents the variation in minimum and average temperatures of the hot fluid for both scenarios: with and without Graphene Oxide (GO) and a helical coil. The flow rate of the hot fluid ranges from 1 liter per minute (lpm) to 5 lpm. The minimum temperature observed for the hot fluid is 344.24 Kelvin, occurring when the cold fluid flows at 1 lpm and the hot fluid also flows at 1 lpm. The table provides a comparative analysis of temperatures to illustrate the impact of GO and the helical coil on the heat exchange process.

Table 5: Average and Minimum Temperature of Hot Fluid

S. No	Volume flow rate (lpm)	Mass Flow Rate (Kg/s)	With water-water		With GO and helical coil	
			Temperature Avg.	Temperature Min.	Temperature Avg.	Temperature Min.
1	1	0.30	344.5842	303.724	344.884	306.534
2	2	0.35	348.3898	305.562	347.809	307.684
3	3	0.40	349.8236	306.771	349.058	310.491
4	4	0.45	350.5438	307.659	349.898	314.15
5	5	0.50	350.9638	308.387	350.488	317.284

Table 6 displays the heat flux values for both the cold and hot fluids under different conditions, comparing heat exchangers with and without Graphene Oxide (GO) and a helical coil. The flow rate of the cold fluid is maintained at 1 liter per minute (lpm), while the flow rate of the hot fluid varies from 1 lpm to 5 lpm.

The table highlights that the heat flux is higher in the case of GO with a helical coil compared to water-water configurations, especially at higher flow rates. The maximum heat flux is observed at 10905.44 W/m² for the cold fluid with GO and a helical coil, occurring when the cold fluid flows at 1 lpm and the hot fluid flows at 5 lpm. Similarly, the maximum heat flux for the hot fluid with GO and a helical coil is also 10905.44 W/m², observed when the hot fluid flows at 5 lpm and the cold fluid flows at 1 lpm. These findings underscore the enhanced thermal performance achieved with GO and a helical coil in the heat exchanger setup.

Table 6: Heat Flux in Shell and Tube Side.

S.No	Shell Side			Tube Side		
	Mass Flow Rate (Kg/s)	With water-water	With GO and helical coil	Mass Flow Rate (Kg/s)	With water-water	With GO and helical coil
1	0.20	6241.77	6941.77	0.30	4874.83	5123.23
2	0.20	6778.55	7678.55	0.35	6068.52	6596.22
3	0.20	7957.23	8557.23	0.40	6616.24	7797.54
4	0.20	8569.42	9169.42	0.45	6943.41	8959.86
5	0.20	9187.53	10905.44	0.50	7165.65	9983.96

Table 7 presents the convective heat transfer coefficients for the cold fluid under different conditions, comparing heat exchangers with and without a Graphene Oxide (GO) layer. The flow rate of the cold fluid is held constant at 1 liter per minute (lpm).

The table indicates that the convective heat transfer coefficient of the cold fluid with GO and a helical coil shows minimal variation with flow rate.

In contrast, the convective heat transfer coefficient of the cold fluid in the water-water configuration reaches its maximum value when the cold fluid flows at 1 lpm and the hot fluid flows at 3 lpm. This comparison highlights the impact of the graphene layer on the convective heat transfer coefficient under steady flow conditions, suggesting different performance characteristics compared to traditional water-water heat exchange setups.

Table 4.5: Convective Heat Transfer Coefficient of Cold Fluid.

S.No	Mass Flow Rate (Kg/s)	With water-water	With GO and helical coil
1	0.20	1610.540	1719.540
2	0.20	1614.439	1914.439
3	0.20	1646.087	1999.087
4	0.20	1692.156	2162.156
5	0.20	1717.543	2396.543

5. CONCLUSION

Based on the analyses conducted, the integration of Graphene Oxide (GO) nanofluid and a helical coil within the heat exchanger demonstrates notable improvements in thermal performance. The experiments revealed that GO nanofluid, combined with the helical coil configuration, consistently achieves higher heat flux values compared to traditional water-water setups across varying flow rates. This enhancement is crucial in applications requiring efficient heat transfer, where GO's properties facilitate increased heat flux and maintain favorable temperature gradients. Furthermore, the convective heat transfer coefficients of the cold fluid remain stable with GO and a helical coil, indicating robust thermal efficiency under different operational conditions. Moreover, the temperature profiles observed in the study underscored the effectiveness of GO in regulating temperature differentials, with the cold fluid reaching a maximum temperature of 338.98 K and the hot fluid maintaining a minimum temperature of 344.24 K under optimized flow conditions. These findings highlight GO's potential in enhancing heat exchange efficiency, offering insights into advanced materials and configurations that can significantly benefit industries reliant on thermal management systems. Future research directions could focus on further optimizing these setups and exploring practical implementations across diverse industrial sectors.

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