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Investigations on Double Pipe Heat Exchanger using Nano Particles of Varied Concentrations with Base Fluid as Water

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Abstract

Heat Exchangers (HXs) are devices created to facilitate the transmission of heat between fluids with varying temperatures. Depending on the type of HX employed, the heat transfer process can be liquid to gas, gas to gas, or liquid to liquid. Double pipe HX is one of the heat exchange devices that allows transferring heat between hot and cold liquids. Double pipe HXs are used in boilers, compressors, refrigeration systems and power plants due to their flexibility and compactness. Most of the research works are conducted on increasing the performance of double pipe HX by using different nanoparticles like TiO_2, CuO, and Al_2O_3, with various base fluids like water, propylene glycol and distilled water. The study explores nanoparticle concentrations ranging from 0.05% to 0.2% by volume. Results indicated that as the concentration of Graphene nanoparticles increases, the overall Heat Transfer Coefficient (HTC) improves. The HTC is increased by 48% at 0.2% volume concentration compared to the base fluid. This improvement in heat transfer is attributed to the enhanced thermal properties of the fluid with nanoparticles. The results suggested that Graphene-based Nano fluids can significantly boost the heat transfer efficiency of double pipe heat exchangers.

Major Findings: *Incorporating Graphene nanoparticles into base fluids enhances heat transfer in double pipe heat exchangers. A 0.2% volume concentration of Graphene nanoparticles increases the Heat Transfer Coefficient (HTC) by 48% compared to the base fluid. The improvement is due to the enhanced thermal conductivity provided by the Graphene-based Nano fluid*

Keywords: *Double Pipe Heat Exchanger, Graphene Nano-Particles, Overall Heat Transfer Coefficient, Thermo-Physical Properties, Water*

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1.0 Introduction

Heat exchange occurs between different elements, such as a process flow and a medium that supplies or absorbs heat, like cold water or pressurized steam. Heat exchange can also take place between a flowing fluid and a power source, like electric heating, or even between two separate fluid flows. A heat exchanger usually manages two process flows, but in energy-demanding processes like Liquefied Natural Gas (LNG) processing, multi-stream heat exchangers are used to improve cost efficiency. In the last twenty years, the fusion of thermal engineering and nanotechnology has led to the development of a specialized type of heat transfer fluid called 'Nano fluids. The improvements in system efficiency with various Nano fluids (NFs) were observed. For instance, Sic Multi-Walled Carbon Nanotube (MWCNT)/water NFs achieved 99.9% absorbance in solar collectors, while Ag-rGO/ water and Ag-ZnO/ silicon oil NFs enhanced efficiency by 210% and 240%, respectively. In flat tube HEXs, water-alumina NFs increased convective heat transfer rates by 123.6% and friction factors by 210%. Additionally, helical coil exchangers exhibited a 47.35% reduction in pressure drop with MWCNT/water NFs and a 69.62% rise in heat transfer coefficient with polyaniline-water NFs[1].

The thermos physical properties of Gr-based NFs, including thermal conductivity, heat capacity, density, and viscosity, all of which directly influence heat transfer performance. The substantial improvements in thermal conductivity, with increases of up to 40%, make Gr-based NFs highly efficient compared to other commonly studied metal oxide NFs. Additionally, Gr-based NFs offer better performance at lower nanoparticle concentrations and exhibit lower increases in density and viscosity, which are critical factors for reducing pumping power requirements[2].

NFs are created by dispersing Nanoparticles (NPs) made of high thermal conductivity materials into a Boron Mono fluoride (BF), forming a stable suspension. Various types of nanoparticles, including metallic ones like Silver (Ag), Copper (Cu) and Gold (Au), have been explored as additives to different base fluids due to their excellent thermal conductivity. However, a key challenge in using these metallic nanoparticles is their limited availability and high cost[3]. The thermo-physical properties of Alumina, Titanium and Silica/water-based Nano fluid with volume concentrations ranging from 1 to 2.5%. They found that thermal conductivity and viscosity enhancements vary from 0.5 to 20% and 0.5 to 60%, respectively. When differentiated with base fluid, they observed that the measured data was good with available experimental values[4].

The thermo-physical properties (thermal conductivity and viscosity for various temperatures ranging from 20 to 50^{0}C and 20 to 80^{0}C respectively) of MWCNT and graphene NFs studied were used. They noticed that the improvement in thermal-conductivity of MWCNT and Graphene NF was up to 7.7% for a 0.15%, up to 5.9% for a 0.1% volume concentration, respectively. The thermal conductivity of MWCNT is enhanced by 9.2% for lower temperatures, and 29.7% for higher temperatures, respectively[5]. The dynamic viscosity of CeO_2-Ethylene Glycol was evaluated across a temperature range of 25 to 50°C and volume concentrations from 0.05% to 1.2%. They studied that the Nano fluid viscosity enhances with the enhancement of volume fraction at constant temperature. The maximum viscosity enhancement is 1.2% volume fraction at 25^{0}C[6].

This experimental study examines the thermos physical properties, heat transfer coefficient, entropy generation, and exergy efficiency of ZrO_2/DI-water Nano fluids circulating through a tube under turbulent flow conditions. ZrO_2 NPs were synthesized using the sol-gel method, and their performance was analyzed across a temperature range of 20–60°C, volume concentrations of 0.2 – 1.0%, and Reynolds numbers between 2000 and 22,000. Results show that at 1.0% volume concentration, thermal conductivity increases by 24.96% at 60°C, while viscosity rises by 45.57% at 20°C compared to the base fluid[7]. This study investigates the heat transfer properties of aqueous Al_2O_3/Ag hybrid Nano fluids, which are developed to enhance thermal conductivity compared to single-component NFs. They indicated that the Al_2O_3/Ag hybrid Nano fluid achieves better thermal conductivity than Al_2O_3 NFs alone[8]. This study introduces an improved approach for accurately measuring the thermal conductivity of NFs under flow conditions. The thermal conductivity of water-based Al_2O_3 NFs at concentrations of 0.2 wt%, 0.5 wt%, and 1 wt% was measured using ISFM. Experimental results showed that the thermal conductivity of Al_2O_3 Nano fluids increased by 10.5%, 16.7%, and 22.8% for 0.2 wt%, 0.5 wt%, and 1 wt% concentrations, respectively, compared to the base fluid[9].

This study examines the dynamic viscosity, thermal conductivity, and isobaric specific heat capacity of MgO and ZnO nanoparticles dispersed in water and Ethylene Glycol/Water (EG/W) mixtures. The nanoparticle concentrations range between 0.25% and 1%, and temperatures range from 40 to 120°C. Results indicated that viscosity and thermal conductivity increase with higher nanoparticle concentrations. The highest viscosity increase was 34.5% for 1% MgO-(50:50) EG/W and 45.1% for 1% ZnO-(50:50) EG/W. Thermal conductivity improvements reached 33.1% for 1% MgO-EG/W and 23% for 1% ZnO-EG/W[10]. This study explores the specific heat of Titanium Oxide Nano fluids and compares them to their base fluids, including ethylene glycol (40%)/water (60%), pure ethylene glycol, and water. In this work, new correlations are developed to predict the specific heat and density of Nano fluids as functions of temperature. These correlations were evaluated against existing theoretical models, demonstrating improved accuracy in predicting specific heat and density[11].

This review examines the impact of nanoparticle additives on the thermos physical properties of fluids and evaluates existing models for measuring the thermal conductivity of Nano fluids. This study highlights that increasing nanoparticle concentration and temperature leads to higher thermal conductivity. They were revealing that non-spherical nanoparticles enhance thermal conductivity in ionic fluids more than spherical ones. The study considers temperature ranges from 10 to 250°C and nanoparticle concentrations between 0.01% and 50%[12]. The study examines the effects of nanoparticle volume fraction and temperature on the thermal conductivity and viscosity of water-based CuO, TiO_2, and ZnO Nano fluids. Nano fluids were prepared using the two-step method with concentrations ranging from 0.1% to 0.5% by weight. Results indicated that thermal conductivity increases while viscosity decreases with rising temperature, and both properties were enhanced with higher nanoparticle concentration. Among the tested Nano fluids, CuO exhibited the highest thermal conductivity and better viscosity performance[13]. The enhancement of heat transfer rate in double-pipe HX with counter and parallel flow configuration using (Al_2O_3) Nano fluid of volume concentrations ranging from 0.001% to 0.01%, base fluid as water. They found overall HTC augmented with volume concentration up to 0.008% and then decreases[14].

The improvement of heat transfer coefficient and Nusselt number in a Nano fluid containing γ- Al_2O_3 nanoparticles (20nm) with volume fractions ranging from 0.1% to 0.3%. The effects of temperature and nanoparticle concentration on heat transfer performance were analyzed in a double-pipe heat exchanger with counter-turbulent flow. Experimental results align well with theoretical predictions, demonstrating an increase of 19%–24% in both heat transfer coefficient and Nusselt number[15]. The development of convective HTC techniques using Nano fluids and the enhancement of thermo-physical properties were studied. They reviewed correlations for friction- factor and HTC for dissimilar kinds of NF movement in a natural tube under laminar flow- turbulent flow conditions. The correlations were developed under the laminar to turbulent region using inserts[16].

Experimental investigations on laminar flow forced convective heat transfer and friction factor of silver-water Nano fluids in a horizontal circular pipe under uniform heat flux conditions. The heat transfer coefficient and friction factor were analyzed based on nanoparticle volume concentration (0.01%–0.1%) and Reynolds number (500–2300). Results showed that increasing nanoparticle concentration and Reynolds number enhances both the Nusselt number and heat transfer coefficient, with a maximum improvement of 36.1% at 0.1% concentration and Reynolds number of 2300[17]. A numerical study analyses turbulent forced convection flow of water in a horizontal circular channel under constant heat flux conditions. The Nusselt number and friction factor were examined for Reynolds numbers ranging from 5000 to 20000. Results showed that heat transfer improves with increasing Reynolds number, while the friction factor rises as Reynolds number decreases[18].

An exploratory setup was created to study the flow characteristics and convective HT of Nano fluids in a tube. The ff and convective HT of the Nano fluid samples were also measured[19]. Nano fluid research has advanced significantly since its enhanced thermal conductivity, but challenges such as inconsistencies in findings and limited understanding of their formulation and mechanisms have hindered broader applications. They suggested that limiting factors for heat transfer applications of NF for further development[20]. This study presents numerical research on the turbulent flow of magnetic Ni NF in a tube under constant heat flux conditions. Simulations

were conducted for Reynolds numbers between 3,000 and 22,000 and nanoparticle concentrations ranging from 0% to 0.6%. Results indicated that increasing the NP concentration and Reynolds number enhances heat transfer performance[21].

An exploratory study was conducted to explore the impact of hybrid NF on the friction factor and total HTC. The TiO_2–SiC/water hybrid Nano fluid with a nanoparticle ratio of TiO_2: SiC = 1:2 is the most effective, as it provides significant heat transfer enhancement with little impact on friction factor. The transfer of heat is increased by 22.92% and the friction factor is increased by 11.20% compared to the base fluid when using a mixture of TiO_2 and SiC in a 1:2 ratio[22].

The objective is to investigate HT enhancement and friction factor in a counter-flow concentric

tube heat exchanger using CuO, Al_2O_3, and TiO_2 Nano fluids through experimental and numerical analysis. A standard k-ε turbulence model was applied to solve momentum and energy equations for Nano fluids, with simulations conducted for Reynolds numbers between 2,000 and 12,000 and nanoparticle concentrations of 0.05% and 0.2%. Results show that all NFs enhance heat transfer, with CuO exhibiting the highest performance index[23].

This study analyses the thermal efficiency of a Shell and Tube Heat Exchanger (STHX) using hybrid Ag-MgO NFs. The effects of Reynolds number (2,500–12,000) and NP volume fraction (0.01–2%) were evaluated, with an inlet NF temperature of 40°C. Results showed that incorporating hybrid NFs improves heat transfer performance, with a 16% increase in the heat transfer coefficient at the highest NP concentration. However, the pressure drop also rises significantly compared to water as the heat transfer fluid[24].

An experimental study used a double-pipe counter-flow HX with cold (30°C) and hot (70°C) water as working fluids. NFs were produced by introducing different amounts (0.1%, 0.3%, and 0.5%) of TiO_2 NPs into water and evaluating their thermal conductivity and viscosity. At a concentration of 0.5% nanoparticles, the total HTC decreased, while at a concentration of 0.3%, it rose. An efficiency rise of up to 23% was seen when the NP concentration reached 0.3%[25].

The utilization of NFs in heat exchangers has been extensively investigated, with materials including Al_2O_3, CuO, and TiO_2 receiving considerable focus. The graphene-based NFs, despite their exceptional thermal characteristics, are still inadequately investigated in real industrial applications such as double-pipe heat exchangers. The literature on graphene Nano fluids mainly focused on isolated conditions, leaving a gap in understanding their practical applications. Despite hybrid Nano fluids, there is a lack of direct comparisons, limiting the understanding of graphene's benefits. There is also a need to explore the environmental and economic implications of graphene Nano fluids, particularly their long-term stability, cost-effectiveness, and sustainability. The novelty of the present study is in the multi-dimensional assessment of heat transfer efficiency,

utilizing Nusselt number, Reynolds number and performance evaluation criteria, while also offering practical suggestions for optimal NP concentrations and flow rates.

The novelty of this work lies in the innovative approach of incorporating Graphene NP into the base fluid of a double pipe HX to enhance heat transfer performance. While previous studies have focused on various nanoparticles like TiO_2, CuO, and Al_2O_3 with different base fluids, this research uniquely emphasizes the use of Graphene, known for its exceptionally high thermal conductivity.

2.0 Materials and Methodology

2.1 Experimental Methods

Double-pipe heat exchangers are uncomplicated but efficient apparatuses used for the transmission of heat between two dissimilar fluids. Their construction consists of two tubes, one inserted into the other, creating a "U" or "hairpin" configuration. These tubes provide the independent flow of two fluids, with one contained inside and the other external to the tube. The fundamental idea behind double pipe heat exchangers is the transmission of heat. A single fluid, often referred to as the "hot fluid," transfers thermal energy that has to be moved to another fluid, known as the cold fluid, which needs to be heated. As the fluid flows through the inner tube, it transfers heat to the tube's wall, causing it to increase in temperature. Thermal energy is conducted through the wall of the tube and transferred to the cooler fluid that

flows through the outer tube. The cold fluid is heated as it flows through the exchanger during this heat exchange operation.

An advantage of double pipe heat exchangers is their versatility. They may be engineered to operate in either a parallel flow or counter-flow arrangement. Counter flow refers to a situation where the hot and cold fluids travel in opposing directions, which usually leads to the most optimal heat transfer. In parallel flow, both fluids move in a similar direction although this configuration is often less effective in terms of heat transmission.

2.2 Data Reduction

Nusselt number, Prandtl Number Reynolds Number equations are given below.

$$R_e = \frac{\rho\, ud}{\mu} \tag{1}$$

$$P_r = \frac{u}{\alpha} \tag{2}$$

$$N_u = \frac{hl}{k} \tag{3}$$

$$N_u = f(R_e P_r) = aR_e P_r \tag{4}$$

The variables ρ, d, u, μ, CP, K, h, L, and K, which stand for density, characteristic diameter, flow velocity, viscosity, fluid specific heat, fluid thermal conductivity, convective HT, and HT length, respectively.

Those are crucial for optimizing heat exchanger performance, especially when using nanofluids like graphene oxide, which enhances heat transfer efficiency.

To establish a relationship between these parameters, several correlations have been constructed by altering the basic Maxwell equation.

$$K_{nf} = \frac{K_p + \left(2K_f\right) - \left(2\emptyset\left(K_p - K_f\right)\right)}{K_p + \left(2K_f\right) + \left(\emptyset\left(K_p - K_f\right)\right)} \tag{5}$$

Since solid particles, such as nanoparticles, typically have a lower heat capacity than base fluids, their addition reduces the specific heat capacity of the base fluid. While there may be some concerns regarding the accuracy and applicability of these equations for NP and base fluid pairings, they can still serve as key reference values for heat capacity.

$$cp,(nf) = (1 - \varphi)\, cp(bf) + (\varphi cp(np)) \tag{6}$$

$$cp,(nf) = [(1 - \varphi)\, \rho(bf) cp(bf)\, (\varphi\, \rho(nf) cp(np))]\, /(\rho(nf \tag{7}$$

The viscosity and density of NFs, denoted as ρ(nf) and μ(nf), respectively. These should be based on the densities of Nanoparticles (NPs) and Base Fluid (BF), denoted as ρ(nf) and ρ(bf), respectively, as well as the viscosity of the BF, denoted as μ, and the volume fraction (φ).

$$\rho_{nf} = (1 - \varphi)\rho_{bf} + \varphi\rho_{np} \tag{8}$$

$$\mu_{nf} = (1 + 2.5\varphi) + 6.25\varphi^2 \tag{9}$$

The ratio of effective conductivity (Ke) to fluid conductivity is calculated using Maxwell's equation[3].

$$\frac{K_e}{K_f} = \frac{K_p + 2k_f + \left(2\left(k_p - k_f\right)\varphi\right)}{k_p + 2K_f - \left(\left(k_p - k_f\right)\varphi\right)} \tag{10}$$

The particles' thermal conductivity (Kp) and the base fluid's thermal conductivity (Kf) are shown, along with the volume fraction of particles (φ).

The most popular model for nanofluids is the Hamilton-Crosser model, developed in 1962 by Hamilton and Crosser. They extended Maxwell's theory to account for non-spherical particles.

$$\frac{K_e}{K_f} = \frac{K_p + (n-1)k_f + \left(\left(n-1\right)\left(k_p - k_f\right)\varphi\right)}{k_p + (n-1)K_f - \left(\left(k_p - k_f\right)\varphi\right)} \tag{11}$$

A spherical particle has a shape factor of 3, whereas a cylindrical particle has a shape factor of 6. In this case, the model predicts the composite's effective thermal conductivity (Ke) as determined by the MG model.

$$\frac{K_e}{K_m} = \frac{\left[K_p(1 + 2\alpha) + 2k_m\right] + 2\varphi\left[\left(k_p(1 - \alpha) - k_m\right)\varphi\right]}{\left[k_p(1 + 2\alpha) + k_m\right] - \left[\left(k_p(1 - \alpha) - k_m\right)\varphi\right]} \tag{12}$$

The variables matrix thermal conductivity (km) NP thermal conductivity (kp), and particle volume fraction (φ) are all used in this context.

Maxwell's equation now becomes

$$\frac{K_e}{K_f} = \frac{[K_{pe} + 2k_f] + 2[(k_{pe} - k_f)(1+\beta)^3\varphi]}{[k_{pe} + 2k_f] - [(k_{pe} - k_f)(1+\beta)^3\varphi]} \quad (13)$$

The particle's effective thermal conductivity (kpe) is obtained by dividing the liquid layer thickness by the nanoparticle's radius, denoted as β.

$$k_{pe} = \frac{[2(1-\gamma) + (1+\beta)^3(1+2\gamma)]\gamma}{-(1-\gamma) + (1+\beta)^3(1+2\gamma)} k_p \quad (14)$$

Where ϒ is the ratio of the thermal conductivity of the liquid to the solid nanoparticle.

$$\frac{K_e}{K_f} = 1 + \frac{n\varphi A}{(1-\varphi A)} \quad (15)$$

With the parameter A defined as

$$A = \sum_{j=a,b,c} \frac{k_{pj} - k_f}{k_{pj} + (n-1)k_f} \quad (16)$$

The ellipsoidal nanoparticles' semi-axes are denoted by a, b, and c, where a>b>c.

The weight percentage (φ) is estimated by measuring the mass of nanoparticles (m_p) and water (m_f) with a precision of 0.001 g. [4]

$$\varphi = \left[\frac{m_p}{(m_p + m_f)}\right] * 100 \quad (17)$$

To determine the volume concentration of the nan fluid (φ), the nanoparticle density (ρ_p) and the base fluid density (ρf) at 25 degrees Celsius.

$$\varphi = \frac{\left(\frac{m_p}{\rho_p}\right)}{\left(\left(\frac{m_p}{\rho_p}\right) + \left(\frac{m_f}{\rho_f}\right)\right)} \quad (18)$$

2.3 Thermo-Physical Properties

Several studies employ regression equations for density (ρnf) and specific heat capacity (Cnf).

$$\rho_{nf} = \left(\frac{\varphi}{100}\right)\rho_p + \left(1 - \frac{\varphi}{100}\right)\rho_f \quad (19)$$

$$C_{nf} = \frac{\left(\frac{\varphi}{100}\right)(\rho C)_p + \left(1 - \frac{\varphi}{100}\right)(\rho C)_f}{\rho_{nf}} \quad (20)$$

Regression equations are used to estimate the properties of the base fluid as a function of temperature.

$$\rho_{nf} = 1000 \times \left\{1 - \frac{(T_f - 4)^2}{119000 + 1365 \times T_f - 4(T_f)^2}\right\} \quad (21)$$

$$C_f = 4217.629 - 3.20888 \times T_f + 0.09503 \times {T_f}^2 - 0.00132 \times {T_f}^3 + 9.415e^{-6\times {T_f}^4} - 2.5479e^{-8\times {T_f}^5} \quad (22)$$

$$k_f = 0.56112 + 0.00193T_f - 2.60152749e^{-6\times {T_f}^2} - 6.08803e^{-8\times {T_f}^3} \quad (23)$$

$$\mu_f = 0.00169 - 4.25263e^{-5\times T_f} + 4.92559e^{-7\times {T_f}^2} - 2.0993504e^{-9\times {T_f}^3} \quad (24)$$

The Einstein equation for determining viscosity is used to estimate the viscosity of Nano fluids (μ_f). This equation, developed based on the volume concentration of nanoparticles, has been validated for spherical particles and volume concentrations below 5%.

$$\mu\,(NF) = [\mu(BF)/(1 - (\varphi)^{2.5})] \quad (25)$$

Volume concentration of nanoparticles [5]

$$\varphi = \frac{\left(\frac{m}{\rho}\right)_{np}}{\left(\frac{m}{\rho}\right)_{sol} + \left(\frac{m}{\rho}\right)_{bf}} = \frac{V_{np}}{V_{final}} \quad (26)$$

Where $\left(\frac{m}{\rho}\right)_{np}$ denotes the volume of nanoparticles supplied, $\left(\frac{m}{\rho}\right)_{sol}$ is the volume of water in the pipe inside the pre-dispersed mixture and

$\left(\frac{m}{\rho}\right)_{bf}$ denotes the volume of control fluid Viscosity of nanofluid [6]

Einstein was the first to investigate the viscosity of suspensions. He considered the motion of a single particle through a fluid, computed the effective stress tensor, analyzed the resulting disturbances in the flow field, and derived the effective viscosity coefficient using a simple equation.

$$\eta = \eta_0(1 + 2.5\varphi) \quad (27)$$

Therefore, the volume concentration of dispersed particles (φ) is the primary factor determining the coarse suspension viscosity coefficient (η), which is always higher than the base fluid's viscosity (η_0). The formula accurately describes the viscosity of suspensions with low particle concentrations (φ < 0.01), as confirmed by experimental comparisons. However, at moderate particle densities, particle-particle interactions must be considered.

$$\eta = \eta_0(1 + 2.5\varphi + k\varphi^2) \quad (28)$$

The viscosity is shown to have a quadratic dependency on φ in every instance when the volume concentration of nanoparticles grows.

$$\eta = \eta_0[1 + a\varphi + b\varphi^2] \quad (29)$$

The coefficient is much higher than that for typical suspensions, although it is not universal, just like coefficient a (low concentration). Among the first correlations found were for NFs containing TiO_2 particles.

$$\eta = \eta_0[1 + 5.45\varphi + 108.2\varphi^2] \quad (30)$$

2.4 Experimental Work

The thermo-physical properties of NFs, including specific heat, density, viscosity, and thermal conductivity, can be measured using a thermal conductivity device, as shown in Figure 1. Enhancing the HTC and pumping power are two key aspects of heat transfer that depend on fluid properties such as viscosity and thermal conductivity. As the temperature of NFs increases, their viscosity and surface tension decrease. A viscosity device is used to measure these changes, as shown in Figure 2. Figure 3 shows NFs with different graphene volume concentrations, including 0.05%, 0.1%, 0.15% and 0.2%. The selected graphene nanoparticle concentrations were based on prior research, stability, and practical feasibility. Increasing concentrations enhance thermal conductivity but can also lead to higher viscosity, particle agglomeration, and pumping power issues. Preliminary tests showed that exceeding 0.2% negatively impacted flow behavior. This range balances improved heat transfers with minimal drawbacks that align with existing studies. Tables 1 and 2 show the characteristics of NFs and base



Figure 1. Thermal conductivity measurement device.



Figure 2. Viscosity measurement device.



Figure 3. Preparation of nanofluid.

fluid properties, respectively. Table 3 shows the weight of nanoparticles added to the base fluid.

To improve stability, various techniques such as ultra-sonication, mechanical stirring and the use of dispersing agents are employed. Magnetic fields can also be used in magnetic NFs to prevent aggregation. Stable NFs enhance heat transfer efficiency by maintaining a consistent suspension of nanoparticles, which improves thermal conductivity.

Table 1. Properties of nanoparticles

Type of Nanoparticle	Graphene
Molecular Formula	C
Purity	>95%
Colour	Greyish Black
Bulk Density	0.241 g/cc
True Density	2.2 g/cc
Thermal Conductivity	5000 W/m-k
Specific Heat	0.8 J/kg-k

Table 2. Properties of base fluid

Type	DI Water
Thermal Conductivity	0.611 W/m-
Specific Heat	4200 J/kg-k
Density	991 kg/m^3
Viscosity	0.89 cP

Table 3. Weight of nanoparticles added to the base fluid

Concentration of Nanoparticles In Base Fluid	Weight of graphene nanoparticles in base fluid (grams)
0.05	13.2
0.1	26.4
0.15	93.6
0.2	52.8

$$\varphi = \frac{\left(\frac{m_p}{\rho_p}\right)}{\left(\left(\frac{m_p}{\rho_p}\right)+\left(\frac{m_f}{\rho_f}\right)\right)} \quad (31)$$

2.5 Experimental Procedure for Determination of Viscosity of Nano fluid

Clean the cup for any unknown particles and water bath, and power supply connections are assembled. Adjust the spirit level by levelling screws. Switch on the viscometer and perform the auto zero without fixing the spindle, and fix the spindle CP-40Z by turning clockwise. Connect the temperature sensor from the cup to the viscometer. Place 0.5ml of the given fluid in the cup with the help of a micro pipette and fix it to stand. Press the home button on the viscometer screen and choose an external mode. Connect the "COM3" port in the software and select the parameters like torque, temperature, shear stress, shear rate, viscosity, and spindle speed, etc. The spindle speed is selected for the given test fluid, and the parameters (end conditions) are selected for the test fluid. End conditions like temperature, torque and time are valued. Set the required temperature in the water bath connected to the viscometer and now press the "RUN" button, then the data/graph automatically shows the required viscosity parameters. The obtained results are saved in PDF or Excel. By alerting the temperatures, further reading was taken. Once the test is over, switch off the viscometer and allow the cup to cool down. Also, stop the water bath. Remove the cup and clean it properly without any traces of particles/liquid. Remove the spindle carefully by turning anti-clockwise and wipe off. Place the spindle in the box safely and switch off the viscometer.

2.6 Experimental Values of Viscosity

Figure 4 shows the relationship between viscosity and temperature for water and different concentrations of graphene Nano fluids (0.05%, 0.1%, 0.15%, and 0.2% by volume). As the temperature increases, the viscosity of all fluids decreases, indicating that higher temperatures lead to lower fluid resistance. For any given temperature, higher concentrations of graphene Nano fluids exhibit higher viscosities compared to those with lower concentrations and pure water. This is because the addition of graphene

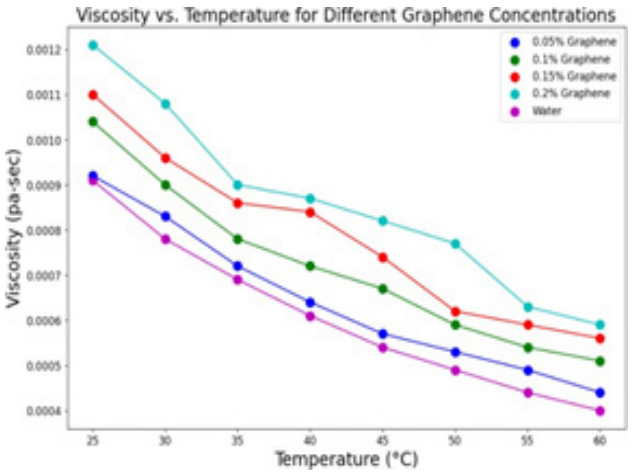


Figure 4. Variation of viscosity with temperature at different volume concentrations.

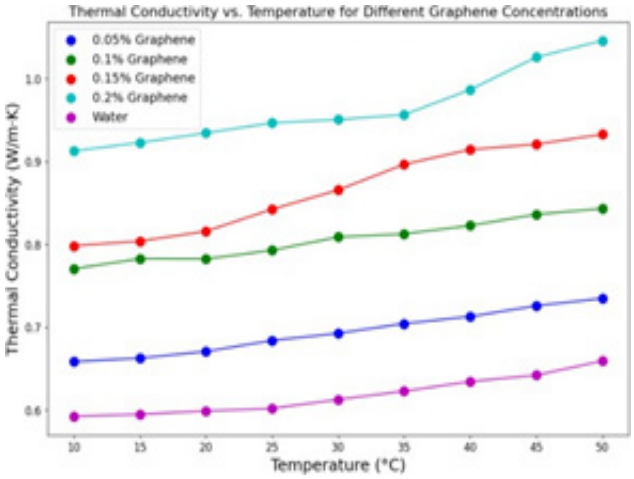


Figure 5. Variation of thermal conductivity with temperature at different volume concentrations.

nanoparticles increases the fluid's overall viscosity. The values measured from the viscometer and compared with the Pok and Cho correlation values. Deviation ranges from 5 to 14 %.

$$\mu\,(NF) = [\mu(BF)/(1-(\varphi)\text{^}2.5)]$$ Pok and Cho correlation (32)

2.7 Experimental Procedure for Determination of Thermal Conductivity of Nano fluid

Turn on the TEMPOS equipment, and select the KS-3 sensor for fluids. Before taking the readings, connect the KS-3 cable to the TEMPOS controller. Using a water bath, maintain the temperature. To prevent any vibrations, make sure to turn off the water before taking readings. After 30 seconds, the sensor will return to its initial state if the temperature differential is less than 0.002 degrees Celsius per second. If the instrument detects an incorrect reading, it will enter the active heating mode automatically. After the first minute of reading, the fluid's thermal conductivity will be shown on the tempo screen. To make sure there are no mistakes in the findings, record the data and run the experiment many times. Figure 5 displays the temperature- dependent thermal conductivity variation at various volume concentrations. As temperature increases, thermal conductivity of the NF increases because nanoparticles added to the base fluid exhibit Brownian motion. Due to this nanoparticle motion, heat transfer increases because it acts like a free electron in a solid. The above tabulated thermal conductivity values are determined from the thermal conductivity device TEMPOS. And these values, compared with Maxwell correlation and obtained a deviation range between 5% to 8%. Figure 6 shows the experimental setup for the double pipe heat exchanger, and Figure 7 shows the mixing of graphene Nano fluid.

A double-pipe heat exchanger is a system designed for efficient heat transfer between two fluids, with one flowing through an inner pipe and the other through an outer pipe. In this setup, Graphene Oxide (GO) Nano fluid is used as a heat transfer medium to enhance thermal performance.

$$\frac{K_e}{K_f} = \frac{K_p + 2k_f + \left(2\left(k_p - k_f\right)\varphi\right)}{k_p + 2K_f - \left(\left(k_p - k_f\right)\varphi\right)}$$

Maxwell correlation (33)

NFs, composed of nanoparticles suspended in a base fluid, are extensively utilized in heat exchangers for their superior thermal conductivity and heat transfer efficiency. However, their stability is a key factor in sustaining performance and avoiding complications such as particle settling, clumping and blockages.

Multiple factors affect Nano fluid stability, including the size, shape, and concentration of nanoparticles, as

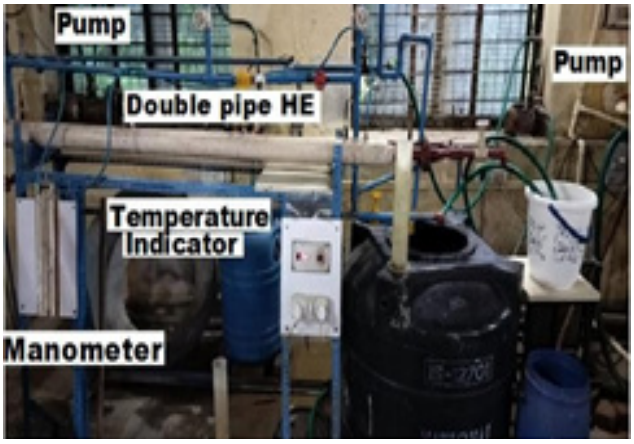


Figure 6. Experimental setup for double pipe heat exchanger



Figure 7. Mixing of graphene Nano fluid.

well as pH levels, surfactants, and dispersion methods. To enhance stability, techniques like surfactant addition, electrostatic stabilization, and ultrasonic dispersion are commonly employed. Well-stabilized NFs contribute to consistent heat transfer, lower pressure losses, and improved overall efficiency in heat exchanger applications.

The uncertainty of the considered parameter (X) has been calculated using Kline and McClintock's equation, which is based on the errors associated with the measured parameters, as shown in Table 4. The general form of the equation for a function f(x1, x2,…,xn) is

$$\sqrt{\left(\frac{\partial f}{\partial x_1}\Delta x_1\right)^2+\left(\frac{\partial f}{\partial x_2}\Delta x_2\right)^2+\cdots+\left(\frac{\partial f}{\partial x_n}\Delta x_n\right)^2} \quad (34)$$

Table 4. Uncertainty analysis

S.No	Parameter	Uncertainty
1	Re	± 1.75
2	Nu	± 1.75

3.0 Results and Discussion

Figure 8 shows the disparity of the overall HTC with different flow rates. The graph displays the overall HTC for water and graphene NFs at various concentrations (0.05%, 0.1%, 0.15%, and 0.2% by volume) and flow

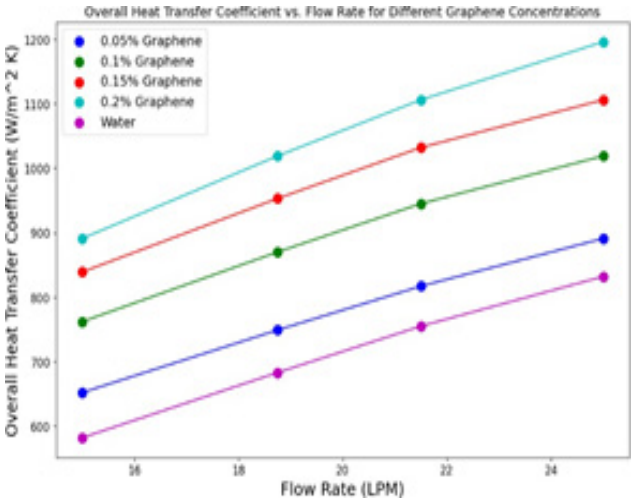


Figure 8. Variation of overall heat transfer coefficient with different flow rates.

rates. It appears that the optimal overall HTC is at a 0.2% volume concentration of graphene NF. This indicates that graphene nanofluids are more effective in improving heat transfer performance compared to water alone across various flow rates. Graphene NF concentrations of 0.05%, 0.1%, 0.15%, and 0.2% all increased the

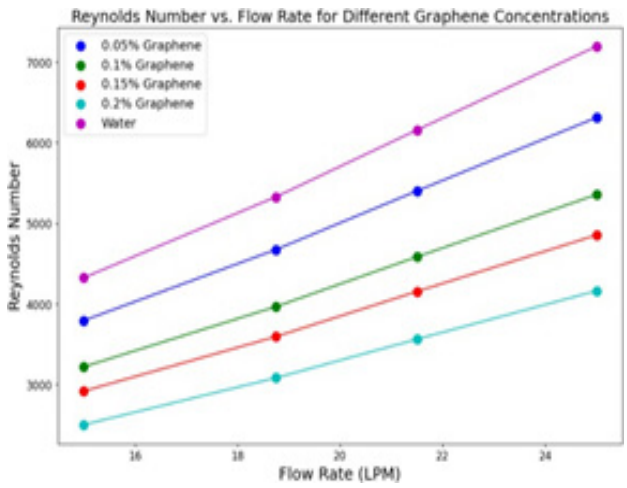


Figure 9. Variation of overall HTC with Re.

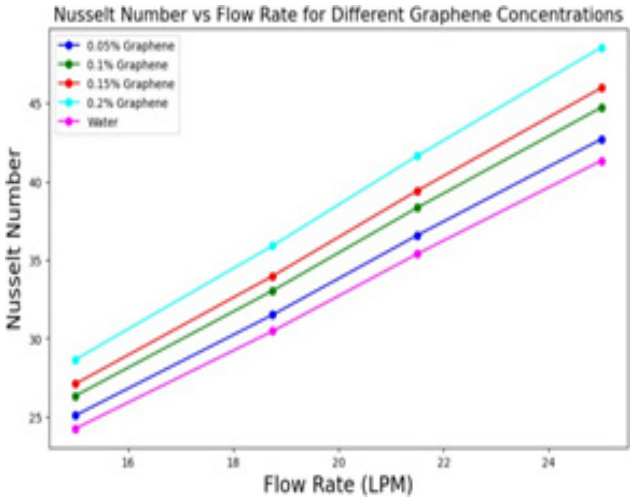


Figure 11. Variation of Nusselt number with flow rate.

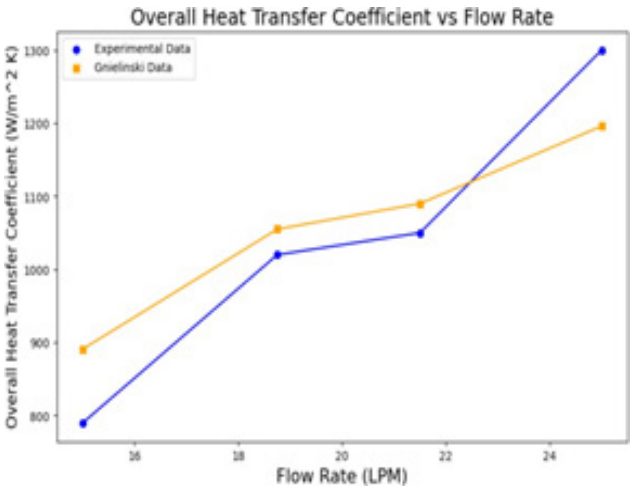


Figure 10. Comparison overall heat transfer coefficient for experimental data and the Gnielinski relation.

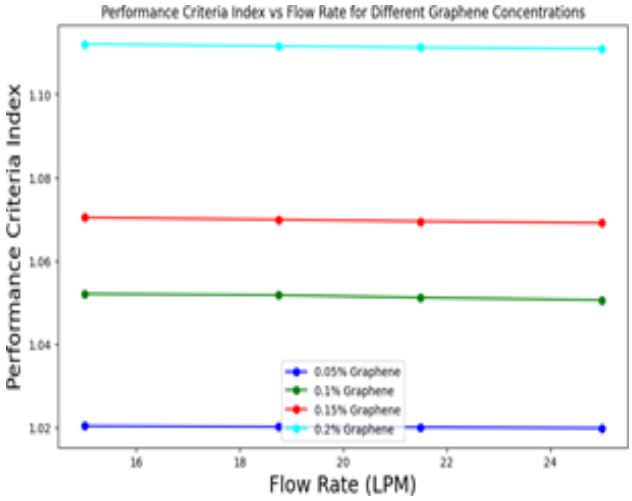


Figure 12. PEC vs flow rate.

overall HTC by 11%, 26%, 37%, and 48% compared to water.

The graph illustrates the relationship between the Reynolds number and the flow rate (in LPM) for water and different concentrations of graphene nanofluids. As the flow rate increases, the Reynolds number also increases, indicating that higher flow rates result in more turbulent flow. The Reynolds numbers for 0.05%, 0.1%, 0.15% and 0.2% and water are 6312, 5356, 4854, 4162 and 7196, respectively.

Figure 10 shows the comparison of the overall HTC for experimental data and the Gnielinski equation. Initially, the overall HTC for the experimental data is lower than the values predicted by the Gnielinski equation. However, as the flow rate increases, the overall HTC for the experimental data surpasses the values obtained from the Gnielinski equation. The optimum overall HTC is achieved at a 0.2% volume concentration of the Nano fluid. This suggests that higher flow rates lead to improved heat transfer performance in the experimental data, eventually exceeding the predictions made by the Gnielinski equation.

Figure 11 shows how the Nusselt number (Nu) changes with the flow rate for water and different

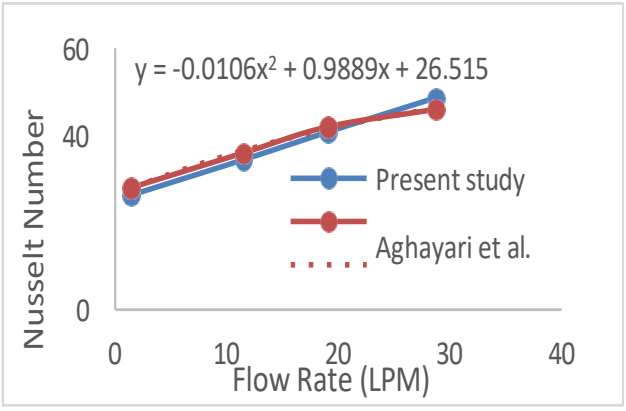


Figure 13. Nusselt number vs. flow rate.

amounts of graphene Nano fluids. From the graph, it is evident that as the flow rate increases, the value of the Nusselt number also increases at each concentration. At a flow rate of 25 LPM, the optimum Nusselt number is 0.2% volume concentration of graphene NF. This suggests that higher concentrations of graphene NF can significantly improve heat transfer efficiency across a range of flow conditions.

Figure 12 shows the Performance Evaluation Criteria (PEC) for Nano fluids at different flow rates. The above graph shows that the PEC for Nano fluids with volume concentrations ranging from 0.05% to 0.2% is greater than unity across all flow rates. The 0.2% volume concentration yields the highest PEC, indicating the most significant improvement in heat transfer efficiency.

Figure 13 shows the relationship between the Nusselt number and the mass flow rate. As the mass flow rate increases, the Nusselt number value increases. The Nusselt number values of the present study deviate by 1.76% compared to literature values.

4.0 Conclusion

This study investigates the performance of a double pipe heat exchanger operating at various flow rates to enhance heat transfer at varied concentrations of graphene Nano fluids. The inner tube is responsible for circulating hot water, while the annulus is designed to carry NF, which is cold water. Experiments have been done under these specified circumstances, exploring various volume concentrations ranging from 0.05% to 0.2%. Based on the results, the following conclusions have been derived.

- The thermal conductivity of graphene nanoparticles increases as temperature increases, because the suspension of nanoparticles in base fluid exhibits Brownian motion and allows for to flow of more heat compared to base fluid. In this work, thermal conductivity of Nano fluid increases up to 52% at 0.2 volume concentration compared to the base fluid.
- Viscosity of graphene Nano fluid decreases as temperature increases, because molecules are energized to overcome intermolecular forces. As volume concentration increases viscosity of NF increases due to high shear rate. In this research work viscosity of the NF increases up to 36% at 0.2 volume concentrations when compared to the base fluid.
- Overall HTC in double pipe HX increases with an increase in volume concentration of nanoparticles, and the optimum value of overall HT coefficient is obtained at 0.2% volume concentration, 48% increase in HTC compared to base fluid.
- At a volume concentration of 0.2% (25 LPM), the optimal value of Nu is 48.55, which rises as the solution concentration increases. The Nusselt number ranges from 20 to 70 for a volume concentration of 0.3% to 0.6%[21]. In this study, the Nusselt number ranges from 25 to 50 at concentrations of 0.05% to 0.2% by volume.
- From experimental observation, the optimum overall HTC obtained is 1300 W/m^2-K at 0.2% volume concentration (25 LPM), and these results are compared with the Gilinsky equation.

The findings of the present study have substantial significance for industries that are related to heat transfer systems, including HVAC, automobile, and energy sectors. The capacity to attain elevated heat transfer rates with minimal concentrations of graphene nanoparticles offers a cost-efficient and energy-saving remedy for heat exchanger applications, possibly lowering operational expenses and improving overall system efficiency.

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