THERMAL PERFORMANCE ANALYSES OF WATER BASED CuO-TiO_2 HYBRID NANOFLUID FLOW IN A HORIZONTAL TUBE

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Abstract
In this study, a CFD modelling of a horizontal straight tube was carried out to investigate the effect of fraction of hybrid water based CuO-TiO_2 nanofluid on thermal performance. In the numerical analysis, in order to ensure fully developed flow, the tested tube was adjusted, and uniform heat flux was applied on outer surface of the test tube. Different turbulence models were examined and *k-ω Shear Stress Transport (SST)* turbulent model was employed to simulate turbulent flow, and analyses were implemented for Reynolds number ranging from 10,000 to 50,000. The flow was simulated as a mixture model, and properties of nanoparticles and water are assumed as not depends on temperature. Thermo-physical properties of nanofluid were calculated from commonly used equations in literature. Nanofluid volume fractions (ϕ) in water were employed as 5, 4, 3, and 2% in which each concentration has different volume fractions of CuO and TiO_2. As a result, the higher volume concentration of CuO compared to TiO_2, the higher heat transfer coefficient was obtained. However, the highest effective Nusselt number of 1.145 is obtained for volume fraction of CuO and TiO_2 is 0.02 and 0.03, respectively at Reynolds number of 50,000.
***Keywords*:** hybrid nanofluid; convective heat transfer; numerical study

1. Introduction

In studies in recent years, nanofluids have shown higher heat transfer performance compared to conventional heat transfer fluids, such as water, oil and ethylene glycol. The reason of that, thermal conductivity of solid metals is so higher than the fluids. Thanks to that, nanofluids enhance the heat transfer coefficient in comparison with distilled fluids. In the other hand, the other advantage of nanoparticles is of higher surface area per volume than micro-particles. Choi [1] is probably the first researcher about the use of particles in nano dimension. Many researchers experimentally studied on this field and reported that nano-particles in the fluids augment heat transfer performance depends on concentration amount, particle size and Reynolds number at last three decades [2-10].

Many numerical studies were conducted to investigate the effect of nanofluid feature on heat transfer enhancement by researchers, due to saving cost and time in comparison with experimental setups.

Demir et al.[11] investigated numerically forced convection flows of nanofluids consisting of water with Al_2O_3 and TiO_2 nanoparticles in a horizontal tube with constant wall temperature used of a single-phase model.

Dawood et al. [12] numerically investigated the effect of nanoparticles on heat transfer enhancement in an elliptic annulus, unlike circular pipe. Al_2O_3, CuO, SiO_2 and ZnO were employed as nanoparticles and volume fraction and Reynolds number respectively was ranging from 0.5% to 4% and 4,000 to 10,000. Their numerical outcomes showed that the best heat transfer was obtained for gyliserin-SiO_2 mixture that was volume fraction of 4% and Reynolds number of 10,000.

Abdolbaqi et al. [13] investigated the effect of water based CuO, TiO_2 and Al2O3 nanofluid flow through a straight square channel under constant heat flux, numerically. They assumed the nanofluid is a single phase since nanoparticles diameters are so smaller (less than 100 nm). They concluded that Nusselt number of CuO has the highest value than the other nanoparticles.

In this study, water based CuO-TiO_2 hybrid nanofluid flow through a horizontal tube is numerically investigated. Volume fraction of the nanoparticles in water is considered as from 2 to 5%. Constant heat flux of 50 kW/m^2 is applied on the outer surface of the test tube. It is assumed that inner wall of the tube has no-slip boundary condition. The test tube material is aluminium and the flow is under developed turbulent condition, Reynolds number is in the range of from 10,000 to 50,000.

2. CFD Investigation

2.1 Validation of Numerical methodology

CFD (Computational Fluid Dynamics) simulations have been commonly used to predict, solve and analyze the problems which involve fluid flows, heat and momentum transfer, by using equations and algorithms of fluid mechanics. Used conversation equations in CFD program are as follows:

Conservation of mass (continuity) equation [15]*:*

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho u) = 0 \qquad (1)$$

Conservation of momentum equation [15]:

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla(\rho \vec{v}\vec{v}) = -\nabla P + \nabla(\bar{\bar{\tau}}) + \rho \vec{g} + \vec{F} \qquad (2)$$

Energy equation [15]:

$$\frac{\partial}{\partial t}(\rho E) + \nabla\big(\vec{v}(\rho E + p)\big) = \nabla\big(k_{eff}\nabla T - \sum_j h_j \vec{J}_i + (\bar{\bar{\tau}}_{eff}\cdot\vec{v})\big) + S_h \quad (3)$$

2.2 Computational domain

A 3D model is composed to describe nanofluid flow characteristic in a straight circular tube under constant heat flux of 50 kW/m^2 and velocity inlet (m/s) depends on Reynolds numbers in a turbulent flow regime. The model is selected as 10 mm diameter and an entrance section (L_1) is considered as a 10D to supply fully developed flow at the inlet of the test region, test section (L_2) is considered as 1m and an exit section (L_3) from the test section is selected as 5D to defect the reverse flow. Boundary condition types and dimensions of the computational domain are depicted in Fig 1. Quad grid structure with boundary layer is generated for the test tube as shown in Fig 2. A non-dimensional parameter, y^+ is used to explain whether the grid structure is appropriate. y^+ value of boundary mesh should be $5< y^+<30$ at high Reynolds numbers as stated by Salim and Cheah [14], and the used grid structure has y^+ of 13.74.

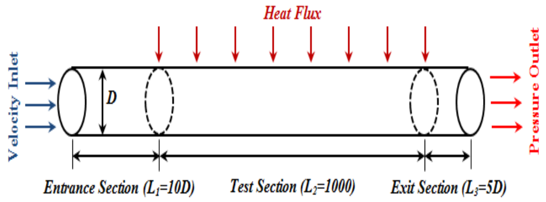

Figure 1. Schematic diagram of the computational domain

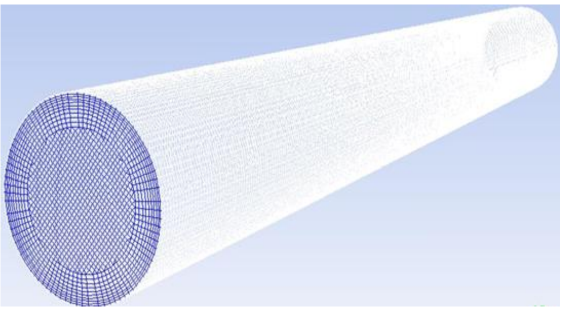

Figure 2. Grid structure of used circular tube

2.3 Validation of the Results

The advantage of CFD simulations is to optimize system variations of models with shorter time and cheaper than experimental setup with ensured validation. In order to ensure accuracy of the numerical methodology, grid independence and turbulence model were tested. *SST k-ω* turbulence model is selected in all considered cases. Detail information about used the turbulence model is available in Fluent Guide [15]. The results were compared with commonly used equations that are Colburn Eq. (4) and Blasius Eq. (5) in terms of Nusselt number (6) and friction factor (8), respectively.

Colburn Equation [16]:

$$Nu = 0.023Re^{0.8}Pr^{0.4} \quad (4)$$

Blasius Equation [17]:

$$f = 0.316Re^{-0.25} \quad (5)$$

$$Nu = \frac{hD}{k} \quad (6)$$

$$h = \frac{q}{T_s - T_b} \quad (7)$$

$$f = \frac{\Delta P}{\frac{1}{2}\rho V^2 \frac{L}{D}} \quad (8)$$

The numerical results are evaluated and compared with these equations (4 and 5) and a study by Rostamani et al. [18] in literature, as in Fig 3.

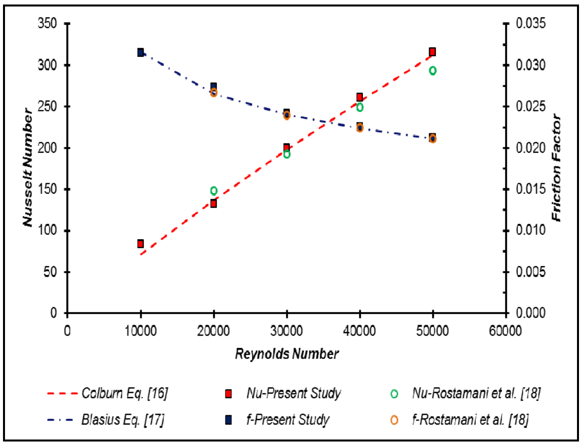

Figure 3. Comparison of distilled water results in terms of both Nusselt Number and friction factor as a function of Reynolds number

In addition to validation of distilled water results, validation of nanofluid results are required for ensuring accuracy of the present study, as well. A single phase model is used for nanofluid flow through the test tube due to saving computational time. Properties of the used materials are given in Table 1. Main aim of using nanofluid is to raise thermal conductivity value and Pr (Prandtl number) as well, and it causes to increase viscous diffusion rate of base fluid.

Table 1. Properties of water and nanoparticles

	Water	CuO	TiO_2
ρ [kg/m^3]	998.2	6510	3980
Cp [j/kgK]	4182	540	690
ε [kg/ms]	1.003x10^{-3}	-	-
k [W/mK]	0.6	18	10.2

Volume fraction of hybrid CuO-TiO_2 nanoparticles into water is totally considered up to 5%. Thermal and physical properties of the nanofluid are calculated with commonly used correlations in independence temperature. The hybrid nanofluid properties are evaluated likewise as below:

Density of nanofluid:

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi\rho_{np} \quad (9)$$

Density of Hybrid mixture:

$$\rho_{nf,hybrid} = \frac{(\varphi_{CuO})(\rho_{nf-CuO}) + (\varphi_{TiO2})(\rho_{nf-TiO2})}{\varphi_t} \quad (10)$$

Specific heat of nanofluid:

$$Cp_{nf} = \frac{(1-\varphi)(\rho_{bf})(Cp_{bf}) + (\varphi\rho_{np})(Cp_{np})}{\rho_{nf}} \quad (11)$$

Specific heat of Hybrid mixture:

$$Cp_{nf,hybrid} = \frac{(\varphi_{CuO})(Cp_{nf-CuO}) - (\varphi_{TiO2})(Cp_{nf-TiO2})}{\varphi_t} \quad (12)$$

Thermal conductivity:

One of most used formula (Eq. 13) for calculation the thermal conductivity of nanofluid is developed by Hamilton and Crosser [19], in 1962.

$$k_{nf} = k_{bf}\frac{[k_{np} + (n-1)k_{bf} - (n-1)\varphi(k_{bf} - k_{np})]}{[k_{np} + (n-1)k_{bf} + \varphi(k_{bf} - k_{np})]} \quad (13)$$

$$n = 3/\psi \quad (14)$$

where n is the empirical shape factor and ɣ is the sphericity, defined as the ratio of the surface area of a sphere to the surface area of the particle (Eq. 14), as stated by Duangthongsuk and Wongwises [20]. The sphericity value assumed as 1. Expressions of k_{nf}, k_{np} and k_{bf} are the thermal conductivity of nanofluid, nanoparticle and base fluid, respectively. Dynamic viscosity of hybrid nanofluid does not need to calculate again due not to including expect of volume fraction (*ű*) in the formula.

Thermal conductivity of hybrid mixture:

$$k_{nf,hybrid} = \frac{(\varphi_{CuO})(k_{nf-CuO}) + (\varphi_{TiO2})(k_{nf-TiO2})}{\varphi_t} \quad (15)$$

Dynamic viscosity:

$$\mu_{nf} = \mu_{bf}(123\varphi_t^2 + 7.3\varphi_t + 1) \quad (16)$$

Result of the nanofluid flow is validated with Rostamani et al. [18] used CuO nanoparticles into water. The validation for water based CuO nanofluid is illustrated in Fig 4.

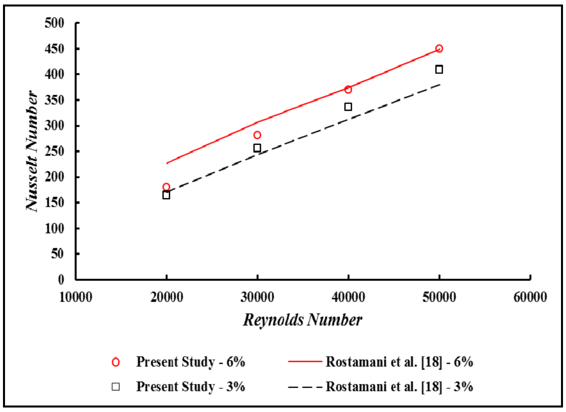

Figure 4. Comparison of CuO nanofluid results in terms of Nusselt number as a function of Reynolds number

3. Results and Discussions

Influence of water based CuO-TiO_2 hybrid nanofluid through a horizontal tube under developed turbulent flow condition and constant heat flux on convective heat transfer and pressure drop was numerically investigated. Variance in individually thermo physical properties for considered volume fraction combinations is given in Table 2.

Table 2. Individually thermo physical properties of used nanofluid

		ű [%]					
		0	**1**	**2**	**3**	**4**	**5**
***ρ* [kg/m³]**	CuO	998.2	1053.3	1108.4	1163.6	1218.7	1273.8
	TiO_2	998.2	1028.0	1057.8	1087.7	1117.5	1147.3
***Cp* [kj/kgK]**	CuO	4182.0	3956.9	3754.2	3570.7	3403.8	3251.3
	TiO_2	4182.0	4046.8	3919.2	3798.7	3684.5	3576.3
***k* [W/mK]**	CuO	0.600	0.616	0.633	0.650	0.668	0.685
	TiO_2	0.600	0.615	0.631	0.647	0.663	0.679
***μ* [kg/ms]**	CuO	0.00100	0.00109	0.00120	0.00133	0.00149	0.00168
	TiO_2	0.00100	0.00109	0.00120	0.00133	0.00149	0.00168
***Pr* [-]**	CuO	6.99	6.99	7.11	7.32	7.61	7.96
	TiO_2	6.99	7.16	7.45	7.83	8.30	8.83

Main purpose of using nanofluid into a fluid is to augment the thermal conductivity property of the fluid. The results show that as the thermal conductivity of the working fluid increases, heat transfer coefficient increases in comparison to distilled water, as illustrated in Fig 5. Furthermore, as can be seen in this figure, when volume fraction of CuO higher than that of TiO_2, more heat transfer coefficient is obtained according to effective thermal conductivity $\left(k_{eff} = k_{nf}/k_{bf}\right)$.

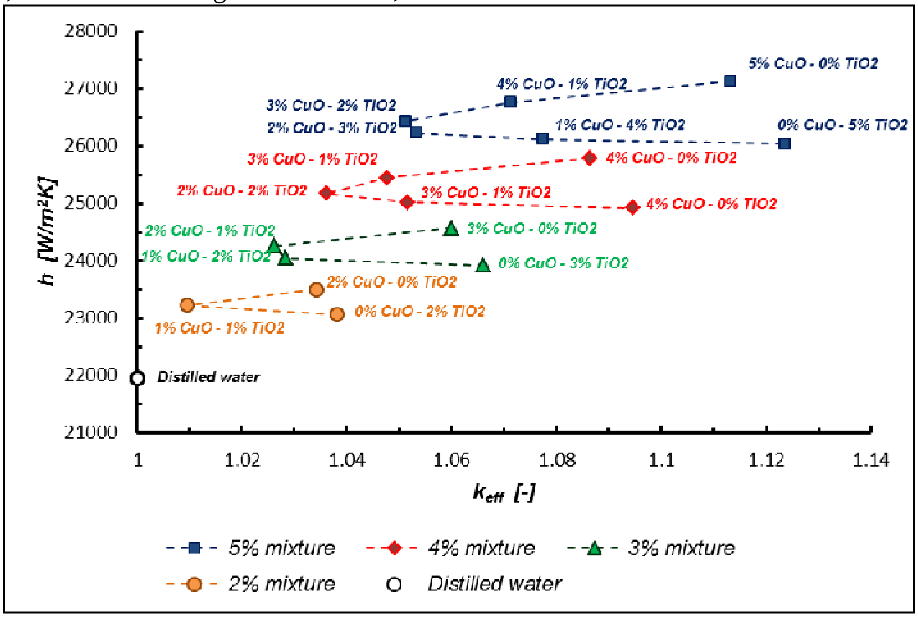

Figure 5. Convective heat transfer coefficient versus effective thermal conductivity for the hybrid nanofluid mixture

In addition to increasing the thermal conductivity of the working fluid, increment in Prandtl number of working fluid has another effect on enhancement heat transfer of the system. Nusselt number is non-dimensional parameter to determine thermal performance for a flow field through a smooth tube which dominantly depends on Prandtl and Reynolds number. In this scope, the results for effective Nusselt number $\left(Nu_{eff} = Nu_{nf}/Nu_{bf}\right)$ at constant Reynolds number of 50,000 revealed that TiO_2 has more positive effect on Nusselt number than CuO, since Prandtl number of TiO_2 is greater than that of CuO. Moreover, when volume fraction of both of them is approximately equal to each other, the highest effective Nusselt number is obtained, as can be seen in Fig 6.

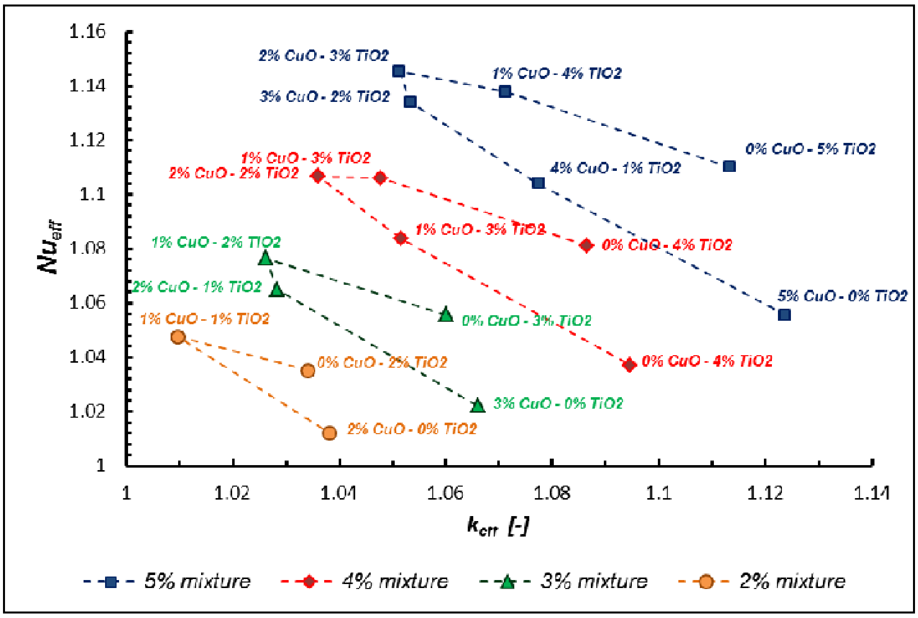

Figure 6. Distribution of average Nusselt number with respect to effective thermal conductivity for the hybrid nanofluid mixture for Reynolds number of 50,000

Hydraulic performance is another parameter to determine a heating system through a tube. Pressure drop results from the present study are given in Fig 7. Supplementing nanoparticles to distilled water increases dynamic viscosity of the distilled water. Thus, pressure drop increases for the all considered nanofluid flow. In the other hand as Reynolds number increases, pressure drop increases. CuO has causes a further increase pressure drop in comparison to TiO_2, as can be seen in Fig 7. The main reason of this result is that, intermolecular bonds are more strength and viscos forces adjacent the walls are more powerful, since CuO especially has more density than TiO_2.

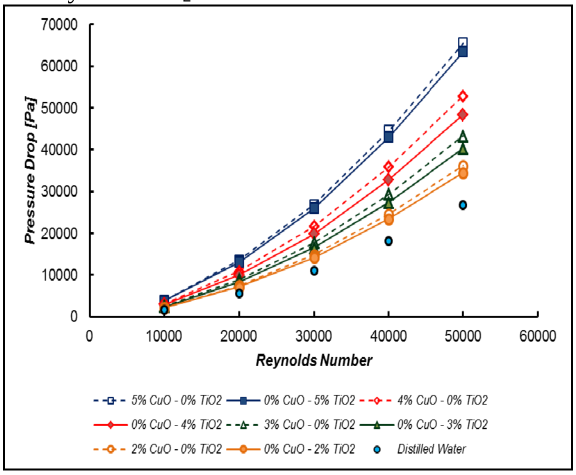

Figure 7. Volume fraction of used nanofluid mixture effect on pressure drop as a function of Reynolds number

4. CONCLUSION

In this study, effect of hybrid nanofluid mixture (CuO-TiO_2) on heat transfer and pressure drop is numerically investigated by using mixture phase model. Results showed that convective heat transfer enhances for all considered volume fraction of the hybrid CuO-TiO_2 nanofluid with increasing Reynolds number. Major reason of the heat transfer enhancement is that thermal conductivity of the nanofluid is so greater than distilled water. In the hybrid nanofluid mixture, the highest effective Nusselt number is obtained for which volume fraction of CuO and TiO_2 is close to each other. In the other hand, hydraulic performance of hybrid nanofluid flow is examined. Adding nanoparticle, especially CuO increases the pressure drop in comparison with distilled water. The main findings can be summarized as below:

- ✓ The mixture model that is used to simulate nanofluid flow shows good agreement with literature on heat transfer and pressure drop.
- ✓ Increasing of effective thermal conductivity causes to increase convective heat transfer coefficient. Furthermore, using CuO instead of TiO_2 shows better performance on increasing convective heat transfer coefficient.
- ✓ The average Nusselt number increases for all nanofluid mixture with increasing effective thermal conductivity in comparison with distilled water. With this conclusion, using hybrid nanofluid can be beneficial even if volume fraction is less than single nanofluid.
- ✓ The highest Nusselt number is obtained for 2% CuO ï 3% TiO_2 for Reynolds number of 50,000.
- ✓ Pressure drop increases in all considered volume fraction as Reynolds number increases. In other hand, the more pressure drop increases, the more CuO nanoparticle is added rather than TiO_2. The main reason of this conclusion is that density magnitude of CuO particles is higher than TiO_2, and it causes to occur more viscous forces adjacent the wall.

NOMENCLATURE

C_p	[J/kg K]	specific heat capacity of air
D	[m]	inner diameter of the tube
f	[-]	friction factor
h	[W/m^{2}K]	convective heat transfer coefficient
k	[W/mK]	thermal conductivity
L	[m]	length of the test tube
n	[-]	empirical shape factor
Nu	[-]	Nusselt number
æP	[Pa]	pressure drop
Pr	[-]	Prandtl number
Re	[-]	Reynolds number
q	[W/m^2]	heat flux
T	[K]	steady state temperature
V	[m/s]	mean fluid velocity
y^+	[-]	dimensionless wall distance

Greek letters

ȷ	[kg/m$^{3]}$	fluid density
ű	[-]	volume fraction
ε	[kg/ms]	dynamic viscosity
ɣ	[-]	sphericity

Subscripts

b	bulk
bf	base fluid
eff	effective
nf	nanofluid
np	nanoparticle
s	surface
t	total

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