Experimental and CFD Analysis of GW70 based Cu Nanofluids in a Parallel Flow Heat Exchanger

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Abstract: The Nusselt number, overall heat transfer, and convective heat transfer coefficients of glycerol-water-based Cu nanofluids flowing in a parallel flow double pipe heat exchanger are estimated using CFD analysis. Single-phase fluid approach technique is used in the analysis. Ansys 19.0 workbench was used to create the heat exchanger model. Heat transfer tests with nanofluids at three flow rates (680<Re<1900) are carried out in a laminar developing flow zone. For testing, a 500 mm long concentric double pipe heat exchanger with tube dimensions of ID=10.2 mm, OD= 12.7 mm, and annulus dimensions of ID=17.0 mm, OD= 19.5 mm is employed. Copper is utilized for the tube and annulus material. This study employed three-particle volume concentrations of 0.2 percent, 0.6 percent, and 1.0 percent. The mass flow rates of hot water in the tube are 0.2, 0.017, and 0.0085 kg/s, while the mass flow rates of nanofluids in the annulus are 0.03, 0.0255, and 0.017 kg/s. The average temperature of nanofluids is 36°C, whereas hot water is 58°C. In comparison to base liquid, the overall heat transfer coefficient and convective HTC of 1.0 percent copper nanofluids at 0.03 kg/s are raised by 26.2 and 46.2 percent, respectively. The experimental findings are compared to CFD values, and they are in close agreement.

Keywords: Glycerol-water mixture, CFD analysis, double pipe heat exchanger, convective heat transfer, overall heat transfer, Cu nanofluids.

I. INTRODUCTION

The thermo-physical parameters of fluid heating or cooling are critical for the development of energy-efficient heat transfer equipment. Meanwhile, in all heat transfer (HT) processes, the fluid's thermal conductivity (TC) is one of the most significant qualities to consider while developing and operating the operations. Nanofluids (NF) are designed colloids made up of a base fluid with nanoparticles (NP) ranging in size from 1 to 100 nanometers.

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Many studies have discovered that nanofluids have better thermal conductivity than basic fluids. With increasing particle concentration (φ), temperature (T), particle size, dispersion, and stability, its value rises. However, additional parameters such as density (ρ), viscosity (μ), and specific heat (Cp) are likely to play a role in the enhanced convective heat transfer coefficient (HTC) of NF's. In comparison to single-phase fluids, NF have a high TC and HTC [1-4].

Because of their higher thermal conductivity, NFs have lately been used in lieu of normal fluids. **Abu Nada [5]** used Cu, Ag, Al_2O_3, CuO, and TiO_2 nanofluid in laminar NF flow over a backward-facing step, with volume fractions (φ) ranging from 0.05 to 0.2 and Reynolds numbers ranging from 200 to 600. According to the data, the Nusselt number climbed as the 'φ' and Re numbers increased. Using a computer model, **Kherbeet et al. [6]** studied HT and laminar NF flow across a microscale backward-facing step. The NP types were Al_2O_3, CuO, SiO_2, and ZnO, with volume fractions ranging from 1% to 4% and an expansion ratio of 2. The Re numbers varied from 0.05 to 0.5, and the NP types were Al_2O_3, CuO, SiO_2, and ZnO, with volume fractions ranging from 1% to 4% and an expansion ratio of 2. The researchers discovered that when Re number and 'φ' increase, Nusselt number increases, with SiO_2 having the highest Nusselt number value.

For NF flow and heat transmission across a backward-facing step, **Hussein et al. [7]** employed numerical analysis. When compared to pure water, the maximal HT improvement was about 26 percent and 36 percent for turbulent and laminar ranges. **Pak and Cho [8]** investigated 30nm alumina oxide and titanium oxide nanoparticles and found that Nu is 30% higher than BL and greater to the Dittus Boelter (DB) equation predicts. **Li and Xuan [9]** employed Copper (100nm) nanofluids in their experiment to investigate the increase of HT under turbulent flow. They observed that the average rise in Nu is far larger than the DB equation predicts. **Heris et al [10]** used Al_2O_3 (20nm) nanofluids suspended in water to study convective HTC in laminar flow. In his investigation, Nu was shown to be greater than pure water.

Kolade et al [11] used Al_2O_3 (40nm & 50nm) nanofluids to determine the impact of HTC and reported Nu number enhancement over BL. **Duangthongsuk et al [12]** showed that nanofluids exhibit a significant increase in HTC over the base fluid using TiO_2 nanoparticles of 21nm size in a turbulent regime.

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Water-based Al_2O_3 (50nm) and ZrO_3 (50nm) nanofluids were employed by **Rea et al [13]** to exhibit a 27 percent increase over water. In a rectangular microchannel, **Jung et al [14]** conducted an experiment using Al_2O_3 NP with an average diameter of 170nm. As the Re grew, the usage of nanofluids over base fluid resulted in a significant increase in Nu. **Lee and Choi [15]** explored HTC improvement of 2.0 percent Cu nanofluids made of water and found a 100 percent increase in Nu number as compared to water. The HTC of glycerol-water (30:70 by volume) based, referred to as GW70 - Cu NF flow for laminar range in double pipe heat exchanger (DPHE) have not been investigated experimentally or numerically yet, according to the literature review; thus, the uniqueness of this work is to experimentally and numerically determine the effects of 'φ' of NP's, Re numbers on the laminar HTC.

II. GEOMETRY, MODELLING AND BOUNDARY CONDITIONS

The schematic representation of parallel flow in a DPHE is shown in **Fig. 1.** The study is carried out on double pipe heat exchanger with an ID of 10.2 mm and an OD of 12.5 mm; an annular pipe with an ID of 17.0 mm and an OD of 19.5 mm; and a length of 500 mm. The tube is filled with hot water, and the annulus is filled with nanofluids. Hot water flow rates of 0.2, 0.017, and 0.0085 kg/s are maintained, whereas nanofluid flow rates are 0.03, 0.0255, and 0.017 kg/s. The average temperature of nanofluids and hot water is 36 degrees Celsius and 58 degrees Celsius, respectively. To reduce heat loss, the annulus pipe's outside wall is insulated with asbestos rope.

2.1 Meshing of Geometry

The geometry was created using the structured meshing approach in Ansys Workbench. Quadratic elements with nodes up to 200000 in the range of 25000 to 36500 are considered for analysis. For analysis, a standard viscous and laminar model is used. **Fig. 2** depicts the DPHE geometry model, whereas **Fig. 3** depicts the meshed model.
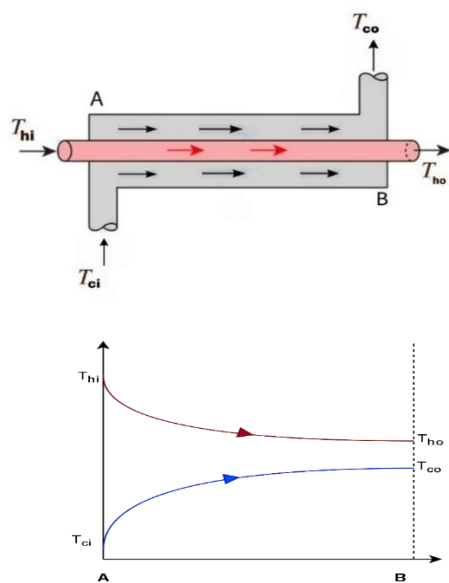

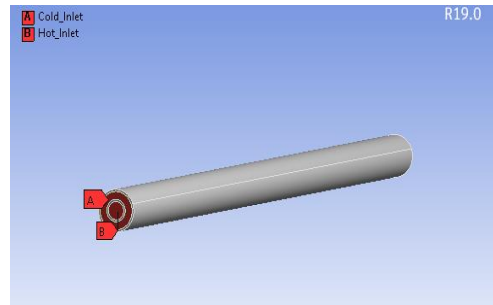**Fig. 1 Schematic representation of parallel flow arrangement in the DPHE**

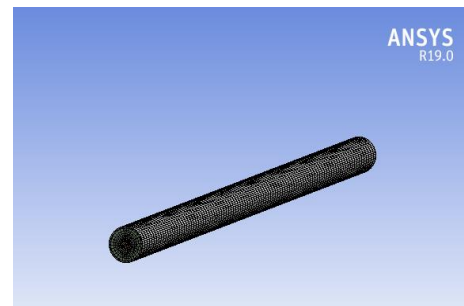**Fig. 2 Geometry model of DPHEwith cold and hot fluid inlets**

Fig. 3 Meshed model of double pipe heat exchanger

2.2 Grid Independence Test

The phrase "grid independence" refers to the process of improving outcomes by doing computations with lower and smaller cell sizes. Grid Independence refers to the ability of computation to arrive at the right conclusion, resulting in a smaller mesh. The standard CFD method is to start with a coarse mesh and progressively improve it until the changes in the data measured are less than a pre-determined acceptable error. There are two issues with this approach. For starters, various CFD tools may make it impossible to get even a single coarse mesh, which might cause issues. Second, improving a mesh by a factor of two or more might take longer. This is blatantly objectionable for software designed to be used as a design tool for engineers working under tight production constraints. Furthermore, the other difficulties have contributed greatly to the impression of CFD as a difficult, time-consuming, and so expensive approach. Finally, grid independence tests were performed in Ansys-Fluent at three flow rates of hot water and cold water, by reducing and increasing the size of the components. For further simulation, the final mesh pieces of 34400 and 175375 nodes were employed.

2.3 Physical models

For single-phase laminar flow in a circular pipe channel, the standard viscous model is utilized. The conventional viscous laminar model is employed for nanofluids with a Reynolds number range of 680 <Re< 1900. Wherever the flow is turbulent, the usual k-ϵ model is utilized for hot water.

2.4 material properties

Thermophysical characteristics of nanofluids as determined by the experiments. Data books are used to determine the properties of hot water.

The data books are used to determine the material parameters of tube and annulus materials, such as copper. All of the parameters are considered in the calculation of heat transfer coefficients at the experimental mean temperatures. Thermophysical parameters of base liquids and nanofluids are taken from the experimental data of **Lahari et al. [16]**.

2.5 Governing Equations

Simulating steady-state conditions was accomplished by solving the mass, momentum, and energy equations for a single-phase fluid, which are written as:

Continuity equation: $\partial\rho/\partial t + \partial/\partial X\,(\rho u\_x) + \partial/\partial r\,(\rho u\_r) + (\rho u\_r)/r = 0$
$\hspace{11cm}(1)$

Momentum equation: $(\partial(\partial u\ \ )/\partial t + (\rho(u.u)^{-}) = \rho g - \nabla P + \nabla.(\tau^{-})$
$\hspace{11cm}(2)$

Energy equation: $(\partial(\partial E))/\partial t + \nabla\,(u^{-}(\rho E + P)) = \nabla.(k\_eff.\nabla T)$
$\hspace{11cm}(3)$

Where ρ is the density, u is the velocity, P is the pressure, τ is the viscous stress, E is the energy and k_{eff} is the effective TC. The altered/changed velocity fields describe the flow conditions. These changes mix conveyed variables like velocity, energy, and species concentration, causing them to vary as well. As a result, changes may happen at a microscopic size and with a high frequency, and they're computationally rich enough to be mimicked directly in engineering calculations. Instead, the exact governing equations may be time-averaged or ensemble-averaged, resulting in a modified set of equations with additional unknown variables that must be determined using turbulence models.

2.6 Boundary Conditions

At the channel inlet, a velocity inlet, uniform mass flow inlets, and a constant inlet temperature were given. The pressure was indicated at the exit. The flow rates for hot water in the tube are 0.2, 0.017, and 0.0085 kg/s, while for nanofluids in the annulus are 0.03, 0.0255, and 0.017 kg/s. For hot water, a temperature of 58°C is used, while for nanofluids, a temperature of 36°C is used. The study considers the constant heat flow boundary condition. For analysis, experimental entrance temperatures are used, and output temperatures are noted and compared to emperical data. The overall heat transfer coefficient (Uo) and HTC (h_{nf}) are also noted and compared to emperical data.

2.7 Method Of Solution

For the CFD approach, commercial software Ansys Fluent 19.0 was used to solve the issue. To discretize the convective transport terms, the Ansys-Fluent solver uses a pressure correction-based SIMPLE method with a 2nd order upwind scheme. The convergence dependent variables criterion is set at 0.001. The experimental values of HTC are obtained in this study. CFD techniques are also used to calculate heat transfer coefficients, which are then compared to experimental data. After establishing the issue's key aspects, the technique for addressing the problem is as follows: first, define the solution method, then initialize the solution, and then perform the computation. Create a geometry model in Ansys workbench according to the experimental setup design. Program-controlled meshing and sizing were performed on the

geometry model to get the requisite element size, nodes, and smoothening. After obtaining the necessary element size and meshing, the domain was given a name before the results were obtained. After meshing is complete, the setup is opened in fluent with governing equations such as energy, viscous-standard, standard wall function to be supplied to essential equations to simulate, material generating and boundary conditions to be given, and ways to compute the moment, pressure, and so on. Finally, after converging the equations, results are achieved by adopting a second-order upwind method for the solution.

III. RESULTS AND DISCUSSION

3.1 Temperature Profiles

The annulus of the heat exchanger (HE) is filled with nanofluids, while the tube of the HE is filled with hot water. The temperature profile of hot water passing through the tube of a twin-pipe HE is shown in **Fig. 4.** The temperature of hot water steadily reduced from the input (T_{hi}) to the exit (T_{ho})of the tube, providing heat to the nanofluid moving in the annulus, as shown in the diagram. **Fig. 5** depicts the temperature profiles of 1.0 percent Cu nanofluids flowing in the annulus of the twin-pipe HE. The temperature of the Cu nanofluid progressively grew from the intake (T_{ci}) to the exit (T_{co})of the pipe, as it gained heat from the hot water moving through the tube, as seen in the figure.
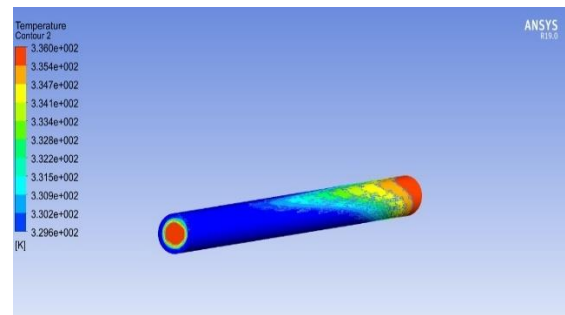

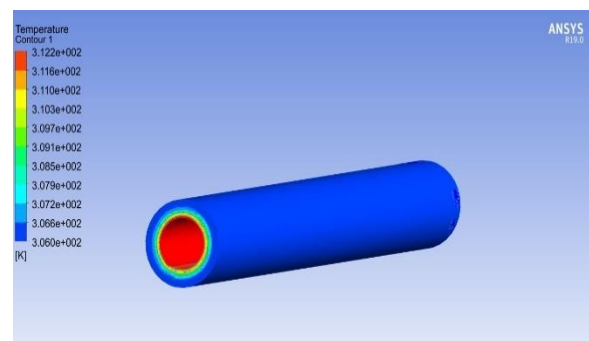**Fig. 4 Temperature profile of hot water flowing in the tube at 0.03 kg/s**

Fig. 5 Temperature profile of 1.0% Cu nanofluid flowing in the annulus pipe at 0.03 kg/s

3.2 Validatiuon of Htc's:

The studies were first carried out using water at various flow rates (1500 <Re< 5500). The water in the inner pipe is kept at a mean temperature of 58°C, while the water in the annulus is kept at 36°C.

Because the length of the HE is short, flow rates of (680 <Re< 1900) in the annulus employing nanofluids and base liquid dropped into the emerging laminar area (0.5m). Surface temperatures are calculated using conventional formulae from data books, and energy balance is confirmed on both the hot and cold sides using Newton's law. The Nu numbers of water moving through the tube are calculated using **Gnielinski's [17]** Eq. (4), which is valid for 2300 <Re <10^6, 0.5 <Pr<2000. The results were compared and confirmed with **Taler's [18]** Eq. (5) for a flow in a tube under UHF boundary conditions, and they were found to be in close agreement, as shown in **Table 2**.

$$Nu = \left[\frac{\left(\frac{f}{2}\right)(Re-1000)Pr}{1.07+12.7\left(\frac{f}{2}\right)^{0.5}(Pr^{2/3}-1)}\right]\left[1+\left(\frac{D_h}{L}\right)^{2/3}\right]\left[\frac{\mu}{\mu_s}\right]^{0.11} \quad (4)$$

and $f = [1.58\,ln(Re) - 3.82]^{-2}$

$$Nu = Nu_{m.q}(Re = 2300) + \left[\frac{\left(\frac{f}{8}\right)(Re-2300)Pr^{1.008}}{1.08+12.39\left(\frac{f}{8}\right)^{0.5}(Pr^{2/3}-1)}\right]\left[1+\right.$$

$$\left.\left(\frac{D_h}{L}\right)^{2/3}\right]\left(\frac{Pr}{Pr_s}\right)^{0.11} \quad (5)$$

Valid for $2300 \leq Re \leq 10^6$; $0.1 \leq Pr \leq 1000$;

$\left(\frac{D_h}{L}\right) \leq 1$

Where $Nu_{m.q}$ is mean Nusselt number estimated for a combined developing flow in a tube.

The base liquid and nanofluids then flow in the annulus at three different flow rates in experiments. HTC was calculated across a shared surface area. The following values are calculated: LMTD, Uo, HTC (h_{nf}), and Nu. For most nanofluid concentrations, the flow resulted in the laminar zone, showing a simultaneous increase of the hydrodynamical and thermal boundary layer thickness. The experimental Nu number of nanofluids and base liquid is compared and verified with Eq. (6) of **Muzychka and Yovanovich [19],** which is valid for the simultaneous formation of hydrodynamic and thermal boundary layers, developed flow with linear velocity profile, and temperature and FD flow. Between experimental Nu and values calculated using Eq (6)., there is a maximum variation of 2.48 percent.

$$Nu = \left[\left(\frac{2\,f(Pr)}{\sqrt{z^*}}\right)^m + \left(\left\{0.7515\left(\frac{fRe}{Z^*}\right)^{1/3}\right\}^5 + \right.\right.$$

$$\left.\left.\left\{3.86\left(\frac{fRe}{8\sqrt{\pi}}\right)^{1/3}\right\}^5\right)^{m/5}\right]^{1/m} \quad (6)$$

Where $f(Re) = \left[\left[\frac{12}{\left[2\left\{1-\frac{192}{\pi^5}tanh\left(\frac{\pi}{2}\right)\right\}\right]}\right]^2 + \left(\frac{3.44}{\sqrt{Z^+}}\right)^2\right]^{1/2}$;

$m = 2.27 + 1.65 * Pr^{1/3}; Z^+ = \frac{L}{D\,Re} \quad (6a)$

3.3 Validation Of Experimental Results With Cfd Results

The experimental and CFD heat transfer coefficients are found to be in excellent agreement. The temperature difference between the hot water exit (T_{ho}) and the nanofluid outlet (T_{co}) was 1.46 and 1.45 percent, respectively. The

deviations for Uo and HTC are 9.06 and 1.19 percent, respectively. **Table 3** shows these findings.

3.4 Overall Heat Transfer Coefficients And Convective Htc

Fig. 6 shows the fluctuation of Uo and h_{nf} as a function of Re number. The Uo and h_{nf} grew as Re and concentration increased. At Re=1271, a maximum augmentation of 26.2 percent and 46.2 percent in the Uo and h_{nf} was recorded using 1.0 percent copper nanofluids. Improved heat transfer coefficients are achieved by increasing the TC of NF owing to the larger surface area of NP's, particle rearrangement, and alteration of the thermal boundary layer due to the presence of nanoparticles. In their investigation, **Lahari et al. [20]** reported a similar trend.
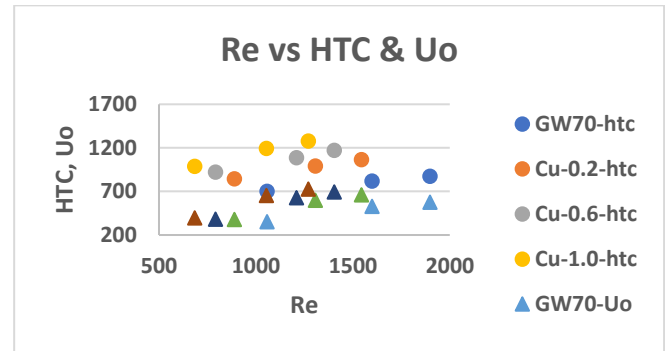

Fig.6: Re Vs HTC & Uo

IV. CONCLUSION

Ansys Fluent 19.0 was used to simulate steady-state computational fluid dynamics (CFD) models. The influence of Reynolds number on nanofluid flow dynamics is investigated. With increasing 'φ' and Re, the HTC improved. The findings of the CFD and experimental data of T_{ho}, T_{co}, Uo, and HTC are quite close, with maximum deviations of 1.46, 1.45, 9.06, and 1.19 percent, respectively. For a 1.0 percent concentration of Cu nanofluids at 0.03 kg/s, the Uo and HTC are increased by 26.2 and 46.2%, respectively.

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