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EVALUATING THE HEAT TRANSFER CHARACTERISTICS OF HYBRID NANOFLUID FLOW INCIRCULAR DUCTS WITH CONSTANT HEAT FLUX

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ABSTRACT

Researchers have recently been interested in introducing solid nanoparticles into thermal systems in order to improve their thermal performance as a nanofluid. Researchers have investigated nanoparticle types, sizes, and concentrations using theoretical, numerical, and experimental approaches. In the present study, a hybrid nanofluid was utilized in two concentrations, namely (0.5% ZnO+0.5% SiO_2-distilled water) and (1% ZnO+1% SiO_2-distilled water), in a 45^o inclined heated pipe at a constant heat flux of 12000 W/m^2 and a range of 4000 to 12000 for the Re number.Initially, the performance of the test apparatus was evaluated using distilled water in the same conditions as the hybrid nanofluids experiment, and its results were compared to an empirical relation to ensure accurate results. The experimentation results indicated that the nanofluids significantly improved heat transfer coefficients when nanoparticle concentration increased in hybrid fluids. This indicates that increasing nanoparticle concentrations can substantially improveheat transfer coefficients. Using hybrid nanofluids with a concentration of (0.5 and 1)% increasesthe heat transfer coefficient by 1.2 and 1.4 times compared to distilled water.

Keywords: hybrid nanofluid, heat transfer enhancement, ZnO and SiO2 nanoparticles, heating atconstant heat flux.

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Nomenculature		Greek symbols	
Cp	Specific heat (J. kg^{-1}.K^{-1})	α	inclination angle (degree)
d	Diameter (m)	β	Coefficient of thermal expansion (K^{-1})
g	Gravitational acceleration (9.81 m. s^{-2})	θ	Tangential coordinare (degree)
h	Convection heat transfer coefficient (W.m^{-2}.K^{-1})	μ	Dynamic viscosity (Pa.s)
k	Thermal conductivity (W. m^{-1}.K^{-1})	ρ	Density (kg.m^{-3})
$\dot{m}$	Mass flow rate (kg. s^{-1})	ϕ	Volume fraction (Vol%)
n	Shape factor (equal to 3 for sphyrical nanoparticles)	φ	Thermal diffusivity (m.s^{-2})
Nu	Nusselt number	Subscribts	
P	Pressur (Pa)	b	Bulk
Pr	Prandtl number	exp	Experimental
Q	Rate of heat ransfer (W)	f	fluid
r	Inner radius of the tube (m)	in	Inlet
Re	Reynolds number	j	Thermocouples sequence
T	Temperature (K)	n	Nanofluid
$\bar{T}$	mean temperature (K)	nf	nanofluid
u	Velocity in r- direction (m.s^{-1})	out	Outlet
v	Velocity in θ-direction (m.s^{-1})	s	Solid
$\dot{V}$	Volumetric flow rate (m^3.s^{-1})	W,i	Inner tube surface
w	Velocity in z-direction (m.s^{-1})	W,o	Outer tube surface

INTRODUCTION

One of the most active fields is nanotechnology, which draws attention from the research community because of its increased potential for enhancing the performance of many systems. Choi and Eastman were the first to introduce the idea of nanofluids, which allow for the modification of the properties of common heat exchange liquids such as purified water, ethylene glycol, and so on by adding nano-scale metallic inclusions at different volume concentrations. Nanofluids are prepared

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by adding threaded or platelet- and tube-shaped particles with lengths ranging from 1 to 100 nm into traditional cooling fluids such as water or ethylene glycol [1]. Nanofluids have been tested for their potential to improve heat characteristics in thermal apparatus through a variety of theoretical, numerical, and experimental investigations, including:

Shariat *et al*. [2] investigated numerically the influence of the aspect ratio of the elliptic pipe, soild volume fraction, and buoyancy force on the Nusselt number and skin friction factor when a nanofluid (Al_2O_3 - H_2O) was passed through it under conditions of laminar mixed convection with constant heat flux. By solving the Navier-Stokes equations in three dimensions using a finite volume approach, they calculated (Al_2O_3-H_2O) nanofluid's thermal conductivity and dynamic viscosity based on the Brownian movements of nanoparticles. Simulated results were in good agreement with other similar studies. A proportional relationship was also found between solid nanoparticle volume fractions Nu and f at the same Reynolds number (Re) and Richardson number(Ri).

In a flat microchannel, Nguyen and Menn [3] A numerical model was developed based on Al2O3 nanoparticles suspended in water and two distinct particle sizes, 36 nm and 47 nm, to simulate heat transfer from laminar flow. A finite element method was used to solve momentum, energy, and temperature-dependence equations to determine the thermal conductivity and viscosity of nanofluids. The model incorporated both two-phase and single-phase fluids. This study conducted simulations for Re values between 200 and 2500. In addition, the two-phase model demonstrates that particle concentrations are significantly non-uniform in the area of heated walls; these results indicate that nanofluids have a beneficial impact on heat transfer coefficients. In a major portion of the channel's middle, the temperature is fairly consistent, although it varies considerably near the heated walls. A comparison of models for single-phase and two-phase fluids shows a significant disparity between the results produced.

Davarnejad and Haque[4] used Brownian motion and thermophoretic diffusion to make a mathematical model of how peristaltic nanofluids move in a protruding annulus tube. In mathematical modelling, it is assumed that the wavelengths are long and the Reynolds numbers are low. It has looked at how the Brownian motion parameters (Nb) and thermophoresis parameters (Nt) changed over time, as well as how the inclination of the annulus changed. Based on the results, Brownian motion effects cause the temperature and concentration of nanoparticles to rise significantly, while increasing the inclination angle causes the pressure to rise.

Ahmed *et al*. [5], [6] studied heat transmission and boundary layer flow in a porous extending tube with a heat sink by employing nanofluids. This product is created using a water-based nanofluid comprising various volume fractions of different types of nanoparticles, including Cu, Ag, CuO, and TiO2. The study compares four thermal conductivity and dynamic viscosity models based on the nanoparticles' shape. As the Re number and suction/injection parameter increased, it was discovered that the Nu number increased, but the F factor decreased. Hayat and Nadeem [6] investigated the enhancement of heat transfer rate utilizing Ag–CuO/water nanofluid hybrids. This 3D model is used to study thermal radiation, heat generation, and chemical reactions in order to predict sheet overstretching when rotation is present. Also, when radiation, heat production, and chemical processes are present, the heat transfer rates of a hybrid nanofluid surpass those of a basic nanofluid.

Shanmugapriya *et al*. [7] studied heat and mass transfer improvement using magnetohydrodynamic (MHD) hybrid nanofluid presence activation energy. In the present study, nanofluids were prepared from water with two hybrid nanoparticle types suspended: CNTs with single walls and CNTs with multiple sides. The fine point of hybrid nanofluid flow under a magnetic field, thermal radiation, and activation energy with a binary chemical reaction was investigated using magnetic field, thermal radiation, and activation energy. The hybrid nanofluid exhibited superior cooling and heating properties compared to other hybrid nanofluids. In addition, an increase in the activation energy value accelerates the nanoparticle transfer rate of a hybrid nanofluid.

Lin *et al.* [8] studied the performance of a heat pipe utilizing an annular magnate's hybrid nanofluid of Fe3O4–carbon nanotubes (CNTs). The heat transfer properties of the Fe3O4-water nanofluid were determined by analyzing numerous parameters, including nanoparticle vol.% in the range of 0.4–1.2% and Reynolds number in the range of 476–995. The most significant local Nu number at the Re number 996 for the Fe3O4–CNTs–water nanofluid with a volume percentage of 1.44 % and a magnetic field rose by 61.54% compared to the absence of a magnetic field. In contrast, the most significant improvements in the average Nu number for the Fe3O4–CNTs–water nanofluid with and without magnetic field are 67.9% and 20.8%, respectively, as compared to deionized water.

Hayat and Nadeem [9] compared the heat transfer properties of (MHD) rotating conventional nanofluid to those of the newly developed hybrid nanofluid (Ag-CuO-H2O). The present study attempts to increase heat transfer in boundary layer flow. Constant angular velocity is utilized to rotate the nanofluid about the vertical axis. In the presence of a magnetic field, they discovered that the heat transfer rate of a hybrid nanofluid (Ag–CuO-H2O) is greater than that of a traditionalnanofluid (CuO-water).

Balla *et al.* [10] presented a numerical study examining the enhancement of the laminar convection heat transfer coefficient with hybrid nanoparticles under constant heat flux. The simulation involved three nanofluid compositions. The performance of hybrid nanofluids comprised of (CuO-Cu) nanoparticles was compared to that of nanofluids composed of CuO and Cu. It was discovered that pressure loss increases as Reynolds number, nanoparticle density, and particle volume fraction increase. However, the flow demonstrates an extraordinary improvement in heat transfer as the Reynolds number for the nanofluid flow increases.

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Manjunatha *et al.* [11] evaluated the enhancement of heat transfer using a hybrid nanofluid with variable viscosity. In the presence of specific factors, they discovered that the thermal conductivity of hybrid nanofluids is better compared to that of conventional nanofluids. In order to gain a greater comprehension of the issue, the flow and energy transfer characteristics are investigated for various values of significant factors such as variable viscosity, convection, magnetic field, and volume fraction. The results obtained are consistent with those previously published.

The present study examines improving the heat transfer characteristics by using hybrid nanofluids suspended in distilled water at two volume fractions (0.5 and 1) % in an inclined heated cylinder at a constant heat flux using ZnO and SiO2 nanoparticles. Two methods are used in this study, numerical and experimental, and their results are compared.

Mathematical Model

Figure-1 is a schematic illustration of a tube with uniform heat flux (0.05 m in diameter and 1 m in length). To develop a hybrid nanofluid, solid nanoparticles of ZnO and SiO2 were suspended in distillation water. This numerical analysis assumes the hybrid nanofluid is in thermal equilibrium, there is no slip between them, and their thermophysical parameters remain constant. Formulation of the governing equations of a laminar, homogeneous, and steady single-phase fluid model.

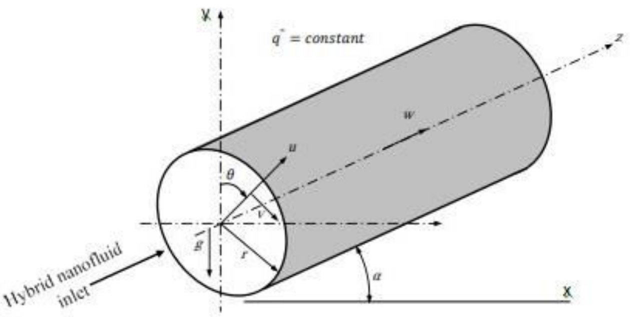

Figure-1. Mathematical model schematic diagram.

a. The continuity equation

Mass conservation can be expressed in cylindrical coordinates as follows [12]:

$$\rho_n\frac{\partial(ru)}{\partial r} + \frac{\rho_n}{r}\frac{\partial v}{\partial \theta} + \rho_n\frac{\partial w}{\partial z} = 0 \quad (1)$$

And by adopting the second assumption (w = 0), Equation (1) can be simplified as follows:

$$\rho_n\frac{\partial(ru)}{\partial r} + \frac{\rho_n}{r}\frac{\partial v}{\partial \theta} = 0 \quad (2)$$

b. Momentum equation

In cylindrical coordinates, the radial, tangential, and axial directions (r, θ, z) can be used to express the equations for momentum conservation as [13]:

- r- Coordinate

$$\rho_n\left(u\frac{\partial u}{\partial r} + \frac{v}{r}\frac{\partial u}{\partial \theta} - \frac{v^2}{r}\right) = -P_r + \mu_n\left(\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r} + \frac{1}{r^2}\frac{\partial^2 u}{\partial \theta^2} - \frac{u}{r^2} - \frac{2}{r^2}\frac{\partial u}{\partial \theta}\right) - \rho_n(\cos\theta\cos\alpha) \quad (3)$$

- θ- Coordinate

$$\rho_n\left(u\frac{\partial v}{\partial r} + \frac{v}{r}\frac{\partial u}{\partial \theta} - \frac{uv}{r}\right) = -\frac{1}{r}\frac{\partial P}{\partial \theta} + \mu_n\left(\frac{\partial^2 v}{\partial r^2} + \frac{1}{r}\frac{\partial v}{\partial r} + \frac{1}{r^2}\frac{\partial^2 v}{\partial \theta^2} - \frac{v}{r^2} - \frac{2}{r^2}\frac{\partial v}{\partial \theta}\right) - \rho_n(\sin\theta\cos\alpha) \quad (4)$$

- z- Coordinate

$$\rho_n\left(u\frac{\partial w}{\partial r} + \frac{v}{r}\frac{\partial w}{\partial \theta}\right) = -\frac{\partial P}{\partial \theta} + \mu_n\left(\frac{\partial^2 w}{\partial r^2} + \frac{1}{r}\frac{\partial w}{\partial r} + \frac{1}{r^2}\frac{\partial^2 w}{\partial \theta^2}\right) - \rho_n g(\sin\alpha) \quad (5)$$

$$\rho_n = (1-\theta)\rho_f + \theta\rho_s \quad (6)$$

Each section's inner wall temperature is represented as:

$$T_w = T_{w,} + \left(\frac{\partial T}{\partial z}\right)_w \quad (7)$$

The gradient of temperatures along the axial direction is constant $\left(\frac{\partial T}{\partial z}\right)_w = B$, and $T_{w,o}$ represents the wall temperature at the beginning of the thermally fully developed zone.

c. Energy equation

Using cylindrical coordinates, energy equations are expressed as follows [13]:

$$\rho_{nf}C_{nf}\left(u\frac{\partial T}{\partial r} + \frac{v}{r}\frac{\partial T}{\partial \theta} + w\frac{\partial T}{\partial z}\right) = k_{nf}\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2} + \frac{\partial^2 T}{\partial z^2}\right] \quad (8)$$

The $\frac{\partial T}{\partial z}$ is constant along an axis parallel to the main flow (z-direction). As a result, $\frac{\partial^2 T}{\partial z^2} = 0$, and Eq. (8) is simplified as:

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$$\left(u\frac{\partial T}{\partial r}+\frac{v}{r}\frac{\partial T}{\partial \theta}+\right)=k_{nf}\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2}+\frac{\partial^2 T}{\partial z^2}\right]-w\frac{\partial T}{\partial z} \quad (9)$$

Calculation of thermophysical properties

The following procedures were taken to calculate the Thermo-physical properties of the hybrid nanofluid using theoretical methods.

Effective thermal conductivity

It is calculated using the equation described in Ref. [14].

$$k_{nf}=\left[\frac{k_s+(n-1)k_f-(n-1)\Phi(k_f-k_s)}{k_s+(n-1)k_f+\Phi(k_f-k_s)}\right]k_f \quad (10)$$

Thermal diffusivity

The thermal diffusivity of nanofluids is computed using the formula below:

$$\alpha_{nf}=\frac{k_{nf}}{(1-\Phi)(\rho c)_f+\Phi(\rho c)_s} \quad (11)$$

Thermal expansion coefficient [15]

The thermal expansion of nanofluids is determined as follows [15]:

$$\beta_{nf}=\left(\frac{1}{1+\frac{(1-\Phi)\rho_f}{\Phi\rho_s}}\frac{\beta_f}{\beta_s}+\frac{1}{1+\frac{\Phi}{1-\Phi}\rho_f}\right)\beta_f \quad (12)$$

Specific heat

The following expression is used to determine the specific heat of nanofluids [15]:

$$c_{nf}=\left(\frac{(1-\Phi)(\rho C_p)_f+\Phi(\rho C_p)_s}{(1-\Phi)\rho_f+\Phi\rho_s}\right) \quad (13)$$

Effective viscosity

Nanofluids' effective viscosity can be determined with the use of the following formula [16]:

$$\mu_{nf}=123\Phi^2+7.3\Phi+1 \quad (14)$$

Data reduction

To estimate the heat transfer coefficient based on experimental data, the following procedure is followed [17]:

$$h_{exp}=\frac{Q}{\pi d L\,(T_w-T_b)} \quad (15)$$

where

$$\bar{T}=\frac{\sum_{i=1}^{j}T_i}{j} \quad (16)$$

$$T_b=\frac{T_{in}+T_{out}}{2} \quad (17)$$

$$\dot{m}=\rho\times V \quad (18)$$

As the turbulent range flow rates have been used to conduct experiments, the Dittus and Boelter empirical relation is used to determine the heat transfer coefficient theoretically, as given [18]:

$$Nu=0.023\,Re^{0.8}\,Pr^{0.4} \quad (19)$$

where

$$h_{th}=\frac{Nu\times k}{d} \quad (20)$$

$$Re=\frac{4\dot{m}}{\pi\mu d} \quad (21)$$

$$Pr=\frac{c_p\,\mu}{k} \quad (22)$$

Experimental setup

Figure-2 shows a schematic diagram of the detailed components of the test rig used in this study. It is made up of a copper tube with a diameter of 25.4 mm and a length of 1 m and a silicon rubber electric heater that is webbed around its outer surface and covered in fibreglass; it is inclined by 45^{o} to the base of the test rig. Heat flux values are controlled by connecting the heater to the power supply. Before being used in the experiment, nanofluid was prepared in order to assess the physical properties of the process and compare them to theoretical calculations and then transferred into thetank. A supply tank was equipped with an electric mixer that continuously mixed nanoparticles with distilled water to create a homogeneous mixture of nanofluids.Nanofluid was pumped to the heat exchanger by a 1/4-horsepower, 1440-rpm centrifugal pump and its flow rate was controlled by a rotameter before it was returned to the tank; it passed through a cooling coil for cooling hot fluid and to keep the inlet nanofluid temperature as constant as feasible. In two experiments, a Renumber of 4000 to 12000 and a hot flux of 12000 W/m^2 have been studied employing 0.5 and 1% hybrid nanofluids, including two different nanoparticle types (SiO_2 and ZnO). Six T-type thermocouples were mounted in six different positions in the heat exchanger and used for data acquisition model Applent (AT4532); two of these have used to measure the temperature of the heat exchanger's inlet and outlet nanofluids, and the remaining thermocouples were distributed on theinner surface of the tube at equal distances to measure the temperature distribution of the tube wall.

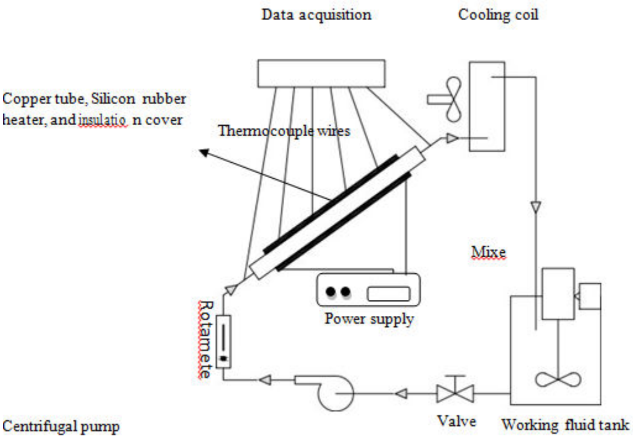

Figure-2. The test rig's schematic diagram, which was used.

Calculation of thermal properties of the Nanofluid experimentally

A hybrid nanofluid was created by mixing SiO_2 (30 nm) and ZnO (30 nm) in two concentrations,0.5% and 1%, with distilled water as the base fluid. Each type of prepared nanofluid and distilled water was sampled to evaluate the thermal properties required to calculate Nu and Re numbers, such as density, dynamic viscosity, and thermal conductivity. Standard thermal property values for the hybrid fluid components are shown in Table-1. While these values were measured in the thermo-fluid laboratory with the following precise instruments to ensure sure that the experimentalresult is valid as possible when compared to a numerical solution:

Table-1. Thermophysical properties of different nanoparticles types.

Materials	Density (kg/m^3)	Specific Heat (J/kg.K)	Viscosity Pa.s	Thermal Conductivity (W/m.K)
SiO_2	2200	745	-	1.40
ZnO	5600	495	-	13
Distilled water	997.64	4180.4	0.001	0.6022
0.5% hybrid	1105	4098	0.0016	0.72
1% hybrid	1155	4148	0.0024	0.77

A. Density

A sensitive balance model Pioneer (4 digits), shown in Figure 3-a, is used to measure the mass of nanofluids prepared for testing, followed by calculating density as mass per unit volume.

a) Viscosity

The dynamic viscosity of a nanofluid was measured using a U-shaped capillary viscometerdevice, as shown in Figure-3-b.

b) Thermal conductivity

The thermal conductivity of a nanofluid was measured using a transient hot wire device type(THW-L2), as shown in Figure-3-c.

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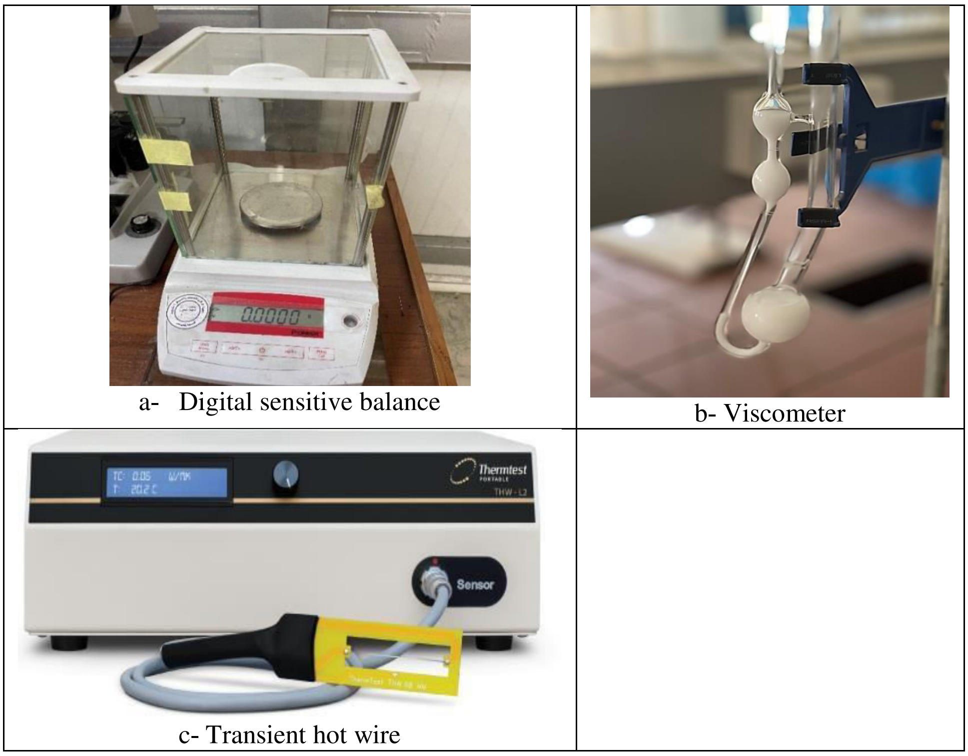

a- Digital sensitive balance

b- Viscometer

c- Transient hot wire

Figure-3. Photos of instruments that are used to measure the thermal properties of the nanofluids.

RESULTS AND DISCUSSIONS

Tests in the thermo-heat laboratory were performed on distilled water and nanofluids to determine their actual values of densities, viscosities, and thermal conductivities. A good correlation was found between the theoretical values and the properties of the tested fluids. Where the difference in density value was less than 0.1%, viscosity was less than 8%, and thermal conductivity was less than 2%. It can be seen in Figures 4 to 6 that the difference between theoretical and experimental values of density, viscosity, and thermal conductivity for fluids has an apparent effect on these properties compared to distilled water as a base fluid; nanoparticles appear to increase these properties. It was estimated that the density of hybrid nanofluids is 10.8% or 11.7% higher than that of a based fluid for 0.5% and 1% hybrid fluids, respectively. In addition, it was estimated that the hybrid nanofluids increased their viscosity, thermal conductivity, and viscosity by (16.23 to 27.15) % and (27.6 to 70.5) %, respectively.

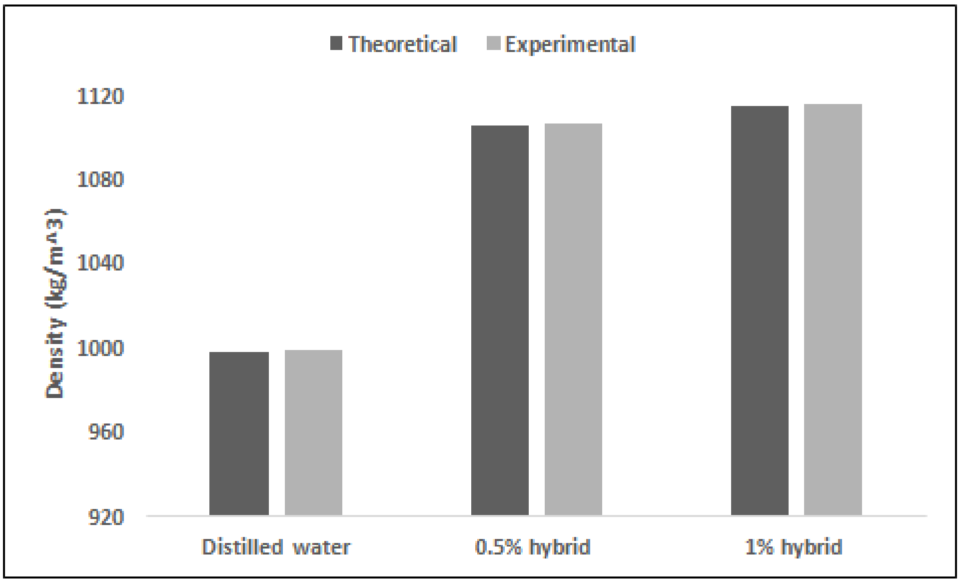

Figure-4. Comparison of theoretical and experimental values of hybrid nanofluid density.

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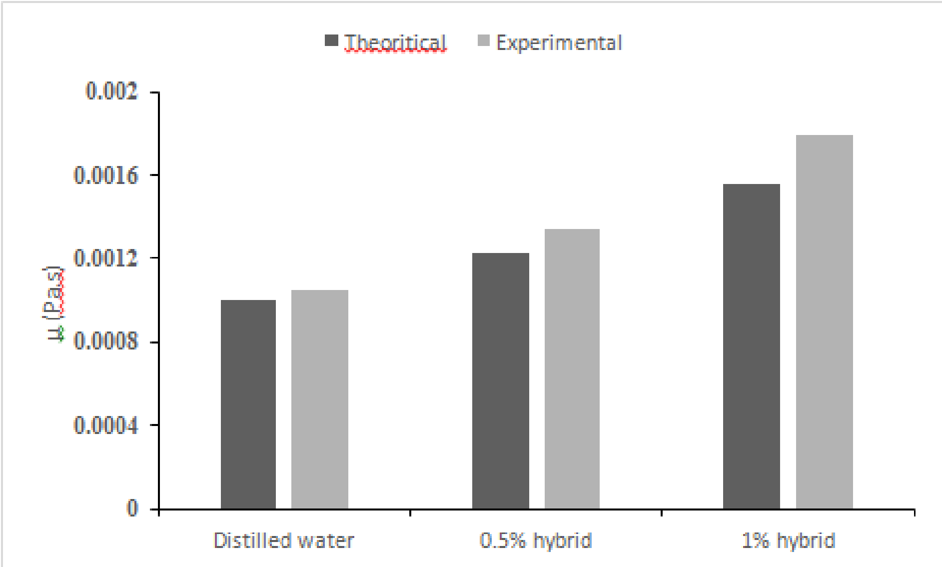

Figure-5. A comparison of the theoretical and experimental viscosities of hybrid nanofluids.

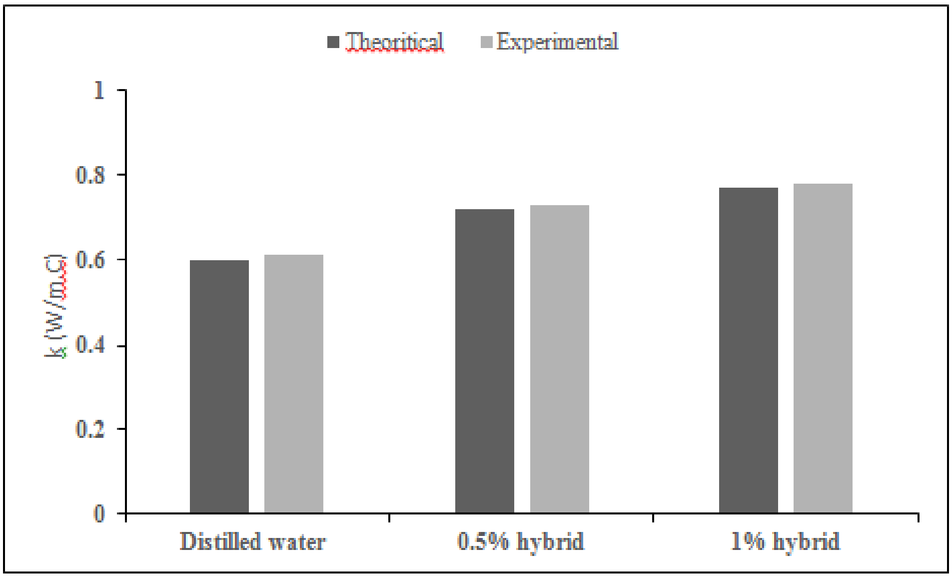

Figure-6. Comparing the thermal conductivities of hybrid nanofluids based on theoretical andexperimental measurements.

A test rig was initially examined using distilled water within the range of Re numbers 4000 to 12000 before testing hybrid nanofluids. To validate the test rig's performance with the empirical relation Eq.19, a constant heat flux of 12000 W/m2 was used. It can be seen from Figure-7 that the results of the two methods are in good agreement. Consequently, the data produced by the test rig will have a good level of reliability.

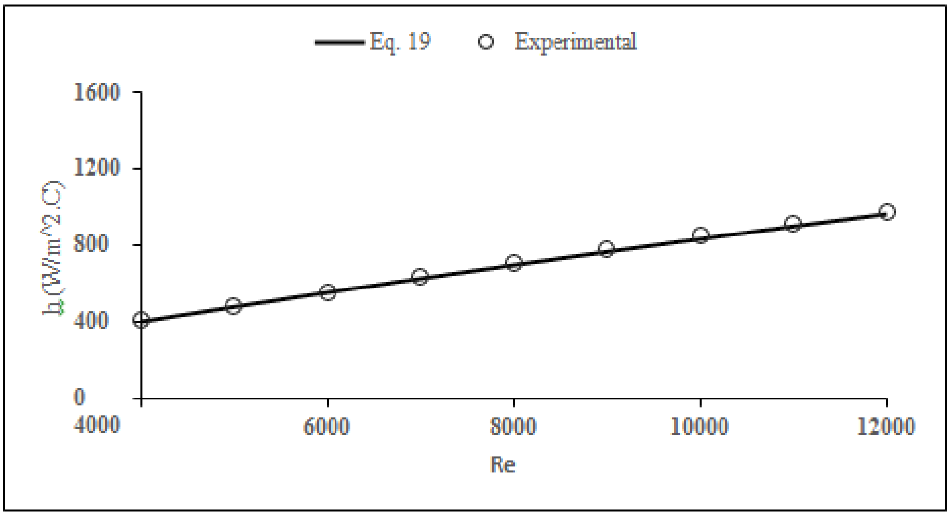

Figure-7. The validation of experimental and theoretical heat transfer coefficients.

The correctness of the test rig was verified by using distilled water, and then nanofluids were used in experiments at the same conditions as the base fluid, which was at constant heat flux and turbulent flow, and the Re number is between 4000 and 12000. According to the simulation results presented in Figure-8, using nanofluids improves heat transfer significantly. In addition, the increase in nanoparticles has contributed to an increase in heat transfer coefficients against Re. The average heat transfer coefficient has been improved and is estimated at 1.2 to 1.4 times in the Re 4000 to 12000 range, for nanufluids of 0.5 and 1% compared to the distilled water, respectively. It is also indicated that there is a good match between theoretical and experimental results in eachhybrid nanofluid.

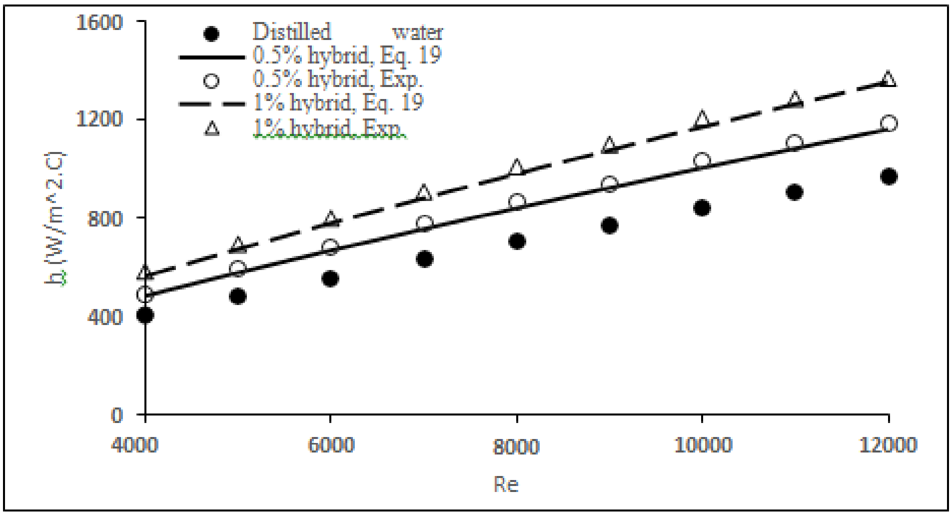

Figure-8. A variation of experimental heat transfer coefficients with respect to Re number.

CONCLUSIONS

This study examined the influence of nanoparticle concentrations of ZnO and SiO2 on the heat transfer coefficient under turbulent flow regimes in an inclined heated pipe with a constant heat flux. Experiment results indicated significant improvements in heat transfer coefficient comparedto the base fluid (distilled water). The improvement ratios obtained are between 1.2 and 1.4 times that of the base fluid, and the theoretical and experimental results agree well.

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