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AN EXPERIMENTAL AND NUMERICAL INVESTIGATIONS OF HEAT TRANSFER ENHANCEMENT FOR CuO-WATER NANOFLUID IN TURBULENT FLOW CONDITIONS

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ABSTRACT

In this paper, both experimental and numerical studies were performed in a fully developed turbulent region heat transfer of the CuO-water nanofluid in a horizontal 0.019m diameter, 1.5m long copper tube that subjected to a uniform heat flux at its outer surface. An experimental investigation was done to evaluate the heat transfer characteristics, friction factor and the pressure drop of the CuO-water nanofluid are conducted in the particle volume concentration range of $0.01\% < \varphi < 2\%$, and Reynolds number range of $5020 < Re < 19985$. The thermal conductivity, specific heat, density and viscosity of the nanofluids were measured. In numerical study, the finite volume method using Ansys R.15, standard $\kappa - \varepsilon$ turbulence model employed to solve the continuity, momentum, energy and turbulence equations in three-dimensional domains. The experimental and numerical results showing that the data were satisfied within a 1.7% maximum difference. The effects of the nanoparticle concentration with uniform heat flux on the enhancement of the heat transfer turbulent flow condition were presented. The Nusselt number (Nu) of the CuO-water nanofluid case was higher than that the base fluid by approximately 48.7%. However, the increase in the pressure drop ranged is about 18%. Finally, the results reveals that the CuO-water nanofluids could be considered as a good and alternative conventional working fluid in heat transfer applications.

KEYWORDS : nanofluid, convective heat transfer, turbulent flow, distilled water .

دراسة عملية وعددية لتحسين انتقال الحرارة باستخدام مائع نانوي (اوكسيد النحاس-الماء) في ظروف جريان اضطرابي.

محمد وهاب **فائز طعمة**

الخلاصة :

في هذا البحث تم اجراء دراسة عملية وعددية لمنطقة جريان اضطرابي كامل التطور باستخدام مائع نانوي (اوكسيد النحاس-الماء) في انبوب نحاسي افقي بقطر (0.019m) وطول (1.5m) معرض الى فيض حراري منتظم على سطحه الخارجي. اجريت الدراسة العملية لتقييم خصائص انتقال الحرارة، معامل الاحتكاك، وهبوط الضغط للمائع النانوي (اوكسيد النحاس-الماء) ولتركيز جزيئي حجمي بمدى $(0.01\% < \varphi < 2\%)$ و مدى رقم رينولد $(5020 < Re < 19985)$. الموصلية الحراريه، الحرارة النوعية، الكثافة واللزوجه للمائع النانوي تم قياسها عمليا. تم أعتماد التحليل العددي بطريقة الحجم المحدد وبرنامج (Ansys R.15) وبالاستعانة بنموذج الاضطراب القياسي $(\kappa - \varepsilon)$ لحل معادلات الاستمرارية، الزخم، الطاقة والاضطراب في مجال ثلاثي الابعاد. اظهرت النتائج العملية والعددية ان البيانات كانت مرضية وبأختلاف مقداره (1.7%) كحد اقصى. تم دراسة تأثيرات تركيز الجزيئات النانويه تحت تأثير فيض حراري منتظم على تحسين انتقال الحرارة في ظروف الجريان الاضطرابي. كان رقم نسلت (Nu) للمائع النانوي (اوكسيد النحاس-الماء) اعلى منه للمائع الاساسي بمقدار (48.7%) تقريبا. كذلك فأن الزيادة في هبوط الضغط كانت حوالي (18%). واخيرا، اوضحت النتائج انه يمكن اعتماد المائع النانوي (اوكسيد النحاس-الماء) كبديل جيد وملائم للعمل في تطبيقات انتقال الحرارة.

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Nomenclature

A	Surface area of the tube, m^2
C	Specific heat, kJ/kg.K
D	Diameter, m
f	Friction factor
H	Heat transfer coefficient, $W/m^2.K$
I	Current, A
k	Thermal conductivity, W/m.K
L	Length, m
$\dot{m}$	Mass flow rate, kg/s
m	Mass, kg
Nu	Nusselt number
P	Presser, Pa
Pr	Prandtl number
$\dot{q}$	Heat flux, W/m^2
Re	Reynolds number
T	Temperature, c^o
Z	Test section length, m

Abbreviation

ANSYS	Analysis System
CFD	Computational fluid dynamic
CMC	Carboxyl methyl cellulose
CNT	Carbon nanotube
FLUENT	Fluid And Heat Transfer Code
NSE	Navier–Stokes equations

Subscripts

H	heater
in	Inlet
nf	Nanofluid
s	Surface
s_i	Inner surface
s_o	Outer surface
t	Turbulent
V	Vessel
W	Water

Greek letters

φ	volume concentration of nanoparticles
μ	Dynamic viscosity, kg/m.s
υ	Kinematic viscosity, m^2/s
κ	Turbulent kinetic energy, m^2/s^2
ρ	Density, kg/m^3
Δ	Difference between two value

INTRODUCTION :-

A wide variety of thermal engineering processes involves the transfer of heat energy. Thereby, a source for energy recovery during processes of fluid heating or cooling obtained. This issue is therefore of fundamental importance in many branches of engineering. Thus, interested researchers are seeking for new heat transfer enhancement methods between surfaces and the surrounding fluid. The effectiveness of a given augmentation techniques depends largely on the mode of heat transfer, the type of heat exchanger , the properties of fluids, as well as the pressure drop over the given device that creates the enhancement and then the additional power required to cover the increase of the pressure drop. The improvement of such process may create a saving in energy, reduce process time, raises thermal rating, reduces cost and size of the heat transfer equipment, and lengthen their working life. Bergles 1998.Conventional heat transfer fluids have inherently poor thermal conductivity compared to solids, thus the advent of high heat flow processes has created significant demand for new technologies to enhance heat transfer. Modern material technology provides opportunities to produce miniature nanometer sized particles, which are quite different from the parent material in mechanical, thermal, electrical, and optical properties. Thus, the age of nanotechnology is emerged. Nanofluids are a new class of advanced heat transfer fluids engineered by dispersing nanoparticles smaller than 100-nanometer diameter in a conventional heat transfer fluids. A nanofluid is therefore a nanocomposite where the matrix is a liquid or as a colloid where the suspensions consist of nanoparticles. Sarit K et al.2008. Many researchers using different types of nanofluids have conducted a more extensive work in this respect Wen D., Ding Y 2004, presented for, the first, time the heat transfer, and flow characteristics, of nanofluid consisting, of water, and TiO_2 nanoparticles, at 0.2% volume concentration, in a double-tube, heat exchanger. Their results, showed that the convective, heat transfer, coefficient of nanofluid, was only, slightly higher, than that of the base, liquid by, about (6–11%) and had, a little penalty, in pressure, drop. The reasons, for this enhancement, were attributed, to (i) the nanofluid with, suspended, nanoparticles, increased, the thermal conductivity, of the mixture,, and (ii) a large energy exchange, process resulted, from the chaotic, movement of, nanoparticles. Anoop et al. 2009, conducted convective heat, transfer experiments, using Al_2O_3/water, nanofluids in the, developing, region of pipe, flow with, a constant heat, flux to evaluate the effect, of particle size, on the convective, heat transfer coefficient. In their work, two particle sizes (45 nm and 150 nm) were, used, and it was, observed that the, nanofluid with, 45 nm particles, showed, higher heat, transfer coefficient, than that with, 150 nm, particles. They, concluded that the, observed increase, in convective, heat transfer with nanofluids, is due to some effects, beyond, the increase, in thermal conductivity like, particle migration effects, and thermal dispersion. Yu W et al. 2009, the heat transfer rates were, measured, in the turbulent flow of SiC/water nanofluid consisting of a volume, concentration of 3.7% with 170 nm silicon, carbide particles. Heat transfer, coefficient, increase of 50–60% above the base, fluid water obtained when compared the basis of constant Reynolds number. Heat transfer mechanisms that involve particle interactions, are believed for, heat transfer, enhancement. Sommers & Yerkes 2010, The thermal–hydraulic performances, of dilute suspensions, of 10 nm, aluminum, oxide nanoparticles, in propanol are recently, explored there, results revealed, that the observed, augmentation, in heat transfer was and enhanced thermal physical properties, of the Al_2O_3,/propanol nanofluid and not, due to mechanisms, like, Brownian, motion induced, nanoconvection, liquid, layering, or other interfacial, effects. Two different, mechanisms, have been proposed, to explain, this enhancement. The first, it is, believed that, the addition of the nanoparticles, may have actually, served to precipitate, an earlier transition from, laminar to turbulent, flow, which would, mean, higher Nusselt numbers. The second, mechanism in which, explain, the enhancement, lies with, the rheology of the, fluid. Because, the nanofluid is shear thinning, and the shear rate, is highest near, the wall, better, fluid flow performance should, be realized near the, wall. Thus, the, non-uniform distribution, of the viscosity, field across the, tube cross, section (and/or the Possibility of a reduced, boundary layer,) might, also, explain this, enhancement. For copper oxide nanofluid (CuO/water) effects on the convective heat transfer Fotukian and Esfahany 2010,Turbulent convective, heat transfer, performance, and pressure, drop of very, dilute (less than 0.24% volume) CuO,/water nanofluid, flowing through a circular, tube were investigated, experimentally. The increase, in heat transfer, coefficient, was observed, to be on an average, of 25% with 20% penalty, in pressure, drop. The augmentation of heat, transfer coefficient, was not, attributed, to the increase, of thermal conductivity, but due to the augmented, thermal, energy transfer from the wall, to the nanofluid, flowing, in the tube, with the presence of nanoparticles. It was proposed, that the nanoparticles, hit the wall, and absorb, thermal energy, lowering, the wall temperature,, and mix, back with the bulk, of the fluid resulting, in enhanced thermal, performance. Aluminum oxide nanofluid (Al_2O_3) effects on heat transfer M.M Heyhat & F. Kowsary 2012, In this research, the convective heat, transfer and friction, factor of the nanofluids, in a circular tube, with constant wall, temperature under, turbulent flow Al_2O_3 nanoparticles with diameters, of 40 nm dispersed, in distilled water, with volume concentrations, of 0.1–2 vol. % were used as the, test, fluid. All physical properties of the Al_2O_3–water, nanofluids needed, to calculate, the pressure, drop, and, the convective heat, transfer coefficient, were measured. Results, showed that, the heat transfer, coefficient, of nanofluid is higher, than that of the base, fluid and increased, with increasing, the particle concentrations. Moreover, the Reynolds, number has a little, effect on heat transfer enhancement. The experimental, data were compared, with traditional, convective, heat transfer and viscous, pressure, drop correlations for fully developed, turbulent flow. It was found, that if the measured, thermal, conductivities and viscosities, of the nanofluids, were used in calculating, the Reynolds, Prandtl, and Nusselt, numbers, the existing correlations perfectly, predict the convective, heat transfer, and viscous pressure, drop in tubes. Jianli Wanga et al. 2013, investigated, experimentally, the heat transfer and pressure; drop of nanofluids, containing carbon, nanotubes in a horizontal, circular tube with Reynolds, number range, (30-200). A considerable, enhancement in the average, convective heat, transfer was observed compared, with the distilled water. For the nanofluids, with volumetric, concentration, of 0.05% and 0.24%, the heat, transfer enhancement, were 70% and 190% at Reynolds, number of about 120 respectively, while the enhancement, of thermal conductivity, was less than 10%, therefore, the large, heat transfer increase, cannot be solely, attributed to the enhanced, thermal conductivity. By measuring, the pump, power supply and the thermal, conductance, of the test tube, results suggest that the nanofluids at low concentration enhance, the heat transfer, with little extra penalty, in pump power thus it have, great potential, for applications, in the heat transfer systems. Rabienataj Darzi et al. 2013, numerically, investigated turbulent, heat transfer, in heated helically, corrugated tube for, pure water, and water–alumina nanofluid, using two-phase approach. The study was carried out for different corrugating, pitch and height ratios, at various, Reynolds, numbers ranging from 10,000 to 40,000. The effect, of nano-particles in heat, transfer augmentation, for smooth tube and helically, corrugation, tubes was discussed, and their relative Nusselt, number was compared. Results, show that the heat, transfer enhancement is promoted, extremely by increasing, the volume fraction, of nano-particles. In addition, adding 2% and, 4% nano-particles, by volume, to water enhances the heat transfer by 21% and 58%, respectively. In addition, the overall, enhancement, in heat transfer, using two mechanisms, simultaneously, compared to using pure, fluid within, smooth tube exceeds, over 330%. Results indicate that using nanoparticles, yields different, enhancement, in heat transfer of tube for different corrugation height and pitch.

METHODS AND MATERIALS :-

The main objective of this work is to develop a numerical & experimental investigation tool for the analysis of the flow and the heat transfer characteristics of [(distilled water) & nanofluid (CuO - distilled water)], in a horizontal circular tube under fully developed turbulent flow and uniform heat flux condition. Numerical and experimental approaches were the working methods of this project.

Mathematical Model and Numerical Approach

Basic Governing Equations

The single-phase conservation, equations for continuity, momentum, and energy, equations and the turbulent, model are used (Ansys Fluent, Version 15, Ansys) 2013, under the following assumptions:
Steady state, Incompressible fluid, Newtonian fluid, turbulent, Three-dimensional. were presented

Conservation of Mass (Continuity)

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \qquad (1)$$

Momentum Equation

$$\frac{\partial(\rho u u)}{\partial x}+\frac{\partial(\rho v u)}{\partial y}+\frac{\partial(\rho w u)}{\partial z}=-\frac{\partial p}{\partial x}+\mu\left[\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right] \qquad (2)$$

Energy Equation

$$\nabla.\left(\overline{V}(\rho E)\right)=\nabla(k\nabla T-\rho C\vec{V}T) \qquad (3)$$

Numerical Approach

The simulation of the system performance carried out as presented in the following mathematical model:

The heat flux on the tube outer surface given by:

$$Q_{heater}=power\ of\ heater \qquad (4)$$

The amount of the heat transferred from the heating wire to the nanofluid given by:

$$Q_{fluid}=\dot{m}_{nano}\,C_{nano}\,(T_{out}-T_{in}) \qquad (5)$$

Workbench, scheme with spacing interval, size (0.0006) chosen, as shown in figure, (1). The Workbench, grid generator has, approximately between (4 – 4.2) million computational, cells for different cases. The inlet and outlet temperature of the nanofluid (T_{in}, T_{out}) at the test section, are shown in figure (2)

The heat flux in figure (2) given by:

$$\dot{q}=\frac{Q_{fluid}}{A_s}=\frac{Q_{fluid}}{\pi D z} \qquad (6)$$

The local heat transfer coefficient calculated as follows:

1. Starting from the known values { $\dot{q}$, Tso(z) }
2. Using the conduction equation in the cylinder to calculate { Tsi(z) }, Holman J. P., 2010:

$$\dot{q}=\frac{Q_{fluid}}{A_s}=\frac{2\pi k\Delta z\,[T_{so}(Z)-T_{si}(Z)]}{\pi DZ\ x\ \ln[r_o/r_i]}=\frac{2k\,[T_{so}(Z)-T_{si}(Z)]}{D\ x\ \ln[r_o/r_i]} \qquad (7)$$

3. Also, from the energy balance in the tube, the mean temperature of nanofluid can be expressed by, Holman J. P., 2010:

$$T_{O\,(Z+\Delta Z)}=T_{in\,(Z)}-\frac{\dot{q}\times\pi DZ}{\dot{m}_{nf}\times c_{nf}} \qquad (8)$$

Thus, the local heat transfer coefficient becomes

$$h_{(z)}=\frac{\dot{q}}{T_{si(Z)}-T_{(Z)}} \qquad (9)$$

$$Nu_{(z)}=\frac{h_{(z)}D}{K_{nf}} \qquad (10)$$

$$Pr=\frac{\mu_{nf}\times C_{nf}}{k_{nf}} \qquad (11)$$

$$Re=\frac{\rho_{nf}\,v\,D}{\mu_{nf}} \qquad (12)$$

4. The model used in the present work was Realizable κ–ε (RKE) model. Shih T., et. al. 1995.

The theoretical analysis with ANSYS FLUENT workbench R.15 Design modeler software to predict the effects of Reynolds number, nanofluid concentration, Nusselt number, velocity profile, and friction factor on the nanofluid heat transfer enhancement. Based on the practical measured pressure drop the friction factor can be evaluated using Darcy equation, which is a theoretical representation to predict the frictional energy loss in a pipe based on the velocity of the fluid and the resistance due to friction and it is expressed as Frank M. White, 2001.

$$f = \left(\frac{2l}{\rho\, V^2\, D}\right)\Delta P \qquad (13)$$

Experimental work

Work conducted experimentally in the University of Kerbala mechanical engineering Department Laboratory, and the test rig designed according to the test requirement. Parts and arrangement of equipment are presented in figures (3 and 4).Experimental work conducted through a closed cycle nanofluid flow system. The circulation of the already prepared nanofluid starts from the nanofluid tank using centrifugal pump. The flow rate is monitored through a U-tube manometer and adjusted by a control valve before entering the testing region. The test tube is a (2.5 m) long (1.9 cm) diameter copper pipe, the first (1 m) of which is used as hydrodynamic fully developing flow section, while the remaining (1.5 m) is the thermal heat transfer section. Exiting of the tested fluid directed to a spiral water-cooled heat exchanger to maintain a steady low temperature (30 °C) nanofluid for the next cycle, thereby consistent data recording ensured. The thermal test tube section is shown in Fig.5 where the tube outer surface is electrically heated by a tungsten coil connected to an AC power supply to generate heat flux, it is (10 m) long and (4 mm) width with (1000 W) heating power, winded over an electric insulator on the tube to generate the uniform heat flux. Protection Aluminum foil is used between the electric heater and rock wool type insulation. The electrical circuit of the heating element consists of Variac transformer to adjust the heater input power as required, a digital Multimeter to measure the power consumed by the heater, and a digital clamp meter and voltmeter for measuring the heater voltage and current. Spiral tube heat exchanger was fabricated from a spiral copper tube coil of (15 m) long and (1.9 cm) diameter and used to cool the hot fluid coming from the test section to make sure that cycle overheating does not occur, and thereby, temperature control can be maintained. The coil placed in a galvanized steel tank (50 cm) diameter and (100 cm) height, filled with recirculation tab water, as shown in Figure (6). Ten (k–types) thermocouples used to measure the temperatures at different locations along the outer surface of the test tube section, spaced (13.6 cm) apart. In addition, two other thermocouples immersed in the flow to measure the inlet and outlet temperatures of the fluid in the test section. All thermocouples connected to Temperature Recorder system to record the thermocouples readings and display to personal computer directly. An interface system used to convert the thermocouples reading to temperature and record it directly to the PC. Central Organization calibrated all thermocouples, thermometer and digital multimeter for Standards and Quality Control (COSQC). The flow meter, however, calibrated by simple timing of a fluid filling a specified tank volume.

Preparations of Nanofluids.

Preparation of nanofluid is the first key step in applying nanophase particles to change the heat transfer performance of conventional fluids. In order to get stable, durable suspension, with low agglomeration of particles, a two – step method was selected to prepare the nanofluids Raghu Gowda, et. al. 2010.

1. The first step is that the nanoparticles and the distilled water mixed directly.
2. The second step is the use of ultrasonic vibrato for preparation of mixed aqueous nanosuspensions.

The concentrations used in the experiments are (φ =0.01, 0.05, 0.1, 0.5, 1, 2) % by volume. Noting that the volume of water used in the test rig is (17 LT),
The volume concentration evaluated from the following relation in percentage

$$\varphi = \frac{\text{Volume of Nanopartical}}{\text{Volume of Nanopartical} + \text{Volume of water}} \times 100 \quad (14)$$

$$\varphi = \frac{(m/\rho)_{nano}}{(m/\rho)_{nano} + (m/\rho)_{base}} \times 100 \quad (15)$$

The Copper Oxide Nanoparticle (CuO, 99%, 40nm) provided from (Skyspring Nanomaterials, Inc. USA) with the properties shown in table (1):

Measurement of Nanofluid Properties

The properties of the nanofluid for each concentration measured as follows:

1) Viscosity – using digital viscometer
2) Specific heat - The apparatus used for measurement of the specific heat consists of a (10 lit) steel vessel isolated from the outside by air gap, with electric mixer and a thermometer as shown in Fig.7. The specific heat can be calculated on two stages, Energy balance in the first stage can be written as:

3) $Q_H = Q_V + Q_W$ (16)
4) Energy balance in the second stage takes the following form:
5) $Q_H = Q_V + Q_{nano}$ (17)
6) $Q_H = [m_V\ C_V\ \Delta T] + [m_{nano}\ C_{nano}\ \Delta T]$ (18)
7) $Q_H = Volt \times current \times time$
8) m_V = 0.5 kg
9) C_V = 0.46 kJ/kg.K

m_{nano} = equivalent to 3 litters

(10)Density measured by a simple method of weighing a sample volume of (500 ml) with different concentrations, and dividing the values of weight by volume. The results of these measurements listed in table (2):

Experiments and testing conditions

The initial test carried with distilled water for validating test rig performance. After completion of construction and calibration of the flow loop, initial tests run for the plane tube with all types of the nanofluids used for the whole range of Reynolds number. The experiments includes the study of Copper Oxide (CuO distilled water) with concentrations (φ = 0.01, 0.05, 0.1, 0.5, 1, 2) % by volume together with plain tube are also used. All the tests were carried out under fully developed turbulent flow with Reynolds number range (5020- 19985), flow rate (4, 6, 8, 10, 12, 14, 16 l/min) and uniform heat flux range (9000 - 9480W/m^2).

RESULTS AND DISCUSSION :-

1. Generally, heat exchangers designed for Reynold's numbers above 5000, thus having fully developed turbulent flow, and therefore better overall convectional heat transfer coefficient can be maintained. Theoretically as starting point, Nusselt number for distilled water evaluated by using the well-known Dittus-Boelter equation:

$$N_u = m(Re)^{0.8}\,(Pr)^n \qquad \text{…. (19)}$$

The values of the coefficients (m & n) for heating process are (0.243 & 0.4) respectively, and the equation is valid for$(0.7 \le Pr \le 300)$. The results show the expected trends of Nusselt number variation with Reynold number. This presented in Fig.8 and Fig.9.

2. Compared to the existing techniques for enhancing heat transfer, the nanofluids show superior potential of increasing heat transfer rates. Nanofluid heat transfer is higher compared to water and increases with volume concentration. Correlations developed based on the experimental data were useful for the estimation of Nusselt number and friction factor of water and nanofluid for flow in a tube.

3. Figure(10) demonstrated the effects of varying Reynold numbers on Nusselt number for various CuO nanofluid concentrations, which is further improved with concentration increase. This is obvious; since it was shown during nanofluid properties measurement that specific heat is improved with concentration, and thus increases the heat absorption capabilities.

4. Furthermore, Reynold – Nusselt numbers correlation is shown in Figure(11) on a comparative basis between 2% concentration nanofluid and distilled water, by which the preference of nanofluid is well demonstration in this respect.

5. Such improvement, however, has its consequences, where pressure drop increases with Reynold number as shown if Figure(12), which increases power needed to satisfy the flow requirement. As a trade-off, such extra power cost is paid off by the improved heat transfer rate. Figure(12) is presented as a sample results for (φ =2%) concentration.

6. On the other hand, friction factor reaches steady value despite the increase of Reynold number as shown in Figure(13) which implies that such loses are irrelevant in this respect.

7. The concepts of this work have been further consolidated by the close agreement between the experimental and numerical results, for both nanofluid and distilled water heat transfer media. This is presented clearly in Figure(14).

8. The temperature contour is a graphical representation of data where the individual values contained in a matrix represented as colors. Such techniques utilized in this work to represent the variation of local temperature in the test section in the form of changes between colors. The direction of heat transfer is set from cold (blue) to hot (yellow) regions. This is clearly demonstrated in Figures(15and 16).

CONCLUSIONS :-

1. A preparation method of nanofuid has been developed using ultrasonic vibrator for direct mixing of nanophase powders and base fluids. Several stable, durable suspension, with low agglomeration sampled particles with (φ =0.01, 0.05, 0.1, 0.5, 1, 2) % by volume concentrations have been prepared.
2. The nanofluid shows great potential in enhancing the heat transfer process, where the suspended ultrafine particles had remarkably improved the thermal conductivity in comparison with plane distilled water. Similar effects of the volume fraction observed.
3. The higher concentration of nanofluid enhances heat transfer compared with the base fluid (distilled water) which is a generally accepted fact in respect to nanofluid behavior.
4. The results shows (φ=2%) gives higher heat transfer enhancement among the studied concentration.at Re 19985
5. The nanofluid CuO– distilled water) shows 48.7 % heat transfer enhancement. Compared with plain distilled water.
6. The temperature contours gave an attractive presentation on temperature variation with various operating variables in terms of color spectrum.
7. Close experimental and numerical results obtained and thereby trustable results assumed.

Table. 1. Properties of Nanoparticle Copper Oxide

CuO (40 nm) – distilled water						
Concentration (vol %)	0.01	0.05	0.1	0.5	1	2
Viscosity x 10^{-3} (N.s/m^2)	0.9994	1.1	1.002	1.0065	1.023	1.0975
Specific heat kJ/kg K	4180	4172.2	4158	4068.03	3970.2	3758.54
Density (kg/m^3)	996.4	998.2	1002.3	1024.5	1051.2	1107.4

Table. 2: Properties of Nanofluid Copper Oxide

Property at (25 °C)		CuO mean diameter (40nm)
Specific Heat	C (kJ/kg K)	535.6
Density	ρ (Kg/m3)	6400
Thermal Conductivity	k (W/m K)	76.5

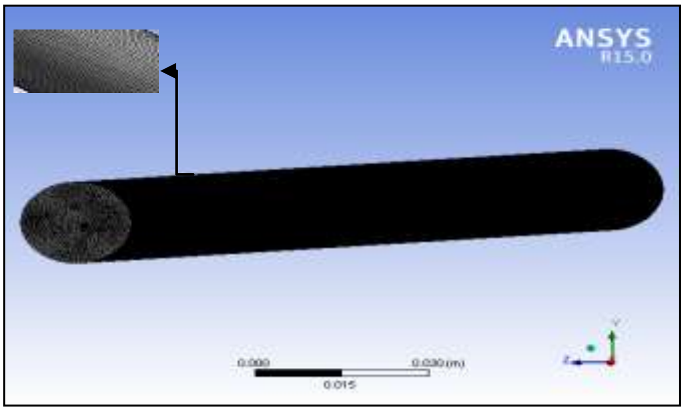

Fig.(1) Mesh Generation Hexahedron Cells

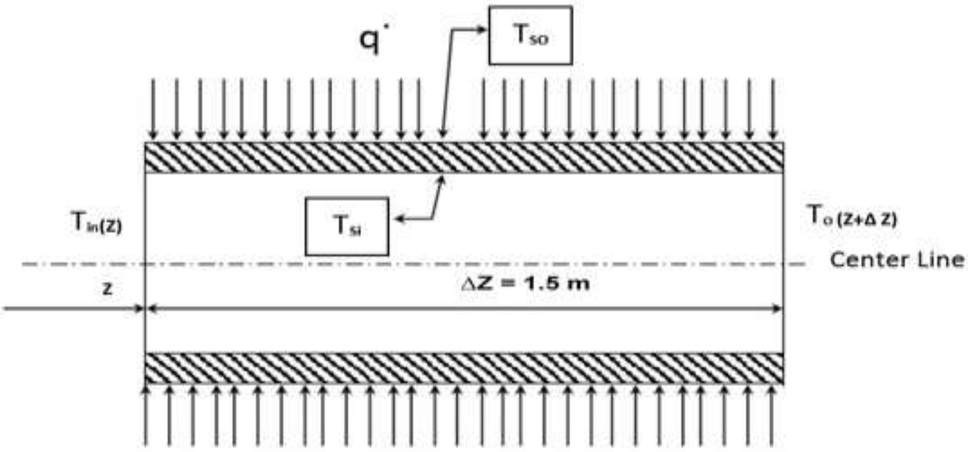

Fig. 2 Section of the pipe of length Δz and at distance (z).

Fig. 3 Photograph of experimental test rig

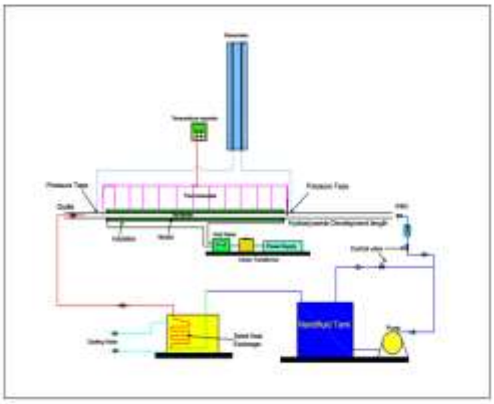

Fig. 4 Schematic diagram of experimental test rig

1-Tube section, 2-Spiral heat exchanger, 3-Nanofluid tank, 4-Centrifugal Pump, 5-Control valve, 6-Variac transformer, 7-U-tube manometer, 8-Thermocouples, 9-Temperature recorder, 10-Flow meter, 11-Clamp meter, 12-PCdata recorder

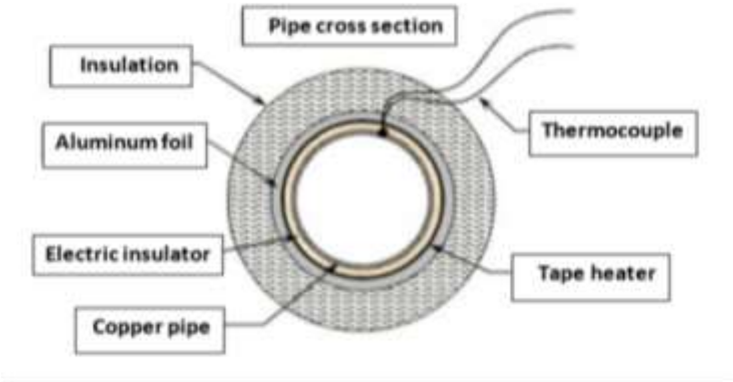

Fig. 5: Schematic diagram of the Test section

Fig. 6: Spiral heat exchanger

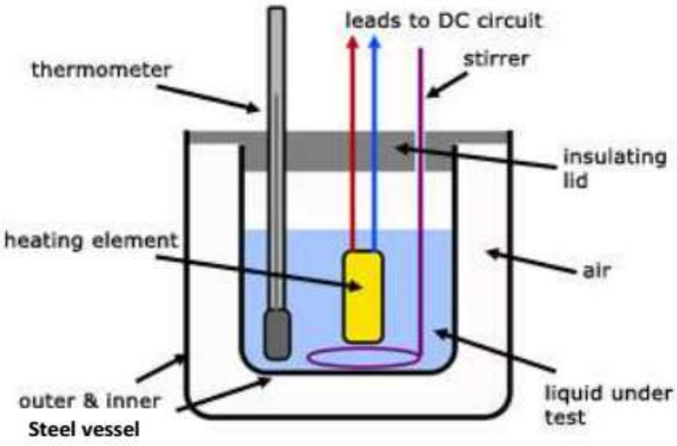

Fig. 7: Specific Heat Apparatus (ESD – 201)

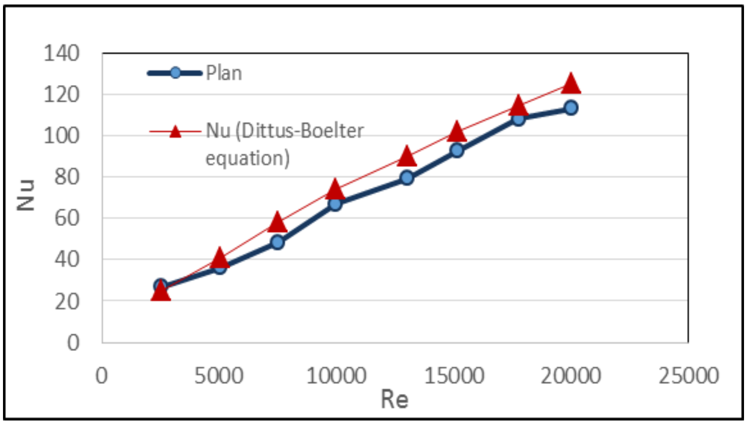

Fig .8: Effect of (Re) on (Nu) for distilled water with Dittus-Boelter equation

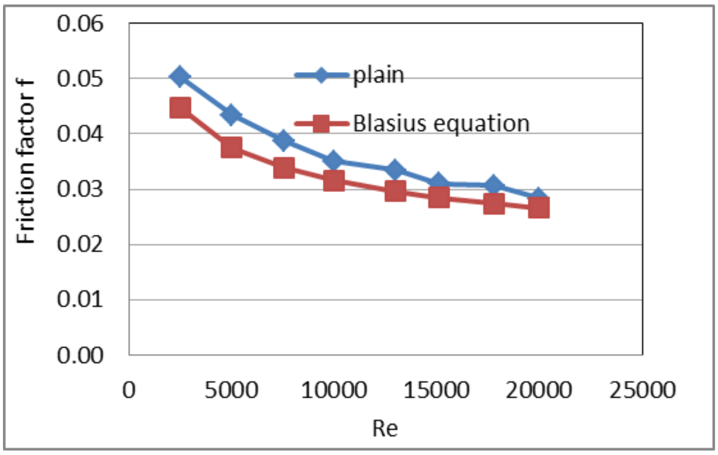

Fig. 9: The effect of Reynolds number on friction factor for distilled water using Blasuis correlation.

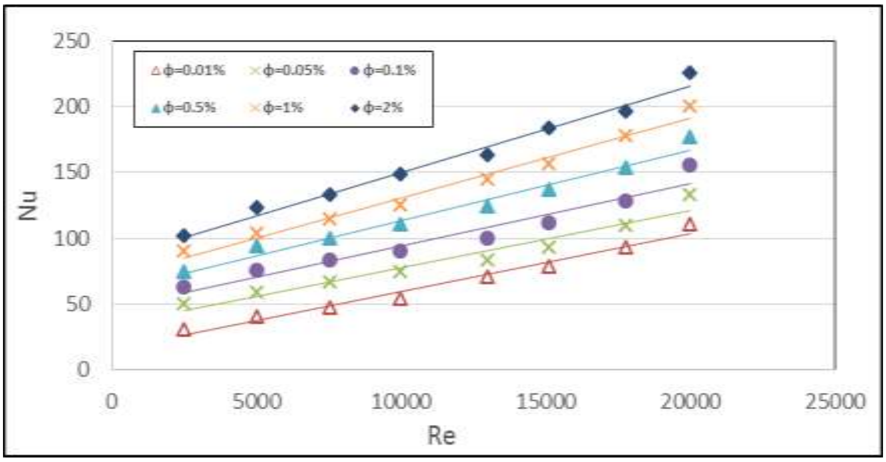

Fig. 10: The Effect of Reynolds Number on Nusselt Number for CuO Nanofluid for different concentrations in a plain tube

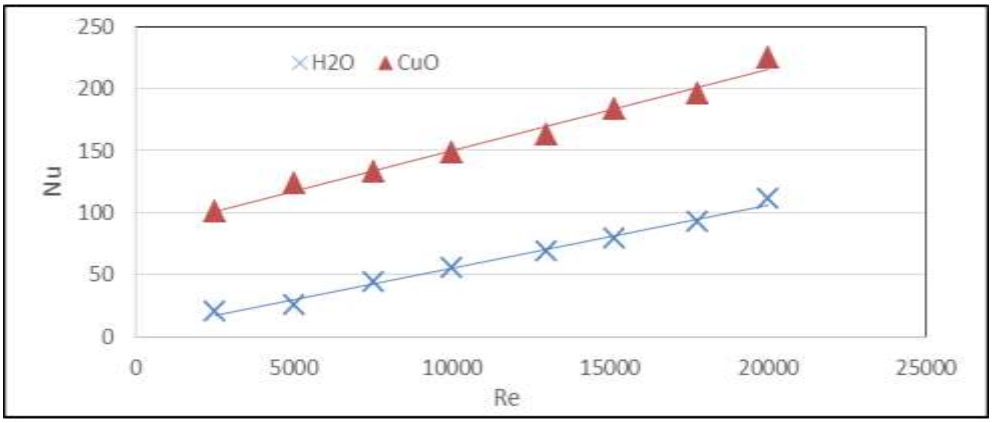

Fig.11: the effect of Reynolds Number on Nusselt Number for concentrations (φ = 2%) in a plain tube

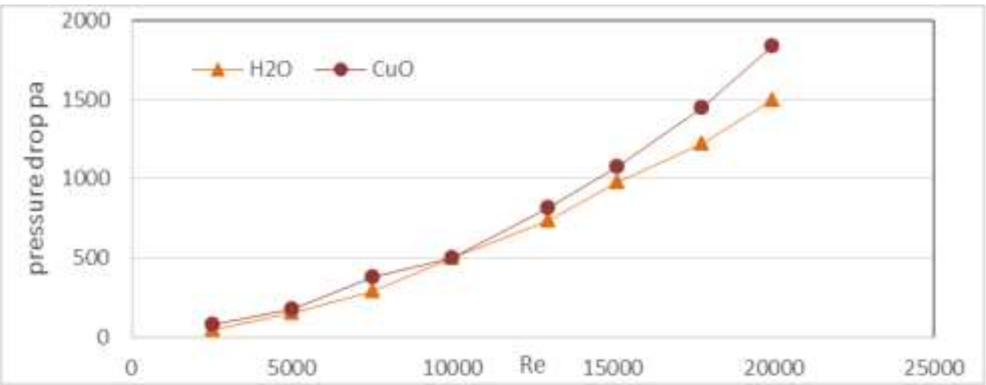

Fig.12: the effect of Reynolds Number on ΔP with constant concentrations (φ =2%) in a plain tube

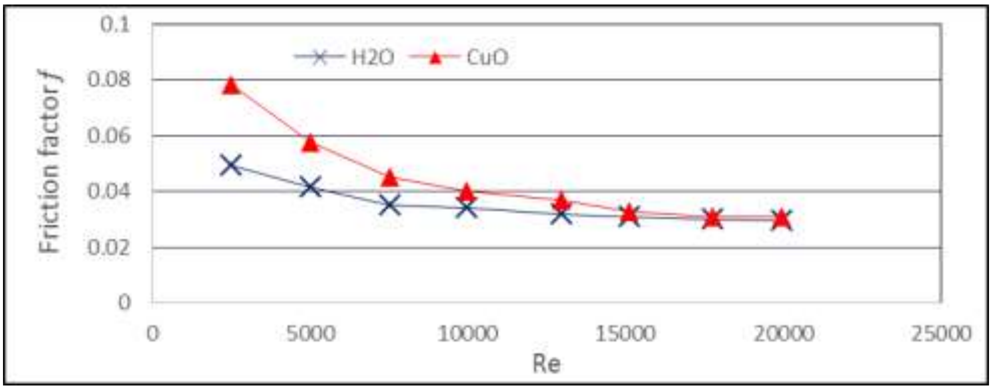

Fig.13: the effect of Reynolds number on friction factor with constant concentrations (φ =2%) in a plain tube

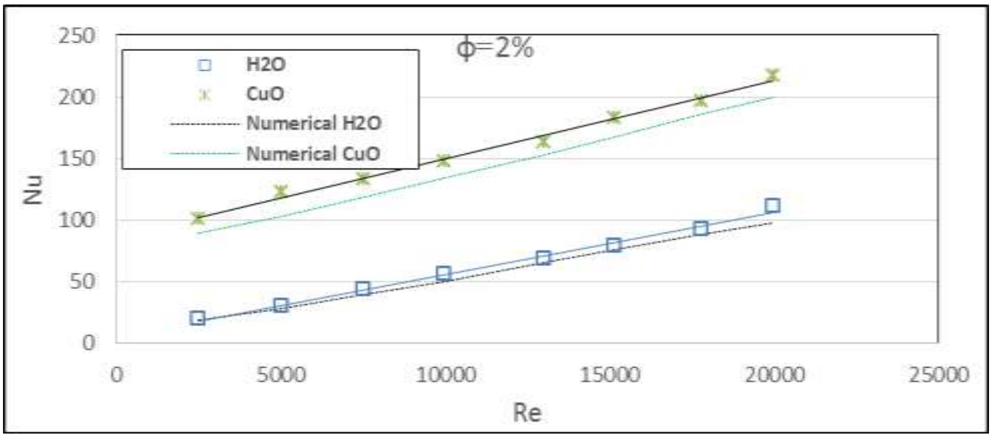

Fig.14: Comparison of numerical and experimental results for distilled water and CuO with concentrations (φ = 2%)

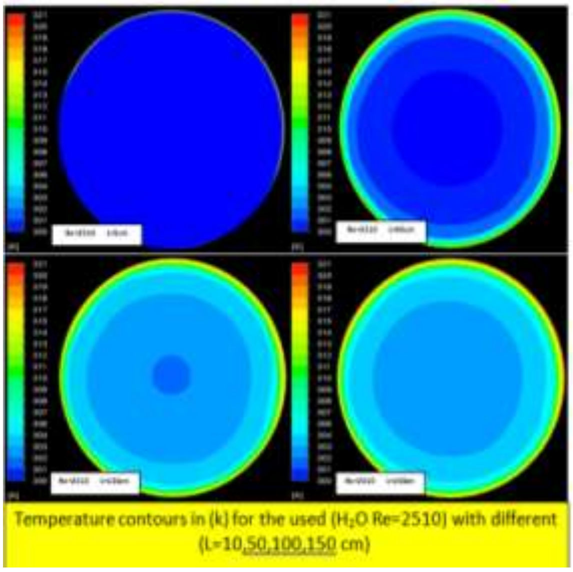

Fig.15: Temperature contours for water (Re = 2510) and (L = 10, 50, 100, 150 cm)

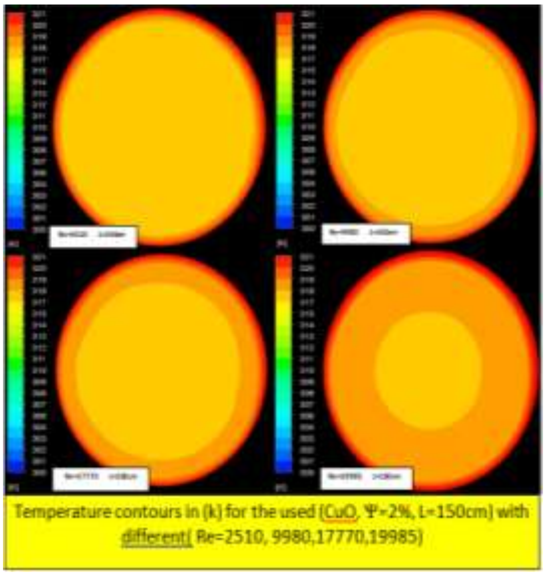

Fig.16: Temperature contours for CuO & (φ = 2%) and (L = 10, 50, 100, 150 cm)

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