Numerical Study of Heat Transfer of Heat Transfer and Fluid Flow Performance of Nanofluids in Flat Tube Heat Exchanger

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Abstract: This paper comprises a survey of heat transfer performance of flat tube heat exchanger by using nanofluids namely alumina and copper nanofluids. In this research Numerical studied the heat transfer rate and fluid flow performance of nanofluid inlet temperature (40–70°C), Reynolds number (12000–30000), particle concentration (0.4–0.8 vol.%) and mass flow rate (0.15–0.55 kg/s) and flow characteristics of water-based alumina and copper nanofluids in a flat tube heat exchanger. The specific heat capacity, viscosity, density, and thermal conductivity were measured experimentally. The rate of heat transfer of fluids increased with increasing the particle volume concentration with increase in fluid inlet temperature, particle volume concentration, and Reynolds number. The heat transfer coefficient also enhanced (up to 16%). The pressure drop increased with increasing the particle volume concentration and Reynolds number, while it decreased slightly with increasing the fluid inlet temperature.

Keywords: Nanofluid; Flat Tube; Rate of Heat Transfer; Pressure drop; Heat transfer coefficient; Alumina; Copper

Nomenclature:

P	Density
N	Kinematic Viscosity
Cp	Specific Heat Capacity

K	Thermal Conductivity
H	Heat Transfer Co-efficient
V	Velocity
Dh	Hydraulic Diameter
Di	Diameter of the inner tube
Do	Diameter of the outer tube
Ah	The cross-sectional area of the inner tube passing hot fluid
Ac	The cross-sectional area of the inner tube passing cold fluid
Δp	Pressure Drop
U	Overall Heat Transfer Co-efficient
Q	Heat Transfer Rate
Re	Reynold's Number
Nu	Nusselt Number
Pr	Prandtl Number
°C	Degree Celsius
ΔT	Temperature gradient
K	Kelvin

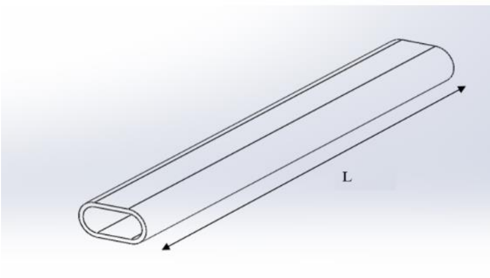
1. Introduction:

The conservation of energy is one of the major issues; it will certainly be one of the most significant challenges shortly. Due to that, researchers and scientists are trying to address this very important concern. More research on the advancement made in heating or cooling industrial devices and also trying to improve the heat transfer as well as increase the operational life of the equipment. For the above-mentioned purpose, various types of heat exchangers are introduced. There are various heat exchangers which have different operating systems to exchange heat from one fluid to another fluid [1]. This research takes more concerned with enhancing the properties of the fluid. Nanofluid is a liquid that contains nanometre size particles. These nanoparticles can be metals, oxides, or allotropes of carbon with thermal conductivity. The nanoparticles are used to increase the thermal conductivity of the base fluid; this idea is offered by Choi [1] for the first time. Choi experimentally studied that by adding and suspending the nanoparticles in base fluid the thermal conductivity increases so heat transfer will also increase. Some research about the effect of adding nanoparticles on heat transfer is mentioned below: They experimentally investigate turbulent friction convective heat transfer of Al_2O_3- water and TiO_2-water nanofluids in circular pipes [2]. They found that the viscosity for the dispersed fluids with Al_2O_3 and TiO_2 particles showed shear-thinning behaviour at or above volume concentrations of 3% and 10%, respectively, and also studied that, the Nusselt number of depressed fluids increased with increasing volume concentration as well as Reynolds number. Also, they offered the first empirical correlation for predicting the nanofluid Nusselt number in a turbulent tube flow. The convective heat transfer feature of Cu-water nanofluids was investigated experimentally in a tube by Li and Xuan [3, 4]. They experimentally showed that suspended nanoparticles increased the heat transfer performance of the base fluid and they found out the heat transfer coefficient is higher of the nanofluids as compared to pure water, with the same Reynolds number. Yang et al. [5] studied the conventional heat transfer performance of graphite nanofluid in a laminar flow through a circular pipe. Experimental results define that the heat transfer performance increases because of adding the nanoparticle to the base fluid. Yang et al. found that to increase the volume fraction of nanoparticles and Reynolds number the heat transfer increased. Pantzali et al. [6], numerically and empirically evaluated the effect of the CuO-water nanofluids at a 4% volume concentration of nanoparticles on the performance of a miniature plate heat exchanger. Heris et al. [7, 8] experimentally indicate that the heat transfer coefficient enhances by increasing the volume concentration of the nanoparticles and Peclet number. They have also compared the heat transfer of Al2O3/ water to CuO/water and the results state that Al2O3/ water has more enhancements as compared to CuO/water. Duangthong suk and Wongwises [9, 10] are investigating the characteristics and heat transfer of the TiO2- water nanofluids which have 0.2% volume of the nanoparticles in the double pipe heat exchanger. Experimental values pretend that the heat transfer coefficient of the nanofluid is enhanced rather than pure or distilled fluid. This enhancement was approximately 6-10% more than the base fluid.

2. Mathematical modelling:

2.1 Geometry:

Figure 1 and Figure 2 shows the geometry of the flat tube which are used for simulation. Nanofluids are flowing inside the flat tube at particular constant inlet temperature. Nanofluids are flowing inside the flat tube, because nanofluids has higher thermal conductivity. Higher conductivity provides an advantage and enhance the heat transfer performance of the tubes.



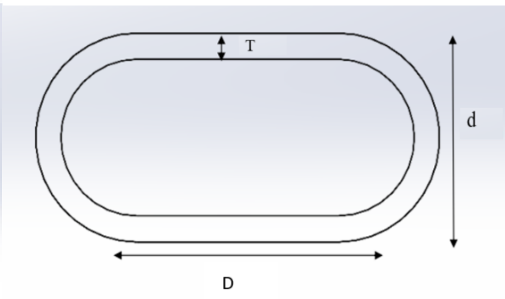


Fig 1. Schematic diagram of Flat Tube Fig. 2 Dimensions of Flat Tube

2.2 Governing Equation:

Nanofluid as a single-phase fluid but the physical properties namely density, thermal conductivity and viscosity are quite different. The nanofluids are used in the model is consider as incompressible and Newtonian behaviour. The volume particle concentration of the nanoparticles is very small. The ambient temperature and air flow is considered as constant. The inlet temperature in each experiment is also constant. In this experiment gravitational forces are negligible because of the drag forces are very high. By using computational fluid dynamics (CFD) method this problem numerically solved under above mentioned conditions.

The flow and heat transfer are assumed by continuity, momentum and energy equation[15], which are following given respectively.

Continuity equation:

$$\nabla.\ \rho_{nf}\ V_m = 0 \tag{1}$$

Momentum equation:

$$\nabla.\ (\rho_{nf}\ V_m V_M) = -\nabla P + \nabla.\ (\mu_{nf}.\ \nabla V_m) \tag{2}$$

Energy equation:

$$\nabla.\ (\rho_{nf}\ CV_m\ T) = \nabla.\ (k_{nf}\ \nabla T) \tag{3}$$

2.3 Numerical approach:

In this study, the heat transfer and fluid flow of nanofluids as a single phase and the governing equations are solved by the finite volume method. Ansys fluent was used for this work and to solve the pressure-velocity coupling used simple scheme for pressured linked equations. All simulations are converged and the residual number for governing equations are 10^{-6}. Velocity components, pressure and temperature are solved in fluid domain of the flat tube and in post processing the outlet temperature is recorded.

2.4 Thermophysical properties of Nanofluids:

Thermal Conductivity of nanofluids was calculated using (4) equation given below[11] :

$$\frac{k_{nf}}{k_f} = 1 + 64.7\emptyset^{0.7460} \left(\frac{d_f}{d_s}\right)^{0.3690} \left(\frac{k_s}{k_f}\right)^{0.7476} Pr^{0.9955}\ Re_b^{1.2321} \tag{4}$$

Velocity of Aluminium oxide and Copper oxide has been calculated by using following equation (5):

$$\frac{\mu_{nf}}{\mu_f} = \frac{1}{1-34.87\left({d_s}/{d_f}\right)^{-0.3} \emptyset^{1.03}} \tag{5}$$

Density of nanofluids was calculated as

$$\rho_{nf} = (1-\emptyset)\, \rho_f + \emptyset_{\rho s} \tag{6}$$

Specific heat of Aluminium oxide and Copper oxide has been calculated by using following equation:

$$\left(C_p\right)_{nf} = \frac{(1-\emptyset)\left(\rho C_p\right)_s + \emptyset\left(\rho C_p\right)_s}{\rho_{nf}} \tag{7}$$

Hydraulic diameter of flat tube was calculated as

$$D_h = \frac{4 \times \left[\left({\pi}/{4}\right) d^2 + (D-d) \times d\right]}{\pi \times d + 2 \times (D-d)} \tag{8}$$

Where, ‘D’ and ‘d’ are the major and minor diameters of the flat tube, respectively.

Heat transfer rate from nanofluid was calculated as,

$$Q = m_{nf} \times c_{p.nf} \times \left(t_{in} - t_{out}\right) \tag{9}$$

The average heat transfer coefficient of nanofluid in flat tube was calculated as

$$h_{exp} = \frac{m_{nf} \times c_{p(nf)} \times \left(t_{in} - t_{out}\right)}{A_s \times \left(t_{in} - t_{out}\right)_{LM}} \tag{10}$$

The bulk mean temperature (Tb) of nanofluid is given by

$$T_b = \frac{t_{in} + t_{out}}{2} \tag{11}$$

2.5 Boundary Condition:

Three sets of boundary conditions have been taken into consideration for the investigation of flat tube Heat Exchanger. The boundary conditions are shown in table (1).

Table 1. Boundary condition of nanofluids.

Set No.	**Fluid**	**Velocity**	**Inlet Temperature (°C)**	**Mass flow Rate Kg/s**	**Hydraulic diameter**
1.	Nanofluid (Al203/water)	2m/s	40-70	15.17596	0.07m
2.	Nanofluid (Cu2O/Water)	2m/s	40-70	15.17596	0.07m

Body sized method is used to discretize the domain of the flat tube. The figure 3 and figure 4 shows the meshing of tube.

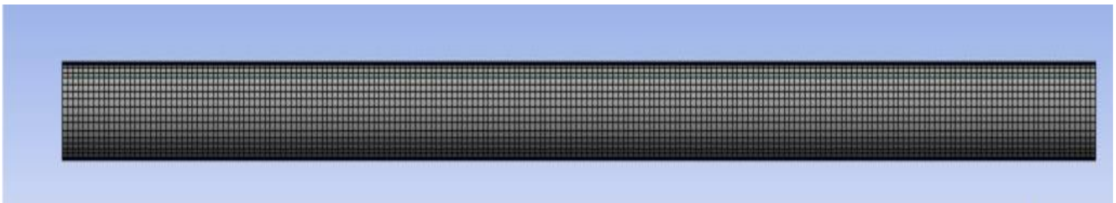


Fig. 3 Meshing of flat tube

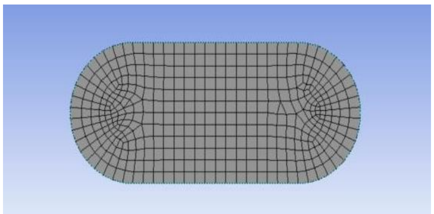


Figure 4.

- The inlet of the tube is defined as tube inlet and the hydrologic diameter of the tube is 0.07 m and the turbulence intensity is 10%.
- While outlet of tube set as pressure outlet.
- The wall thickness is 0.01 m and walls are considered as convection surface.
- The temperature of the wall or ambient temperature is constant that is 20°C.

- Inlet temperature of the tube is varied in each experiment that is 40°C 50°C 60°C and 70°C.

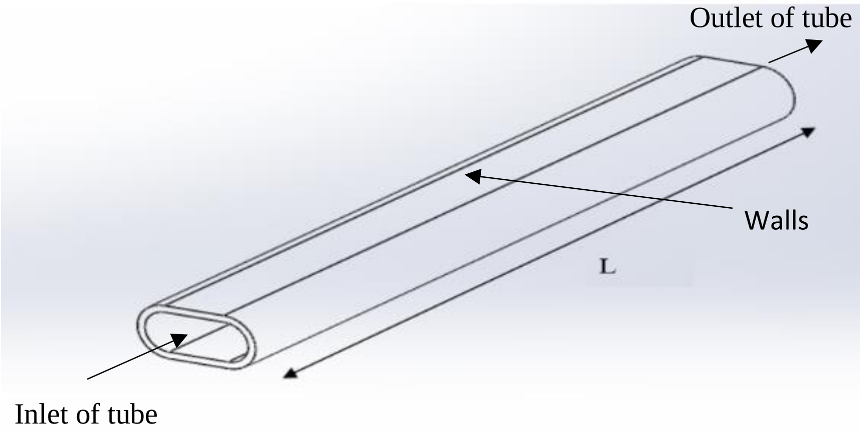


Fig. 5. Boundary condition of domain

- All Simulations are performed using Computational fluid dynamic method (CFD).

3. Result and discussion:

In this investigation, the counter flow configuration of Flat tube heat exchanger has been taken into consideration and different materials and fluids for inner flat tube have been selected. Three different sets of boundary conditions e.g.- inlet temperature, hydraulic diameter, mass glow rate for aluminium oxide and copper oxide have been introduced for the CFD method of flat tube heat exchanger. The output results of flat tube heat exchanger according to the inlet boundary conditions have been studied to determine the heat transfer performance as well as pressure drop characteristics of flat tube heat exchanger. Moreover, relations between various parameters to evaluate the investigation.

3.1 Heat Transfer rate:

The rate of heat transfer determines the heat transfer performance in the Double Pipe Heat Exchanger. It has been evaluated by using following equation:

$$Q = m_{nf} \times c_{p.nf} \times (t_{in} - t_{out}) \tag{9}$$

Table 2. Heat Transfer of Al_2O_3 at 0.4 volume concentration

VOLUME CONCENTATION (%) -- 0.4				
Ti(°C)	To(°C)	M	Cp	Q(watt)
40	39.29666	15.17596	4175.56	44569.35231
50	48.87556	15.17596	4178.56	71304.82107
60	58.393	15.17596	4181.55	101978.6701
70	67.91782	15.17596	4187.55	132322.6975

Table 3. Heat Transfer of Al_2O_3 at 0.6 volume concentration

VOLUME CONCENTATION (%) -- 0.6				
Ti(°C)	To(°C)	M	Cp	Q(Watt)
40	39.21034	15.17596	4172.12	49998.07828
50	48.77831	15.17596	4175.12	77407.98072
60	58.28426	15.17596	4178.11	108789.6349
70	67.85321	15.17596	4184.1	136316.2357

Table 4. Heat Transfer of Al_2O_3 at 0.6 volume concentration

VOLUME CONCENTATION (%) -- 0.8				
Ti(°C)	To(°C)	M	Cp	Q(Watt)
40	39.15642	15.17596	4168.68	53368.04811
50	48.61224	15.17596	4171.67	87857.91677
60	58.18736	15.17596	4174.67	114838.9898
70	67.79064	15.17596	4180.65	140173.5779

It was observed that the heat transfer characteristics of the nanofluid increased. The trends shown in figure 6. of the nanofluid is due to the fact that the nanoparticles presented in the base fluid increase the thermal conductivity and the viscosity of the base liquid at the same time. The enhancement of thermal conductivity leads to increase the heat transfer performance as well as viscosity of the fluid which results into an increase in friction factor and the boundary layer thickness

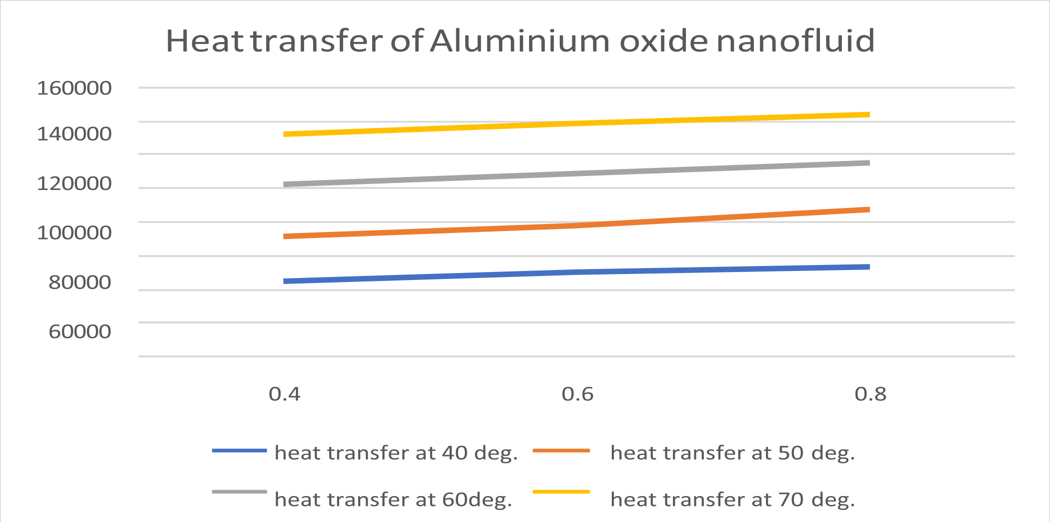


Fig. 6 Heat transfer of Aluminum oxide nanofluid

Similarly, below given tables shows the rate of heat transfer of copper oxide in the flat tube Heat Exchanger.

Table 5. Heat Transfer of CuO at 0.4 volume concentration

VOLUME CONCENTATION (%) -- 0.4				
Ti(°C)	To(°C)	M	Cp	Q(Watt)
40	39.09412	15.17596	2922.89	44357.66172
50	48.5595	15.17596	2924.99	44389.53124
60	57.95542	15.17596	2927.09	44421.40076
70	67.36502	15.17596	2931.28	44484.98803

Table 6. Heat Transfer of CuO at 0.4 volume concentration

VOLUME CONCENTATION (%) -- 0.6				
Ti(°C)	To(°C)	M	Cp	Q(Watt)
40	39.00408	15.17596	2920.49	44140.32012
50	48.48019	15.17596	2922.58	67408.06785
60	57.86516	15.17596	2924.68	94754.50342
70	67.26899	15.17596	2928.87	121389.063

Table 7. Heat Transfer of CuO at 0.8 volume concentration

VOLUME CONCENTATION (%) – 0.8				
Ti(°C)	To(°C)	M	Cp	Q(Watt)
40	38.90011	15.17596	2918.08	48708.43772
50	48.38797	15.17596	2920.17	71439.33907
60	57.78081	15.17596	2922.17	98413.83092
70	67.17404	15.17596	2926.45	125505.6542

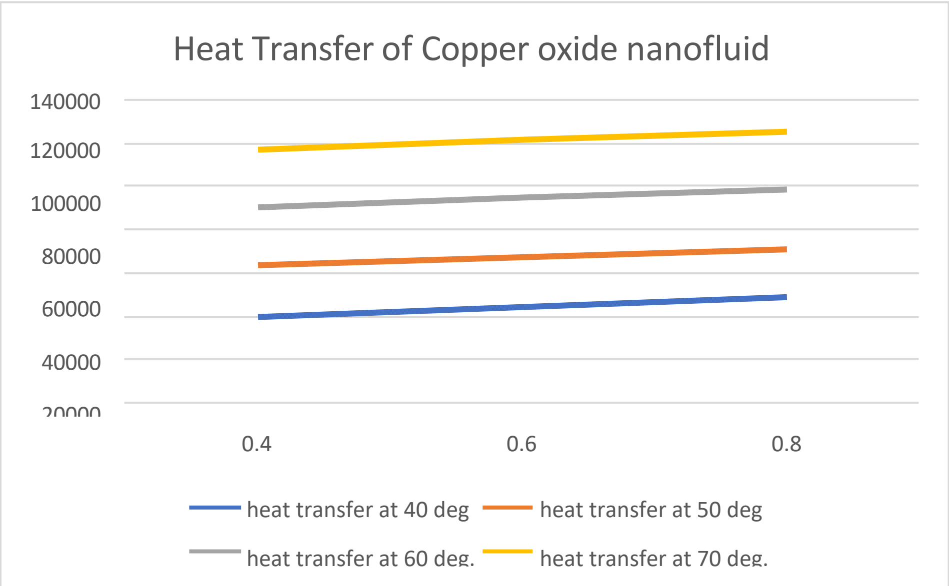


Fig. 7. Graph of heat transfer of copper oxide

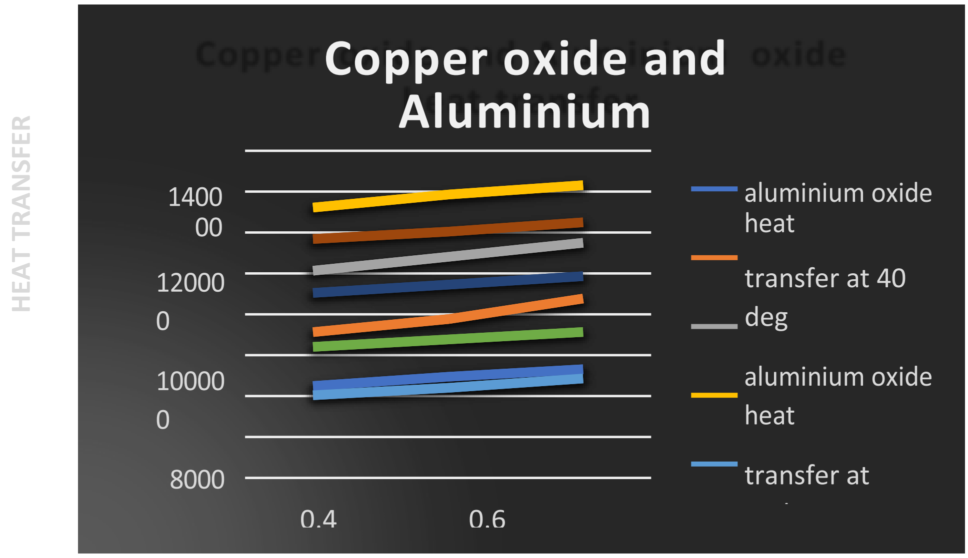


Fig 8. Comparison of Heat transfer of copper oxide & aluminum oxide

3.2 Heat Transfer Coefficients:

The variation of heat transfer coefficient for nanofluids in the flat tube is shown in Tables 8-10. It can be inferred from this figure that concentration of nanoparticles plays a vital role in enhancing the heat transfer coefficient. The wall temperature of tube increases because of increase in heat transfer rate due to the Brownian motion of nanoparticles near the tube wall at high Reynolds numbers. The development of thermal boundary layer near the flat tube wall surface was delayed due to chaotic motion of nanoparticles, which resulted in increased heat transfer at the entrance region of the flat tube. In addition, the heat transfer was significantly affected by fluid inlet temperature.

With the rise in fluid inlet temperature, the heat transfer coefficient increased because of the increase in thermal conductivity and decrease in density and viscosity of fluids. As the inlet temperature of nanofluid was increased from 40°C to 70°C, the heat transfer coefficient improved by 7.8%, for a particular fluid velocity and particle concentration (0.4% v/v). In addition, the heat transfer coefficient also increased with increasing the air flow rate over the tube and resulted in a decrease in the nanofluid temperature at the outlet of the flat tube.

The results of heat transfer coefficient for copper oxide have been shown in the following tables.

The heat transfer co-efficient is calculated as follows:

$$h_{exp} = \frac{m_{nf} \times c_{p(nf)} \times (t_{in} - t_{out})}{A_s \times (t_{in} - t_{out})_{LM}} \tag{10}$$

Table 8. Heat Transfer Coefficient of CuO at 0.4 volume concentration

Volume Concentration (%) -- 0.4					
Ti (Inlet Temp.)°C	To (Outlet Temp.)°C	Tw(wall temp.)°C	A (Effective Area)	Tb (bulk mean temp.) °C	Heat Transfer Coefficient W/m^2K
40	39.09412	20	0.01	39.54706	205.569
50	48.5595	20	0.01	49.27975	218.386
60	57.95542	20	0.01	58.97771	233.012
70	67.36502	20	0.01	68.68251	240.778

Table 9. Heat Transfer Coefficient of CuO at 0.6 volume concentration

Volume Concentration (%) -- 0.6					
Ti (Inlet Temp.)°C	To (Outlet Temp.)°C	Tw(wall temp.)°C	A (Effective Area)	Tb (bulk mean temp.) °C	Heat Transfer Coefficient W/m^2K
40	39.004082	20	0.01	39.502041	226.336
50	48.48019	20	0.01	49.240095	230.532
60	57.86516	20	0.01	58.93258	243.381
70	67.26899	20	0.01	68.634495	249.594

Table 10. Heat Transfer Coefficient of CuO at 0.8 volume concentration

Volume Concentration(%) -- 0.8					
Ti (Inlet Temp.)°C	To (Outlet Temp.)°C	Tw(wall temp.)°C	A (Effective Area)	Tb (bulk mean temp.) °C	Heat Transfer Coefficient W/m^2K
40	38.900106	20	0.01	39.450053	250.428
50	48.38797	20	0.01	49.193985	244.705
60	57.78081	20	0.01	58.890405	253.054
70	67.17404	20	0.01	68.58702	258.311

3.3 Reynolds's Number

Reynolds's Number is a dimensionless parameter which is defined as the ratio of inertia forces to the viscous forces. As the flow configuration in pipes mainly depends on flow velocity, surface geometry, surface roughness, type of fluid among other characteristics, It is found that Reynolds No. increases in case of nanofluids and decreases in case of water as temperature varies according to different sets of data. The flow configurations come out as laminar except CuO by observing the Reynolds No.

Reynolds number for hot fluid and cold fluid has been calculated by using the following equation:

$$Re = \frac{vD}{\nu} \tag{12}$$

The results of Reynolds number. have been shown in following table 11.

Table 11. Reynolds number for different fluid

Sr No.	Fluid	Reynolds's No(Re)
1	Al_2O_3	2910.88
	Water	1356.4
2	CuO	4510.88
	Water	2358.6

3.4 Prandtl Number:

Prandtl Number is a dimensionless quantity which signifies the thermal boundary layers and the relative thickness of the velocity. Prandtl no. for aluminium oxide and copper oxide fluid has been calculated as follows:

$$Pr = \frac{\rho Cpv}{K} \tag{13}$$

The results of Prandtl No. have been shown in following table 12.

Table 12. Prandtl number for different fluid

Sr No.	Fluid	Prandtl No(Re)
1	Al_2O_3	$4.140e^{-6}$
	Water	$2.663e^{-5}$
2	CuO	$7.019e^{-6}$
	Water	$4.663e^{-5}$

Nusselt Number is a dimensionless quantity which signifies the improvement of heat transfer through a fluid layer as a result of convection related to conduction across the same fluid layer. It helps to determine the heat transfer co-efficient in the Heat Exchanger.

The following correlation is used to determine the Nusselt No. for aluminium and copper oxide fluid:

$$Nu = 0.023\ Re^{0.8}\ Pr^{0.4} \quad 4.4$$

The following table 13. shows the results of Nusselt No. for hot and cold fluid:

Table 13. Nusselt number for different fluid

Sr No.	Fluid	Nusselt No(Re)
1	Al_2O_3	0.122
	Water	0.108
2	CuO	1.112
	Water	1.009

3.5 Pressure drop:

Pressure drop plays a significant role in terms of heat transfer performance in the heat exchanger. The pressure drop characteristic has been determined by using the following equation:

$$\Delta p = \frac{32\rho vLV}{D^2} \quad (14)$$

The pressure drop for different sets of boundary conditions has been shown below in table 14.

Table 14. Pressure drop for different sets of boundary condition.

Sr No.	Fluid	Pressure Drop(Δp) Pa
1	Al_2O_3	9.25
2	CuO	9.97

Besides the heat transfer coefficient, pressure drop calculations are also important in Determining the feasibility for practical application of nanofluids. The pressure drop Inside the tube depends on Reynolds number, density and viscosity of nanofluids

4. Conclusion:

This numerical study on heat transfer performance of flat tube Heat Exchanger has been conducted by doing the simulation of the flat tube with different sets of boundary conditions. Aluminum oxide and copper oxide have been considered as nanofluids respectively. Aluminum have been selected as a material for flat tube for the heat exchanger. The mass flow rate for nanofluids is taken as 0.15 kg/s respectively. The inlet temperatures of nanofluids are taken as 40 °C, 50°C, 60 °C, and 70°C. Different parameters have been analyzed to measure the heat transfer performance of the heat exchanger. The following outcomes of the investigation have been observed:

- ✓ The thermal conductivity and viscosity of the nanofluid advise increased once the nanoparticles are dispersed in distilled water, and this enhancement grows as particle concentrations rise.
- ✓ The thermal conductivity enhanced significantly with increase in particle concentration and temperature.
- ✓ The density and viscosity increased with increasing the particle concentration, while they both decreased with increase in temperature.
- ✓ The deviation between viscosity of nanofluids and base fluid reduced with increase in temperature.
- ✓ Nusselt No. increases with the increment of Reynold's No.
- ✓ The heat transfer rate increased with increase in fluid inlet temperature, particle concentration and Reynolds number.
- ✓ Thermal conductivity, other factors such as fluid inlet temperature, Reynolds number and air velocity also affect heat transfer coefficient.

The pressure drop increased with increasing the Reynolds number and particle volume concentration, while it slightly decreased with increase in fluid inlet temperature because density and viscosity decrease with increase in temperature.

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