CFD investigation on heat transfer enhancement in shell and tube heat exchanger using Graphene Oxide Nano Fluid

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Abstract - T*he present study focuses on the computational fluid dynamics (CFD) investigation of heat transfer enhancement in a shell and tube heat exchanger using Graphene Oxide (GO) nanofluid. The aim is to evaluate the impact of incorporating GO nanofluid on the rate of heat transfer and convective heat transfer coefficient within the heat exchanger. The research demonstrates a significant improvement in heat transfer characteristics, with a rate of heat transfer increment of 42% and a convective heat transfer coefficient increase of 62%. The study begins with the development of a three-dimensional computational model of a shell and tube heat exchanger using commercially available software. The GO nanofluid, consisting of graphene oxide nanoparticles dispersed in a base fluid, is introduced into the heat exchanger. The governing equations of fluid flow and heat transfer, including the Navier-Stokes equations and energy equation, are solved numerically using appropriate boundary conditions. Simulation results indicate that the incorporation of GO nanofluid leads to enhanced heat transfer performance compared to traditional fluids. The improved thermal conductivity of the GO nanofluid facilitates more efficient heat transfer between the hot and cold fluids flowing through the heat exchanger. The presence of nanoparticles disrupts the thermal boundary layer and enhances convective heat transfer by promoting better mixing and increased contact area between the fluid and the heat transfer surface. The obtained results demonstrate that the use of GO nanofluid in shell and tube heat exchangers can significantly enhance the overall heat transfer efficiency. This finding has implications for various industrial applications, including HVAC systems, power plants, and chemical processes, where efficient heat exchange is crucial. The research findings provide valuable insights for the design and optimization of heat exchangers to achieve higher performance and energy savings by employing graphene oxide nanofluids. Further experimental validation of these results is recommended for real-world implementation.*

***Key Words*: Heat Exchanger, Nanofluid, Convective Heat Transfer Coefficient, helical Coil, CFD Analysis**

1.INTRODUCTION

Any technology that deals with high power and tiny size is very concerned with heat removal and management. Many scientists throughout the world are interested in using nanofluids to address these problems. A nanofluid can frequently be produced specifically to meet a demand and function as a flexible cooling solution, adjusting to the specifications of a given system. In essence, nanofluids have the potential to develop into the first intelligent/adaptive coolant in the world [1,2]. Choi and Eastman [3] first used the term "nanofluids," which are multiphase systems having a stable colloidal suspension of nanometer-sized particles and a base matrix host fluid. The host fluid and nanoparticles can be synthesised in one step along with the nanofluid, or they can be created separately and combined in two steps [4]. Since its inception, nanofluid have been the subject of intense research because of their frequently abnormal and distinctive thermal transport properties. In terms of the scientific insights acquired from their study and the practically limitless industrial and commercial uses, nanofluid have also shown to be extremely valuable [5,6]. Cryogenic nanofluids are an area of nanofluid science that has received relatively little scientific attention. Cryogenic nanofluids use nanometer-sized particles and are comparable to conventional nanofluids [4,7]. Because they combine the high temperatures associated with cryogenics and the flexible thermal transport properties of nanofluids, cryogenic nanofluids have attracted a lot of attention. As a result, these nanofluids exhibit improved thermophysical properties and hold great potential for the creation of next-generation cryogenic fluids. Conventional nanofluids are fluids or fluid mixtures that may contain one or more types of dispersants, nanoparticles, or other additives. [8,9]. The variety of nanofluids is quite astounding, and in fact, a new nanofluid can be made by mixing together a few distinct base fluids or nanoparticles. Nanofluids can be created in a variety of ways, and even minor alterations to those methods can have a big impact on the final product. [8]. The efficiency of the heat transfer applications needs to be improved because they either directly or indirectly impact people's daily lives [10]. The goods with tiny size, high heat flux, and non-uniform heat flux have taken up a substantial percentage in various industries, along with improvements in manufacturing methods. Heat rejection solutions are in high demand because this trend is anticipated to last for the foreseeable future [11]. Engineering-wise, the fundamental heat transfer solution for the aforementioned cases is always forced convection using liquid coolants in laminar or turbulent flow regimes [12,13]. These methods, however, typically result in a significantly larger pressure loss and increased pumping power [14]. Heat transfer applications are significantly hampered by the low thermal conductivity and high viscosity of frequently used heat transfer liquids such water, ammonia, ethylene glycol, and mineral oil. These characteristics frequently lead to ineffective convective thermal performance and make it difficult to develop small heat rejecting devices. A novel coolant with enhanced heat transfer capabilities, such as nanofluid, is required as a remedy. [15,16]. Numerous studies have been conducted on heat transfer fluid, surface characteristics (such as extension, shape, and roughness), and fluid motion (laminar or turbulent) in an effort to boost the fluid's coefficient of heat transfer. Numerous investigations have recently been done on the creation of nanofluids using carbon-based nanostructures [17]. One of the materials that has been explored the most in this decade is graphene [18,19]. Since it was discovered by Novoselov et al. [20], graphene, a sheet of hexagonally arranged, sp2 - bonded carbon atoms, has drawn a lot of attention due to its distinctive electrical properties, such as its extremely high carrier mobility. The atomic-scale honeycomb (hexagonal) arrangement of carbon atoms in graphene is sp2 bonded, and this pattern serves as the foundation for additional sp2 carbon bonded nano-structure materials [21], including carbon nanotubes [22] and fullerene [23].

1.1 OBJECTIVE OF PRESENT STUDY

In this intriguing article, the focus lies on conducting a CFD analysis of a double pipe heat exchanger adding helical coil on the tube side utilizing graphene oxide nanofluid. Both the heat exchanger configurations, one with the Graphene oxide nanofluid and the other with water, were subjected to meticulous examination. The unique design of the heat exchanger, with its compact shell compared to traditional shell and tube heat exchangers, proved to be thermally efficient and remarkably resilient against thermal induced stresses. Surprisingly, despite a comprehensive review of existing literature, no prior study has explored the integration of a graphene oxide within a heat exchanger. Thus, this groundbreaking article delves into an in-depth analysis of the heat exchanger combined with graphene oxide, breaking new ground in the realm of heat exchange technology.

1.2 DESIGN AND CFD ANALYSIS

Fig. 1 shows the geometry of the heat exchanger which was designed on the ANSYS workbench 2022 R1. Fig. 2 shows the helical coil inside the tube of the heat exchanger. Meshing was done and boundary layer theory was taken care using inflation on both hot and cold fluid. A total of 719 iteration was done on the analysis to achieve convergence. Fig. 3 and 4 shows the meshing and inflation. Materials used are aluminium for both heat exchanger and helical coil.

Table 1: Specifications of heat exchanger

S. No.	Parameter	Value
1	Length of the heat exchanger	1000 mm
2	Shell side diameter	84 mm
3	Tube side diameter	42 mm
4	Tube inner diameter	40 mm
5	Inlet and outlet diameter of cold and hot fluid	40 mm
6	Diameter of Helical coil	1 mm
7	Number of turns	100

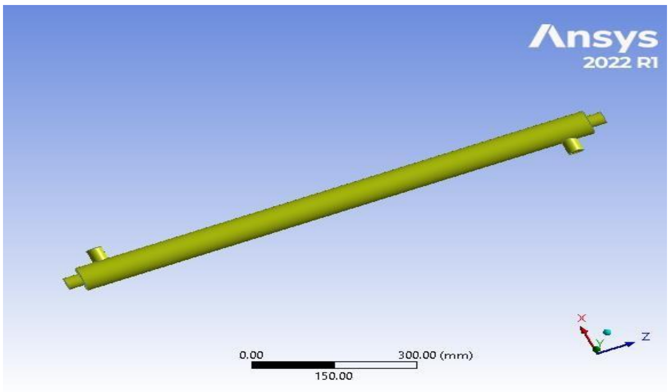

Fig. 1 Geometry of the heat exchanger

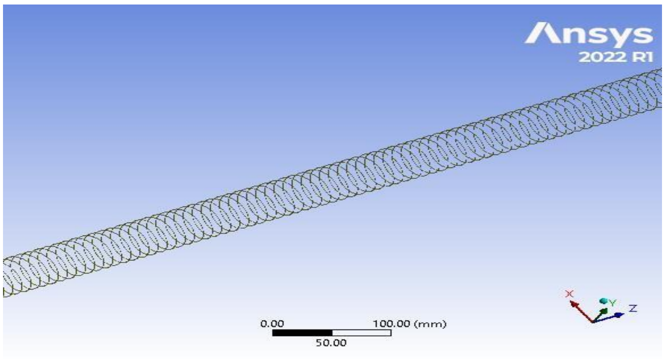

Fig. 2: Helical Coil

1.3 NUMERICAL SOLUTION PROCEDURE

In the CFD analysis of the hairpin heat exchanger, fundamental governing equations such as the momentum equation, energy equation, and continuity equation play a vital role. To ensure an accurate simulation, the PRESTO scheme is employed to couple pressure and velocity within the framework of the SIMPLEC algorithm.

For numerical discretization of these equations, the second-order upwind scheme is preferred due to its higher accuracy compared to the first-order upwind scheme. To achieve convergence, different criteria are set for various parameters. The continuity equation employs a convergence criterion of 1.0e-05, while velocities in all directions share the same value. The energy equation requires a stricter convergence threshold of 1.0e-08, and for k (turbulent kinetic energy) and e (dissipation rate of turbulent kinetic energy), a value of 1.0e-05 is adopted.

To expedite the convergence process and reach the desired values efficiently, relaxation values are assigned to the respective variables. The pressure relaxation value is set at 0.3, while k and ε have a relaxation value of 0.7, and temperature has a value of 0.9.

In the simulation setup, a mass flow inlet boundary condition is applied for introducing the cold and hot fluids into the heat exchanger, while the pressure outlet boundary condition is utilized for the outlet of both fluids, allowing for an accurate and comprehensive analysis of the system.

1.4 BOUNDARY CONDITIONS

The hot fluid's mass flow rate is 1 lpm, 2 lpm, 3 lpm, 4 lpm and 5 lpm but the mass flow rate is kept constant for the cold fluid, which is 1 lpm. The temperature of cold fluid inlet is 300 k while hot fluid inlet is 353 k.

1.5 MESHING

Meshing, in the context of computational fluid dynamics (CFD) and other numerical simulations, refers to the process of dividing the domain or geometry of a physical problem into small and manageable sub-regions called elements or cells. These elements together form a grid or mesh that discretises the continuous domain into discrete points. The purpose of meshing is to convert the governing equations of the problem (e.g., Navier-Stokes equations for fluid flow) into a system of algebraic equations that can be solved using numerical methods on a computer. The mesh serves as a computational grid, allowing the simulation software to approximate the continuous field variables (e.g., velocity, pressure, temperature) at each mesh node or cell. The quality of the mesh plays a crucial role in the accuracy and efficiency of the simulation. A well-designed mesh should have adequate resolution to capture the important flow features and gradients accurately. On the other hand, a poorly designed mesh with irregular elements or excessive distortion can lead to numerical errors and unreliable results. Different types of meshing methods exist, such as structured meshing (regular grid arrangement), unstructured meshing (irregular grid arrangement), and hybrid meshing (combining structured and unstructured elements). Each type has its advantages and is chosen based on the complexity of the problem and the desired level of accuracy. Meshing is a fundamental step in setting up CFD simulations and is crucial for obtaining meaningful insights into the behaviour of fluid flows and other physical phenomena.

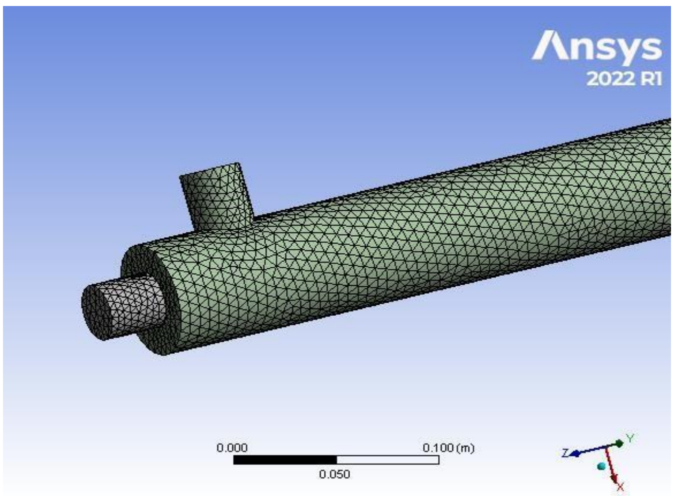

Fig. 3: Meshing of the geometry

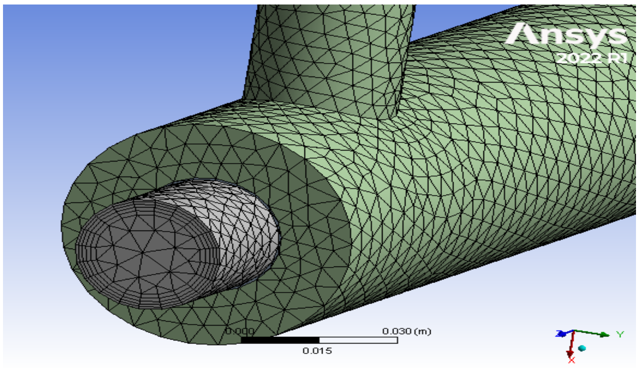

Fig. 4: Inflation on the tube side.

Thermal properties used used for the nanofluid

At volume fraction of 0.6
Nano fluid density (ρ_{nf}):
ρ_{nf} = 2727.28 kg/m^3
Nano fluid specific heat (Cp $_{nf}$):
Cp $_{nf}$ = 1389.02 J/kg-K
Nano fluid viscosity (μ_{nf}):
μ_{nf} = 0.0025075 kg/m-s
Nano fluid thermal conductivity (K_nf):
K_{nf} = 5.13 W/m-K

2. CFD REPORT

2.1 BOUNDARY PHYSICS FOR FLUID FLOW FLUENT

Table 2: Boundary Physics

part cold_fluid	Boundary - hot_fluid_inlet	
	Type	MASS-FLOW-INLET
	Location	hot_fluid_inlet
	Boundary - hot_fluid_outlet	
	Type	PRESSURE-OUTLET
	Location	hot_fluid_outlet
	Boundary - wall part cold_fluid	
	Type	WALL
	Location	wall-part-cold_fluid
	Boundary - wall part cold_fluid part wall shadow	
	Type	WALL
	Location	wall-part-cold_fluid-part-wall-shadow
part hot_fluid	Boundary - cold_fluid_inlet	
	Type	MASS-FLOW-INLET
	Location	cold_fluid_inlet
	Boundary - cold_fluid_outlet	
	Type	PRESSURE-OUTLET
	Location	cold_fluid_outlet
	Boundary - wall part hot_fluid	
	Type	WALL
	Location	wall-part-hot_fluid
	Boundary - wall part hot_fluid part wall	
	Type	WALL
	Location	wall-part-hot_fluid-part-wall

2.2 Mesh

Table 3: Meshing Data

Object Name	*Mesh*
State	Solved
Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	CFD
Solver Preference	Fluent
Element Order	Linear
Element Size	Default (5.3423e-002 m)
Export Format	Standard
Export Preview Surface Mesh	No
Sizing	
Use Adaptive Sizing	No
Growth Rate	Default (1.2)
Max Size	Default (0.10685 m)
Mesh Defeaturing	Yes

Defeature Size	Default (2.6711e-004 m)
Capture Curvature	Yes
Curvature Min Size	Default (5.3423e-004 m)
Curvature Normal Angle	Default (18.0°)
Capture Proximity	No
Bounding Box Diagonal	1.0685 m
Average Surface Area	3.4607e-002 m^2
Minimum Edge Length	9.4248e-002 m
Quality	
Check Mesh Quality	Yes, Errors
Target Skewness	Default (0.9)
Smoothing	Medium
Mesh Metric	None
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	
Rigid Body Behavior	Dimensionally Reduced
Triangle Surface Mesher	Program Controlled
Topology Checking	Yes
Pinch Tolerance	Default (4.8081e-004 m)
Generate Pinch on Refresh	No
Statistics	
Nodes	107865
Elements	224452

3. RESULT AND DISCUSSION

3.1 HEAT FLUX IN SHELL AND TUBE SIDE

Fig. 5 shows heat flux for cold and hot fluid, with and without GO and helical coil. Cold fluid flow rate is kept constant that's 1 lpm and hot fluid flow rate varies from 1 lpm to 5 lpm. Heat flux is more in the case of GO with helical coil when compared to water-water at high flow rate. Maximum heat flux gives the value of 10905.44 W/m^2 for cold fluid with GO and helical coil at the flow rate of 1 lpm of cold fluid and 5 lpm of hot fluid, whereas heat flux has maximum value of 10905.44 W/m^2 for hot fluid with GO and helical coil at the flow rate of 5 lpm of hot fluid and 1 lpm of cold fluid.

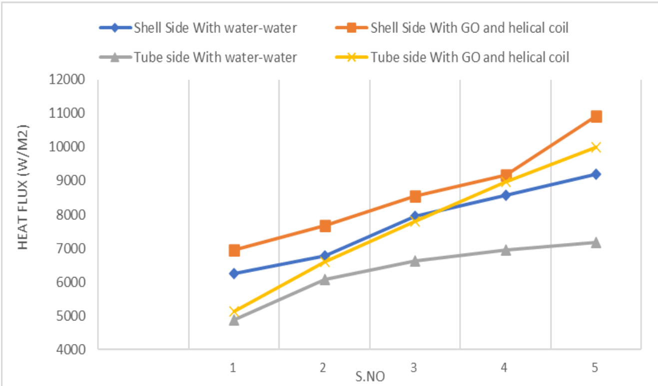

Fig. 5: Heat Flux

3.2 CONVECTIVE HEAT TRANSFER COEFFICNET OF COLD FLUID AND HOT FLUID

Fig. 6 shows convective heat transfer coefficient of cold fluid with and without graphene layer when cold fluid flows at the constant flow rate of 1 lpm. Convective heat transfer coefficient of cold fluid with GO and helical coil doesn't show much variation with flow rate but convective heat transfer coefficient of cold fluid with water-water gives maximum value when cold fluid flows at 1 lpm and hot fluid flows at 3 lpm.

Fig. 7 shows convective heat transfer coefficient of hot fluid for both the cases (with and without graphene layer) for varying flow rate from 1 lpm to 5 lpm. Convective heat transfer coefficient of hot fluid with GO and helical coil has lesser value at low flow rate when compared with water-water. But at high flow rate, convective heat transfer coefficient of hot fluid has high value when compared to with water-water. Maximum value of convective heat transfer attained at the flow rate of 5 lpm of hot fluid and 1 lpm of cold fluid is 1117.27 W/m^2K.

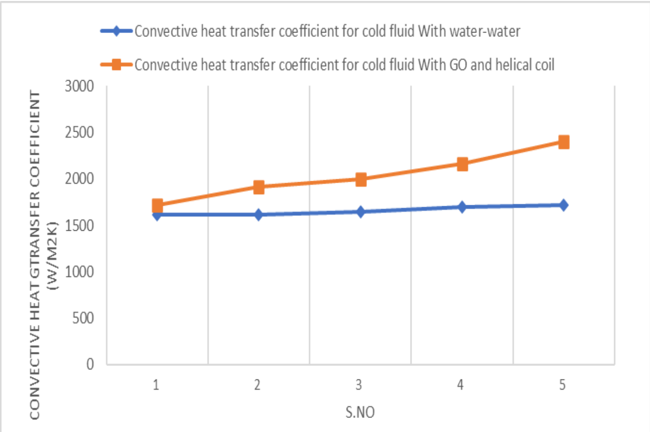

Fig. 6: Convective heat transfer coefficient of cold fluid

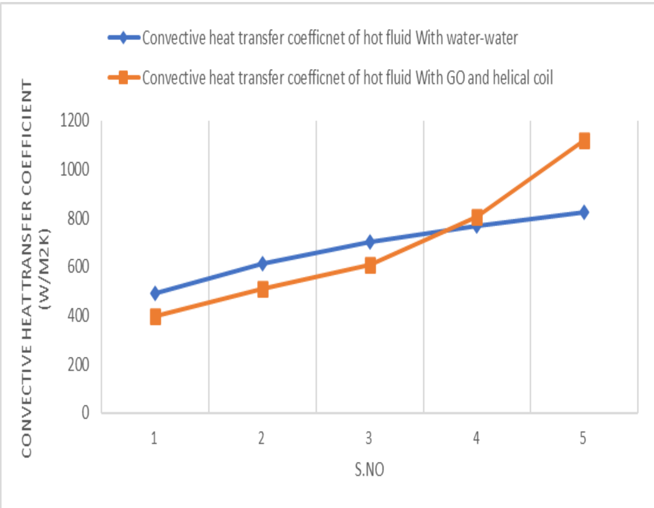

Fig. 6: Convective heat transfer coefficient of Hot fluid

4. CONCLUSION

Heat flux increases as the flow rate of both the fluid increases. It goes up to the maximum value of 10905 W/m^2K. At low flow rate, heat flux is less in the case of heat exchanger with GO & helical coil as compared to heat exchanger with water-water flow. But as the flow rate increases, heat flux is more in the case of heat exchanger with GO & helical coil, as compared to heat exchanger with water-water flow.

As far as convective heat transfer coefficient is concerned, effect of nanofluid can be clearly seen on the cold fluid. Its convective heat transfer coefficient is higher as compared of water. There is very little difference in the convective heat transfer coefficient of hot fluid, when used with GO & helical coil and water-water flow.

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