Performance Analysis of Water Based Copper Oxide Nano Fluids in Heat Exchanger with Twisted Insert

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Abstract: A new experimental setup has been designed for conducting experiments in a copper round pipe heat exchanger with inner diameter $d_i=14.5\text{mm}$ and outer diameter $d_o=16\text{mm}$ and length $L=1720\text{ mm}$. By using two copper oxide nano concentrations of 0.1% and 0.3% with water as base fluid, the heat transfer rates have been obtained with helical twisted insert $H/D=5$ in turbulent flow condition. Reynolds number and friction factor with pressure gradient have been evaluated. The heat transfer rates of 0.1% conc. Nano-fluid with insert was found to be 13.77% more when compared to water.

1. Introduction

Nanan et al [1] investigated in their technical paper the heat transfer phenomena effect in pipe with different baffle tabulators as twisted inserts. The influence of geometrical parameter like pitch ratio and dimensionless Reynolds number under turbulent flow are presented. Twisted cross baffles inserts are yielded better performance compared to straight cross baffles. The twisted-baffles, alternate twisted baffles and cross baffles are shown maximum longitudinal vortex flow patterns around the peripheral of the tube core. However, the twisted cross baffles appeared to be more effective and achieved optimum value for longitudinal vortex flow patterns compared to other twisted inserts used. The maximum thermal performance factor (TPF=1.7) was noticed with twisted cross baffles insert.

Ahmet Selim Dalkilic et al [2] has been developed the cost reduction model for liquids combined with TiO$_2$ nano particles mixtures fluid flow in heat exchanger.

K. Yongsiri et al [3] presented in their technical paper the effect of alternate axis of helically twisted tape on heat transfer mechanisms, friction factor and thermal performance factor under turbulent fluid flow condition. It is can be noticed that the tube with alternate axis shown better results compared to axial axis helically twisted tape with 14.1% and 1.9% increase in heat transfer rate and thermal performance factor respectively. The tube with pitch ratio and alternate length give the maximum thermal performance factor found to be 1.35.
Richa Saxena et al [4] presented in their technical paper the effect of temperature (25-75 °C) on density, viscosity, thermal conductivity, and specific heat and 40nm size alumina nanoparticles with base fluid as distilled water.

Laura Colla et al [5] investigated in their research paper the behavior of convective heat transfer mechanism using alumia nanofluids under turbulent fluid flow condition. The k-ε turbulence model have been validated from experimental results with higher volume fraction of the test solutions alumina oxide nano fluids in a circular tube.

Morteza Khoshvaght – Aliabadi and Mehdi Eskandari [6] presented in their research article overall performance enhancement of heat transfer ,pressure drop and specifications of the non uniform twisted-tape inserts with different length of inserts using copper oxide nanofluids with base fluid as water. The Reynolds number under turbulent flow condition in the range Re=7500-15,000 was tested experimentally in a circular tube. With non uniform inserts yielded better efficiency and increase in overall enhancement ratio about 45% compared to uniform inserts. With 0.3% copper oxide nano fluid and low to high non uniform twisted inserts shown a rapid increase in overall performance about 87%.

Amin Ebrahimi and Ehsan Roohi [7] investigated in their research paper the flow lines and heat transfer rates in mini twisted oval tubes external heated under constant heat flux condition. Non-linear optimization has been carefully studied with different geometries of the tube under laminar flow condition with Re=500-1100. Less irreversibility and achievement of synergy and entropy generation between velocity and temperature fields shown better efficiency compared to the smooth straight circular tube.

Emad Sadeghinezhad et al [8] presented in their research article the characteristics of pressure variation and heat transfer mechanism using grapheme nano fluid in a circular tube . The pressure drop increase was yielded between 0.4%-14.6%.

S. Suresh et al [9] presented in their technical paper the thermal phenomena of alumina oxide and copper oxide nano fluids under transition fluid flow in a round duct with helical screw insert. The increase in heat transfer rates with helical screw twist ratios of 1.78, 2.44 and 3.0 was found to be as 156.24%,122.16% and 89.22% respectively for 0.1% alumina oxide nano fluid when compared to straight tube. On other hand, for 0.1% copper oxide nanofluid, the enhancement in heat transfer coefficients with twist ratios of 1.78,2.44 and 3.0 found to be 179.82%,144.29% and 105.63% respectively. At constant pumping power factor which was based on thermal performance with helical screw inserts yielded better thermal efficiency using copper oxide nanofluid compared with alumina oxide nanofluid.
2. Experimental Setup

The experimental set up consists of a tank with 30 litres capacity. The test fluids are circulated through the loop by using a variable feed pump. A copper straight pipe of 14.5mm diameter and 1.7m long is used in our setup. The pipe is heated uniformly by wrapping with two nichrome heaters of 1000W electrical rating. The space between the test section and outer casing is stuffed with rock wool insulation to minimize heat loss to atmosphere. Four K-type thermo couples are embedded on the surface at equal distance of 0.3m between them. Two Pt-100 thermo couples are insert at the inlet and outlet of the pipe to measure temperatures. Experiments are initially conducted with water and checked for consistency of the results. Experiment is repeated with naofluids at different concentrations and heat transfer coefficient is estimated along with friction factor.

Table 1: Properties of Nano Particles

| S.NO. | PROPERTY               | SPECIFICATION               |
|-------|------------------------|-----------------------------|
| 1.    | Purity                 | 99.8%                       |
| 2.    | Color                  | Black-brown nano powder     |
| 3.    | Mean Particle Size     | 25-55nm                     |
| 4.    | Specific Surface Area  | 30-50 m²/gm                 |
| 5.    | Morphology             | Spherical                   |
| 6.    | Bulk Density           | 0.15-0.35 gm/cm³            |
| 7.    | True Density           | 8.94 gm/cm³                 |
| 8.    | Corrosion Prevention   | Partially Passivity         |

Fig 1 Experimental Set Up for Nano Fluids Test Solutions

Table 2 Details of Experimental Setup
| S.NO | DESCRIPTION       | SPECIFICATION                                                                 |
|------|-------------------|-------------------------------------------------------------------------------|
| 1.   | Feed Pump         | 220V, 6Amps, Head=15m, drive =6.0kW, Discharge= 500 L /Hr.                   |
| 2.   | Pipe              | Length L=1.7m, Inner Diameter=14.5mm, Outer Diameter =16.0mm Material used= Copper |
| 3.   | Heating Coil      | Size : length=1500mm, thickness =6.0 mm, Material used= nicrome wire 1000 Watts, 240 Volts |
| 4.   | U- tube Manometer | Density of mercury Hg=13.6 g/cc, graduate scale reading in cm. Material used= Glass. |
| 5.   | Digital Flow meter| Range = 0-2.0 L/min                                                          |
| 6.   | Dimmer stat       | 240 Volts, 10Amps Current, 50-60Hz, 3 phase                                 |
| 7.   | PT-100 Sensor     | Length of sensor=2 inch, length of wire=1.5m                                 |
| 8.   | Chiller           | Temperature range= 4-8° C , pump =0.25 kW                                   |
| 9.   | Digital Temperature Indicator | 0-1000° C                                                                             |

3. Experimental Procedure:

Distilled water of 25 liters is used in steel vessel and copper oxide nano particles were mixed thoroughly and stir it with automatic impeller for half an hour for each experimental run. Connect the thermo couples to the digital temperature indicator. Run the rotary pump so that the fluid flow take place through the heated round pipe at different flow rates after attaining the steady state temperature, readings for inlet, outlet, four inserted thermo couples temperatures, pressure differentials from manometer and time of discharge also were noted for each flow rate maintaining at constant voltage outlet temperature of the test solution, it is drawn to chiller unit, where the nanofluid and base fluid was cooled to desire temperature. Experimental runs were conducted for each concentration of the test solution with insert and without insert and observations were recorded at regular intervals.

4. Data Analysis:

Rate of heat transfer is evaluated using newton’s law as [8, 9]

\[ Q = hA\Delta T \] (1)

Reynolds number

\[ Re = \frac{(4*m)}{(\pi*d*\mu)} \] (2)

Pressure drop across the pipe

\[ \Delta P = \rho* g* \Delta H \] (3)

Friction factor was evaluated using equation (4)

\[ (f) = \frac{\Delta P}{(L/D)*\rho*(V^2/2)} \] (4)

The following relations has been developed using regression analysis with logarithmic model:
water + 0.1% CuO + tr = 5, friction factor obtained as
\[ f = \{0.1851 - 0.012 \ln (Re)\} \quad (5) \]
water + 0.3% CuO = tr = 5, friction factor obtained as
\[ f = \{0.22 - 0.017 \ln (Re)\} \quad (6) \]
The following equations has been developed using power law model:
water + 0.1% CuO + tr = 5, heat transfer coefficient obtained as
\[ h = 85.025 \ Re^{0.1228} \quad (7) \]
water + 0.3% CuO = tr = 5, heat transfer coefficient obtained as
\[ h = 3.5731 \ Re^{0.4532} \quad (8) \]

5. Results & Discussion:

5.1 The Effect of Different Volume Fractions of Nano fluids:

The effect of copper oxide with 0.1% and 0.3% volume fractions on the Reynolds number and friction factor is plotted in Fig 2 & Fig.3. The results show that the variations for friction factor of copper oxide + water nanofluid with twisted ratio equal to 5 decreases with increasing the Reynolds number for both volume concentrations taken for experimental runs. It was also inferred that from the results obtained show that the friction factor is nearly similar for all particle volume fractions and water with small difference among them. It is seen that the friction factor of all cases through circular tube fitted with twisted insert is dependent of Reynolds number obeying the polynomial equation.

It can be inferred from the Fig 4 & Fig.5 with increase volume fraction have peak motion particles in thermal conductivities, in fact it contribute higher rate of heat transfer. For instance, in the case of 0.3% nanofluid volume concentrations, the heat transfer coefficient is found to be 8.23% larger than 0.1% nanofluid volume concentrations at specific Reynolds number for round tube with twisted insert equal to 5 at power input of 1000 Watts per square meter. It is the fact that when the volume fraction shows tendency for heat transfer coefficient also increases for a particular Reynolds number. This is due to the increment of thermal conductivity of nanoparticles and also a large energy exchange process resulting from the chaotic movement of nanoparticle. Friction factor is calculated using equation (4) from experimental data of pressure drop readings taken from manometer observations at different mass flow rates of the test solutions.
Fig 2 Reynolds number vs friction factor for 0.1% copper oxide nano fluid - twisted ratio=5

Fig 3 Reynolds number vs friction factor for 0.3% copper oxide nano fluid - twisted ratio=5
Fig 4 Reynolds number vs heat transfer coefficient for 0.1% copper oxide nano fluid - twisted ratio=5

Fig 5 Reynolds number vs heat transfer coefficient for 0.3% copper oxide nano fluid - twisted ratio=5
Conclusions:

1. The heat transfer rate of 0.1% CuO + water + tr = 5 was found to be 19.81% more when compared to base fluid water for same mass flow rate Fig.4.
2. For 0.3% CuO + water + tr = 5, the heat transfer rate is found to be 24% larger than the base fluid water for same mass flow rate Fig.5.

3. Using regression analysis, the correlation coefficient and root mean square error for 95% confidence level found to be $R^2 = 0.9689$ & RMSE=0.002566 for 0.1% copper oxide + water + tr=5 from Reynolds number & friction factor calculated data. (equation (5)).
4. Using regression analysis, the correlation coefficient and root mean square error for 95% confidence level found to be $R^2 = 0.8557$ & RMSE=0.001103 for 0.3% copper oxide + water + tr=5 from Reynolds number & heat transfer coefficient calculated data. (equation (6)).
5. Using regression analysis, the correlation coefficient and root mean square error for 95% confidence level found to be $R^2 = 0.8364$ & RMSE=0.002566 for 0.1% copper oxide + water + tr=5 from Reynolds number & heat transfer coefficient calculated data. (equation (7)).
6. Using regression analysis, the correlation coefficient and root mean square error for 95% confidence level found to be $R^2 = 0.9496$ & RMSE=0.001103 for 0.3% copper oxide + water + tr=5 from Reynolds number & heat transfer coefficient calculated data. (equation (8)).

Nomenclature:

| Symbol | Description |
|--------|-------------|
| A      | area (m²)   |
| $d_i$  | inner diameter of the pipe =0.0145 (m) |
| $d_o$  | outer diameter of the pipe =0.016 (m) |
| $f$    | dimensionless friction factor (-) |
| $g$    | acceleration due gravity =9.81 (m/sec.$^2$) |
| $\Delta P$ | pressure drop (m) |
| $Q$    | rate of heat transfer ( Watts) |
| $T_1, T_2, T_3, T_4$ | surface temperature of the pipe in (°C) |
| $T_6$  | outlet temperature of the test solution / base fluid (°C) |
| $\mu$  | absolute viscosity of base fluid (N/sec/m²) |
| $\rho$ | density of the base fluid (kgs/m³) |
| $h$    | heat transfer coefficient (W/m².K) |
| $\Delta H$ | height of the manometer differential (m) |
| $I$    | input current (ampere) |
| $m$    | mass flow rate of the test solution /base water (kgs/sec.) |
| $L$    | length of the pipe =1.7 (m) |
| $\Delta T$ | mean surface temperature of the pipe in (°C) |
| $Re$   | Reynolds number |
| $\pi$  | constant used in equation (2) |
| $V$    | input voltage (volts) |
References:

[1].K. Nanan, C. Thianpong, M. Pimsarn, V. Chuwattanakul, S. Eiamsaard, 2017, Flow and Thermal Mechanisms in a Heat Exchanger Tube Inserted with Twisted Cross-Baffle Tabulators, *Applied Thermal Engineering*, 114(3), p18-24.

[2].Ahmet Selim Dalkilic, Ozgen Acikgoz, Muhammed Ali Gumus and Somchai Wongwises, 2017, Determination of Optimum Velocity for Various Nanofluids Flowing in a Double Pipe Heat Exchanger, *Journal Of Heat Transfer Engineering*. 38(1), p11-25.

[3].K. Yongsiri, C. Thianpong, K. Nanan, S. Eiamsaard, 2016, Thermal Performance Enhancement in Tubes Using Helically Twisted Tape with Alternate Axis Inserts, *Thermophysics and Aeromechanics*. 23(1) 69-81.

[4].Richa Saxena, Dasaraju Gangacharyulu and Vijaya Kumar Bulasara, 2016, Heat Transfer and Pressure Drop Characteristics of Dilute Alumina-Water Nanofluids in a Pipe at Different Power Inputs, *Journal Heat Transfer Engineering*. 37(18), p1554-1565.

[5].Laura Colla, Laura Fedele, Oronzio Manca, Lorenzo Marinelli and Sergio Nardini, 2016, Experimental and Numerical Investigation on Forced Convection in Circular Tubes with , Nanofluids, *Journal of Heat Transfer Engineering*. 37(13-14), p1201-1210.

[6].Morteza Khoshvaght-Aliabadi And Mehdi Eskandari, 2015, Influence of Twist Length Variations on Thermal Hydraulic Specifications of Twisted Tape Inserts in Presence of Cu-Water Nanofluid, *Experimental Thermal and Fluid Science*. 61(2), p230-240.

[7].Amin Ebrahimi and Ehsan Roohi, 2015, Numerical Study of Flow Patterns and Heat Transfer in Mini Twisted Oval Tubes, *International Journal of Modern Physics-Computational Physics and Physical Computation*. 26(12) , p18-26.

[8].Emad Sadeghinezhad, Mohammad Mehrali, Sara Tahan Latibari, Mehdi Mehrali, S. N. Kazi, Cheensean Oon and Hendrik Simon Cornelis Metselaar, 2014, Experimental Investigation of Convective Heat Transfer Using Graphene Nanoplatelet based Nanofluids under Turbulent Flow Conditions, *Industrial Engineering Chemistry Research*. 53(31), p12455-12465.

[9].S.Suresh, K.P.Venkitaraj, P.Selvakumar and M.Chandrasekar, 2012, A Comparison of Thermal Characteristics of Al2O3/Water and CuO/Water Nanofluids in Transition Flow through a Straight Circular Duct Fitted with Helical Screw Tape Inserts, *Experimental Thermal and Fluid Science*. 39(5), p37-44.