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バージョン：

Comparative Experimental and CFD Analysis of Fluid Flow Attributes in Mini Channel with Hybrid CuO+ZnO+H_2O Nano Fluid and (H_2O) Base Fluid

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Abstract: Comparative study is carried out between nano fluid (nf) CuO+ZnO+H_2O and water (H_2O) as solitary fluid through experimental and simulation result. The outcome of nano fluid and solo H_2O flowing inside rectangular strip mini channel with or without mini insert were admit, for study the conduct of fluid flow and heat-exchange features like Nusselt number (Nu), Friction factor (f), Effectiveness (Ɛ), Coefficient of thermal transfer (h), Heat transfer factor (Q), Nu/Nus, f/fs, thermal-performance factor (TPF), Number of transferring unit (NTU) and Reynolds's number (Re). During composing of nano fluid 0.01% volume fraction, 10-20 nm size nano particles were mixed with 0.5ml CTAB surfactant. Experimentation was managed for different operating parameters under counter flow conditions, where nano fluid is flowing inside mini channel of 2 mm diameter with flow rate 0.0001562 kg/sec (9.37 ml/min) to 0.006255 kg/sec (375.30 ml/min) and hot water is flowing inside the concentric tube of 3cm diameter with flow rate of 0.000782 kg/sec (46.92 ml/min). The operating temperature of nano fluid and hot water were 303K and 323K. As per obtained results, the proposed composition of nanofluid showed better performance than normal water due to better thermal conductivity and extra molecular area gain in nanofluid due to addition of nano particle with base fluid, Thus, it improved the results 18%-21% approximately. Whereas better optimum results were observed in case of rectangular mini channel with mini insert compared with other geometry because of rich turbulency gain and extra exposed area due to mini insert. It affects optimum results in terms of better performance up to 9%-15% compared with simple micro channel without inserts.

Keywords: Mini channel, Rectangular strip mini insert, Nano-fluid, Thermal Behavior, Surfactant

1. Introduction

The thermal conductivity of the thermal devices can be improved by upgrading heat transfer, the terminologies which are available are divided into two passive and active technique[1)], by using the diverse nano particles[1)] with different fluids. Nanofluids have exemplary chemical-physical, attributes[1)]. These properties are crucial and helpful to enhance the efficiency and Ɛ in various other applications.

Before introducing nano fluid to improve performance of the thermal devices, it is necessary to analyse the geometrical parameters. In geometrical domain some investigation has been done to perform thermal or heat transfer analysis on various exchangers elements and parameters like analysis on diverse absorber plate shape[2, 3, 4, 5)], specifically HVAC duct[6)], Ventilators[7)], flat surfaces[8)] and tubes of different shape and size in solar air heater and collectors[2, 3, 4, 5)], effect of perforation, shape and size of tapered hollow conical rings[9)], analysis the effect of helical coil, plain tubes, bundle of tubes with or without roughness in shell-tube type heat exchanger[10, 11, 12, 13)], micro-channel[14, 15, 16, 17)], mini channels[18, 19)], analysis of number/location of fins in LED [20)] with diverse fluids like air, water and nano fluid, [20, 21, 22)], nano-lubricant, bio—lubricants, bio-oils[61)], green bio-glycol nano fluid[23, 24, 25, 26, 60)], nano-fluidic or refrigerant[27, 28)]. Some researchers performed work on thermal storage with diverse material characterized as sensible materials under packed bed related to thermal storage like clay, dry clay, nylon 6 etc. [29, 30, 31, 32, 33, 34, 35, 36)] as per new trend some performed worked on phase change material (PCM) and composite PCM[33, 34)] which is coated with different material for diverse application like thermal management of batteries[34]. Many researches performed work on diverse type of nano fluid made of different nano particle like Al_2O_3-CuO, CuO-ZnO, Al_2O_3-ZnO, CuO-ZnO, Al_2O_3-SiO_2, TiO_2-SiO_2 with water as base fluid known as hybrid nano fluid[35, 36] for improvement of electric discharge, hydraulic performance and thermal management of fuel cell.

A lot of work has been done by investigator in past on spiral tube, nano fluids, still there is a huge scope in this area because invention of new advance particles and its involvement in new applications are increasing day by day. Some investigators performed work on particle-laden fluids (PLF) in spiral tube for thermal enhancement[37]. Some researches investigate the effect for screw pitch & nano particle mass fraction with spiral tube. The result predicted that the Nu increases when screw pitch decrease & nano particle mass fraction increase. Screw pitch S=10cm achieved smallest heat transfer but it can be improve by 49.8%-62.0% with spiral tube rotation angle ß = 45° & ß = 90° [38]. Some study focused on the effect of nano particle size on the heat transfer & pressure drop properties for the laminar forced convection in micro channel treat to constant flux. The maximum difference between heat transfer & f is of 11% & 20% was observed between particle size 20-200nm for the particle concentration of 2%. Proposed papers analyse the behaviour of convective heat transfer and thermal conductivity of nano fluids (CuO-water, CuO-EG) (Al_2O_3-water, TiO_2-water) and (TiO_2-water, CuO/EG) in laminar and turbulent flow and it was clearly reported that the thermal conductivity rises with concentration of nano particles and rise in temperature [39, 10]. Recently research focused on wide range of heat exchangers of best thermal conductive materials having different shape and size of tube, channels with or without inserts, fins, baffles etc for enhancing the performance rate and life span of the different equipment's. These hybrid techniques with diverse fluid like nano fluid or nano emulsion are used in various engineering applications for better heat transfer between two or more fluids for thermal storage, cooling and heating process. Some researchers investigated the parametric behaviour of geometrical and hybrid fluid domain. Increasing the concentration of nano particle with smaller particle size in the base fluid improves the Q[40].

Nano particles have exemplary chemical-physical, fluid flow, heat passage, electric, hydraulic & thermal performance and versatile attributes due to which many researchers have keen interest to develop new materials like coated nano particle Fe_2O_3 coated TiO_2[41], Ti^{+4} coated $Al(OH)^3$-MWCNT[42] , Fe_2O_3 coated SiC[59] etc., for making diverse fluid or composite PCM like hybrid nano fluid, tri-hybrid nano fluid[47], PLF etc., through diver technique as per requirements application like thermal management of fuel cell or battery, encapsulation of nanofluid in medical science for treatments[43]. There are wide range of area in which investigators performing investigation, improving different performance level of materials and fluid like, photo-catalytic performance[41], analyzing dye-fragmentation of coated nano particle fluids[42], developing encapsulation method for medical treatments[43] and performance enhancement of pool boiling through heat recovery incinerator and waste water[44]. But still in some areas research is lagging due to stability aspect. Stability of nano fluid play important role for long term performance. Many researchers find some way to deal with it through two techniques first one ultrasonication, second chemical mixing i.e. using surfactants. Both techniques improve the stability problem of nano fluid upto some extent. Higher the time interval of ultrasonication higher will be the stability same as utilization of optimized amount of surfactant leads to better stability[45, 46, 47].

Some researchers performed work on H_2O, titanium di-oxide, beryllium oxide, zinc oxide and copper oxide as nano fluids in different medium, the analysis of heat transfer is bring out for the different Reynolds number ranging from 1000 to 10,000, for all such cases, if the value of Nusselt number rises then the value of Reynolds number also rises, different geometry of the heat exchanger helps in better fluid mixing with the decrement in friction factor and increment in Reynold number and different thermal performance obtained 1.8799 (TiO2), 1.795(BeO) 1.798 (ZnO), 1.601 (CuO) in laminar flow[49]. Study was managed to inspect the outcome of transfer of thermal energy (Nu), friction factor (f) and hot improvement symptom (X) of (CTT) and (COTT) aqua being base liquid. (Re) number differing 7200 and 32400 as twist ratio gets low the value of (Nu), (f), increases, Nusselt number show better result with enlargement in (Re). (CTT) can amplify heat transfer better than (COTT) [49]. By make use of two step method (NDG) nitrogen doped graphene nanofluid were develop in water solution, the inspection describes outcome of experimentation on thermal conductivity, specific heat capacity and viscosity in double pipe heat exchanger with different water base nanofluid as coolant and calculation were obtained on mat lab code. Reynolds no. Were taken under the range of 5000 and 15000 (turbulent flow), were Re improves the heat transfer of taken fluid 0.6wt% nano material in base fluid led to 15.86% enlargement of convective heat transfer coefficient with comparison with water taking NDC water can enhance performance of double pipe heat exchanger[50]. Analysis was explored the outcome of transfer of thermal energy and friction factor of (TiO_2) titanium oxide and (Al_2O_3) aluminum oxide at turbulent flow with different operating temperature. Nano fluid were prepared by taking two step method and dilution process volume concentration 0.5% to 1.0% in a blend of water and EG ethylene glycol 60:40 (W.E.G) working temperature 30, 50, 70 ^{O}C. Al_2O_3 was affected by temperature and increment of thermal conductivity and viscosity was obtained. TiO2 free of temperature both have mostly same value of heat transfer coefficient for 0.1 mass at 50 and 70 ^{O}C and increment of 24% were obtained. Al_2O_3 performed greater than TiO_2 at temperature 30 ^{O}C[51)].

Fluid motion and outcome of transfer of thermal energy properties based on nanofluid in curl tube were experimentally observed the outcome of screw pitches, rotation angle, mass fraction and heat transfer rate. Enlargement in Nusselt number reduce screw pitch and enlargement in mass fraction helix channel with spinning slant B=45 O display the high outcome of transfer of thermal energy improvement proportion with spinning slant B=0 O and helix channel B=90 O displays the minimum Screw pitches (S = 10cm, S = 12.5cm , S = 15cm), rotation angle (B = 0 O, B= 45O, B= 90 O), Mass fraction (W=0.wt%, W = 0.1wt% ,W = 0.5wt%)[52)]. Heat transfer was finding out for shell and spiral coiled tube heat exchanger. Physical quality wasfound out by numerical and experimentally methods. 42 cases and 15 trials were obtained. Working fluid taken as water whose qualities based on the temperature. Outcome shows pitch size is magnified. Shell side Nusselt number enlarges by 0.8%, 50%. Gain in height and dia. give rise to reduce of 34.1% and 28.3% in Nusselt number[53)]. Numerically study the effect of construction parameters on flow properties, heat transfer properties and stress distribution in tube bundles of spiral heat exchanger (WHEs) based on the liquid – solid thermal interaction method. The result show that the shell to tube flow pattern change from transverse to oblique direction and overall heat transfer coefficient increase first and deceases with increasing with angle[54)]. The purpose of this study to analysis the effect of the thermo – hydraulic flow characteristics in the shell of a spirally wound heat exchanger having a sequential shell shape. The result shows that the number of tubes in the first layer is the only one of the main dimensionless parameters that does not affect the flow properties[55)]. The conquest of this experiment is to determining feasibility of various geometries of water cooled corrugated mini-duct heat sinks (CMCHS), such as triangular, trapezoidal and sinusoidal compared to commercially available direct mini-channel heat sinks. Experiments on water flow inside small channel wave form radiators (CMCHS) with different wave forms (triangle, trapezoidal and sinusoidal) and wavelength (10, 20 and 30mm) and ripple amplitudes waves (0.5, l and 1.5mm) were conducted Reynolds no. range from (650 to 3000) [56)].

As a promising replacement for split baffles, spiral baffles are becoming increasingly popular in case and channel thermal interchanger quadrant spiral. Baffles is commonly taken to create an equal helical motion design on the case edge of spiral baffle thermal interchanger, but triangular leakage losses in the connecting slots between adjacent baffles have always been the bottle neck. In this study experimental studies and numerical analysis were performed on SHBX and the effect of inclination angle on the thermal performance and resistance was investigated based on simulation prediction in addition the performance of SHBX was compared with QHBHX in terms of onsite synergy principle analysis[57, 58)].

1.1. Objective:

The main aim of this research work is to enhance the performance of thermal device. After acknowledging the gap in research, it has been found that there is a big opportunity in the field of temperature elimination and performance enhancement of thermal devices. It can be achieved by introducing mini channel and nano fluid simultaneously, in its best way with modified form to determine heat termination rate, performance factor, NTU, effectiveness, Nu and f etc.

1.2. Novelty:

The novelty of this research work is the unique design of mini channel and the mini insert mounted above the surface of rectangular mini channel for enhancement of heat termination, with an increase level of turbulence, which directly affects the life span of devices for diverse applications. Including this modified nanofluid with optimum vol. % and good thermal attributes of diverse nano particle emphasis the selection of perfect nano particle for producing best stable nano fluid, which directly enhance the performance of thermal devices.

2. Material and Methods

Selection of Nano fluid material for the proposed research work was completely based on the literature survey[1, 51)]. Going through multiple research paper first point of consideration was that which of the nano particle are being popularly used and the reasons for why they are popular. The most popular nano particles that came across in terms of cost and properties were Al_2O_3, ZnO and CuO compared to other nano particles as shown in table 1. It could be seen that the CuO Nano fluid showed linear behaviour in their conductivity. While changing the size and concentration of Al_2O_3 the thermal conductivity changes non-linearly.

Table 1: Properties of Nano Material.

Nano particles and Nano Fluid Sample	Thermal Conductivity 'K' (W/m.k)	Specific heat 'Cp' (J/kg.k)	Density 'ρ' (kg/m^3)
Al_2O_3 [1, 2, 10, 12, 40)]	40	880	3700
ZnO [1,2, 60)]	29	544	5600
CuO [1, 2, 14, 60)]	77	540	6800
TiO_2 [1, 2, 10)]	11.2	650	3900

CuO + ZnO + H_2O [48]	0.670	3608.505	1144.92

2.1. Nanofluid Preparation

Preparation of CuO + ZnO + H_2O nano fluid sample is based on technique of ultrasonication process. Where, CuO and ZnO were mixed in water at 0.005% volume fraction[40, 60] each with 0.51 ml of CTAB surfactant[12, 40]. CTAB first mixed with 250 ml ethanol through mechanical string process.

After mechanical string sample is transfer to the ultrasonication tub for providing 6hr ultrasonication. Final prepared sample was ready to undergo for physio-chemical properties evaluation experimentally through diverse apparatus like hydrometer for density measurement, KD2-Pro thermal analyzer for thermal conductivity measurement and Differential-Scanning Calorimeter (D.S.C.) for specific heat measurement as shown in Table number 2. The experimental values were further validated with numerical model[40], as per given equation:

$$\rho_{\mathrm{n\ fd}} = (1-\varphi)\rho_{\mathrm{b\ fd}} + \varphi\rho_{\mathrm{n\ pt}} \tag{1}$$

$$\mu_{\mathrm{n\ fd}} = (1+2.5\,\varphi)\,\mu_{\mathrm{b\ fd}} \tag{2}$$

$$\frac{K_{\mathrm{n\ fd}}}{K_{\mathrm{b\ fd}}} = \frac{K_{\mathrm{n\ pt}}+2K_{\mathrm{b\ fd}}+2\varphi(K_{\mathrm{n\ pt}}-K_{\mathrm{b\ fd}})}{K_{\mathrm{n\ pt}}+2K_{\mathrm{b\ fd}}-\varphi(K_{\mathrm{n\ pt}}-K_{\mathrm{b\ fd}})} \tag{3}$$

$$C_{\mathrm{p\ (n\ fd)}} = \frac{\varphi(\rho.C_{\mathrm{p}})_{\mathrm{n\ pt}}+(1-\varphi)(\rho.C_{\mathrm{p}})_{\mathrm{b\ fd}}}{\rho_{\mathrm{n\ fd}}} \tag{4}$$

Here, $\rho_{\mathrm{b\ fd}}$ is the base fluid density and $\rho_{n\,pt}$ is the hybrid nano particles density. $\mu_{b\,fd}$ is the base fluid viscosity and $\mu_{\mathrm{n\ pt}}$ is the hybrid nano particles viscosity. $K_{\mathrm{b\ fd}}$ is the base fluid thermal conductivity and $K_{\mathrm{n\ pt}}$ is the hybrid nano particles thermal conductivity. $C_{\mathrm{p\ (b\ fd)}}$, $\rho_{\mathrm{b\ fd}}$ is the base fluid specific heat and base fluid density. $C_{\mathrm{p\ (n\ pt)}}$, $\rho_{\mathrm{n\ pt}}$ is the nano particles specific heat and nano particles density.

2.2. Grid Independency Test:

Grid independence is a necessary step of simulation. It is a process of evaluating optimal condition of grid, which has a smallest grid number without generating a difference in the numerical result based upon the evaluation of various grids. The problems which can be solved through simulation technique, they all are dependent on meshing type, it means that the selected mesh can be coarse or fine. In order to achieve accuracy in the results of present research, grid independency test has been carried out successfully as shown in figure 1. The simulation of present work and validated has been done through ANSYS Fluent software. Some boundary, initial condition and parameters have been selected for achieving accurate results through simulation as shown in table 2.

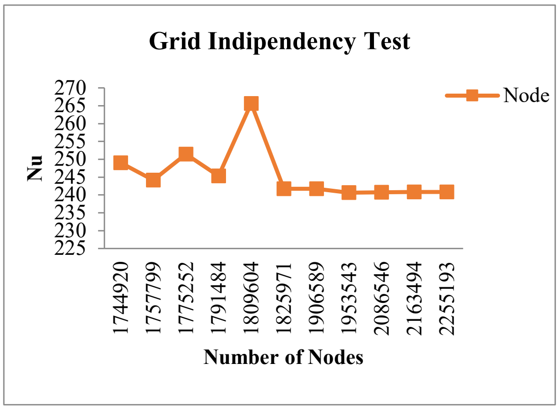

Fig. 1: Graphical representation of Grid Independency Test

Table 2: Diverse Condition used during Simulation

Boundary Condition	
Shell Temperature (^{O} C)	30
Tube side Temperature (^{O} C)	50
Velocity of Shell Fluid (m/s)	0.0000252
Velocity of Tube side Fluid (m/s)	0 to 8
Solution Initialization	Hybrid
Initial Gauge Pressure	Constant
Parameters	
Thermal Conductivity 'K' (W/m.k)	0.670
Specific heat 'Cp' (J/kg.k)	3608.505
Density 'ρ' (kg/m^3)	1144.92
Viscosity (J/kg.k)	0.00085785
Input Conditions	
Specific Method	Intensity and Viscosity Ratio
Turbulent Intensity	5%
Reference Frame	Absolute
Velocity Specification Method	Magnitude-Normal to Boundary
Solver	Type-Pressure based Velocity-Absolute Time -Steady
Model	Energy-ON Viscous- Realizable (k-epsilon)

2.3. Fabrication of test set-up

Experimental test set up of this research consist of following parts namely centre plate, heater plate and mini channel. Here two centre plate having length 280 mm, breath 120 mm and thickness 20 mm are attached together with rubber seal, in such a way that the different grooves (like semi cylindrical groove for shell, semi cylindrical groove for inlet and out let of water supply, semi cylindrical groove for mini channel inlet and out let for water supply, semi cylindrical groove for thermocouples placement and rectangular groove at the starting edges of semi cylindrical groove of shell for mini channel placement) engraved over central plate 1 overlap with central plate 2, every groove have specific function like semi cylindrical groove for shell having length 108 mm, shell diameter 20 mm used for making outer shell chamber for mini channel which is located at 79 mm apart from semi cylindrical groove of mini channel inlet having length 79 mm, diameter 2mm. Mini channel having length 104 mm, breath 10 mm, thickness 3 mm and mini channel diameter 1mm is fixed over rectangular groove which is located at the starting edges of semi cylindrical groove of shell for mini channel placement. Both Center plates tied up nicely with heater plate having and nut & bolts which is placed at back side of both center plates having length 280 mm, breath 120 mm and thickness 20 mm after fixing thermocouples over mini channel which is passed from side way semi cylindrical groove for thermocouples placement having slot length 50 mm, wire diameter 2 mm.

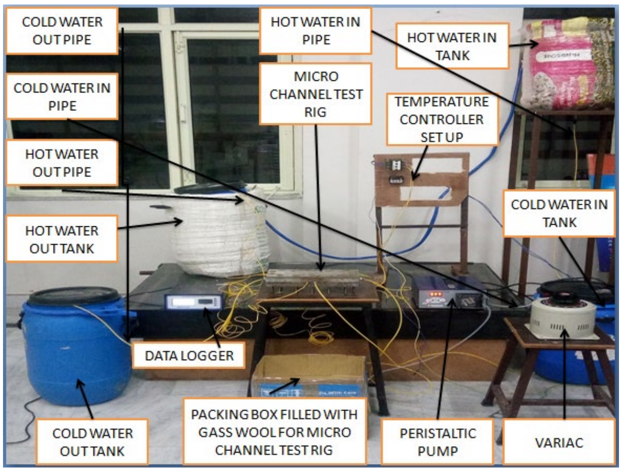

Fig. 2: Photographic View of Experimental Setup.

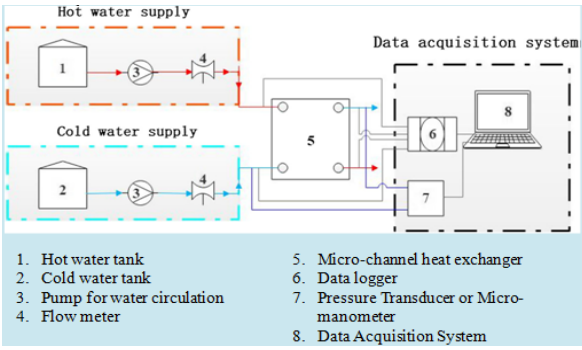

Fig. 3: Line Diagram of Experimental Setup.

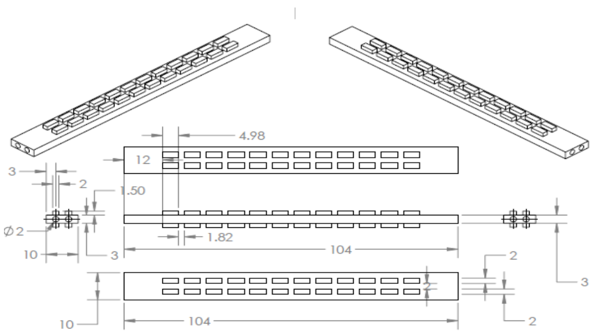

Fig. 4: Mini Insert

Now after assembling all the part of test set up, test set up further assembles with other operating set ups like water supply unit, temperature controller unit and data acquisition unit etc. All the thermocouples which are attached on mini channel surface, inlet and outlet section of shell side and mini channel side, further attache with data logger for recoding the temperature during experimentation and these reading further extracted by data acquisition unit. Under water supply unit peristaltic pump are attached at the inlet section of mini channel side connected from cold water tank and outlet is connected to chiller tank whereas inlet section of shell connected from hot water tank having glass wool tight rap with the help of pipe clamps for controlling the mass flow rate of the fluid. Temperature controller unit is used to maintain the temperature of water in hot water tank which is supplied to shell side of test set up with constant temperature with the help of temperature controller unit and heating coil as shown in figure 2, 3 and 4. Details of peristaltic pump are mentioned in table 4.

2.4. Experimental Procedure

First of all, plain water is supplied to hot water tank where water starts heat up after setting up the operating temperature in temperature control unit, simultaneously fill the cold-water tank with tap water, after achieving fixed temperature at hot water tank, water starts circulate continuously to test section with the help of peristaltic pump at shell side inlet with fixed mass flow rate until it reaches to steady state.

After gaining the steady state condition, cold water has supplied to inlet side of mini channel with the help of peristaltic pump with the fixed mass flow rate indicator as per mentioned in table 4 till next 15 min and all the data are recorded in data acquisition unit related to temperature with the help of data logger, after that all reading like pressure and temperature has been taken from data acquisition unit for further calculation.

2.5. Uncertainty Analysis

The uncertainty in the results occur during experimentation is depends on diverse measurable variables which is dependent on measuring instruments and techniques of measurement. In this research we followed the differential method for calculation uncertainty % for performing uncertainty analysis as per equation number Holman[36].

$$Z_r = \begin{bmatrix} \left(\frac{\partial S}{\partial_{u1}} V_1\right)^2 + \left(\frac{\partial S}{\partial_{u2}} V_2\right)^2 + \\ \left(\frac{\partial S}{\partial_{u3}} V_3\right)^2 + \ldots + \left(\frac{\partial S}{\partial_{un}} V_n\right)^2 \end{bmatrix}^{\frac{1}{2}} \tag{5}$$

Eq. (5), Z_R indicates the uncertainty parameter in result, where independent variables are u_1, u_2, $u_3 \ldots u_n$, S is the functional value and V_1, V_2, $V_3 \ldots V_n$, represents the uncertainties of variables. The uncertainty occurred during experimentation in measuring pressure difference, temperature, Nu number, f factor, and heat flow rate were 0.57%, 5.18%, 2.85% and 3.26% respectively. The uncertainty doesn't effects the developed correlations. Some uncertainties and accuracy level of the measuring equipment used in experimentation is mention in the table 3.

Table 3: Details of Measuring Equipment Accuracy

Measuring Equipment	Accuracy	Max. Uncertainty
Data Logger	99.9%	±0.01%
T type Sensor	99.9%	±0.01°C
Pressure Transmitter	99.9%	±0.1% bar
Mass Flow Meter	99.9%	±0.1% LPM
Rotameter	99.9%	±0.1% LPM

Table 4: Details of Flow Measuring Equipment

Specification of Flow Measurement Equipment	Details of Flow Measurement Device
Manufacturer Name	Everest Hitech
Model name	GMP Model
Measurement range of the instruments	0 ml/Min to 999 Lt./Min
Least Count range of the instruments	0.1 ml/Min

2.6. Data Reduction

Equations were used for determining, fluid flow properties including performance properties and the experimentation was obtained by following data reduction method, for obtaining the fluid rate of flow (hot condition fluid) and fluid rate of flow (cold condition fluid), the data governed by following equation as,

$$Q_{ds} = \frac{Volume}{t} \tag{6}$$

where $Q_{ds} = Area \times V$

$$m_{rf} = \rho_f . A . V_f \tag{7}$$

Here, m_{rf} is the fluid rate of flow which is used to calculate the rate of heat elimination of hot condition fluid and cold condition fluid. Heat transfer rate is obtained by governing equation as,

$$\begin{aligned} Q_{hf} &= m_{hf} . \mathrm{C}_{phf} \left(T_{in} - t_{out}\right) \\ &= Q_{cf} = m_{cf} . \mathrm{C}_{pcf} \left(T_{out} - t_{in}\right) \end{aligned} \tag{8}$$

Where, T_{in} = Outer GI Shell tube inlet temperature, T_{out} = Outer GI Shell tube outlet temperature, *t* = Spiral inner tube inlet temperature and t_{out} = Spiral inner tube outlet temperature. Further steps using L.M.T.D, method for obtaining heat transfer of coefficient and overall coefficient of transfer of heat as per governing equation:

$$Q_r = h . A . \Delta T \tag{9}$$

where $\Delta T = \left(\Delta T_1 - \Delta T_2\right) / \ln\left(\Delta T_1 / \Delta T_2\right)$, $\Delta T_1 = \left(T_{out} - t_{in}\right)$, $\Delta T_2 = \left(T_{in} - t_{out}\right)$

$$U = \frac{1}{\left(\frac{1}{h_i} + \frac{1}{h_o}\right)} \tag{10}$$

After evaluating above parameters, further steps are used to determine fluid flow properties (cold condition fluid) as per governing equation:

$$Nu = \frac{h.D}{k} = 0.023 \Re^{0.8} \Pr^{0.4} \tag{11}$$

where $\Re = \dfrac{\rho.A.D}{\mu}$

$$f = \frac{\Delta P}{\left(\frac{L}{D}\right)\left(\frac{\rho.\upsilon^2}{2}\right)} \tag{12}$$

After evaluating above parameters, further steps are used to determine the performance parameters (cold condition fluid) as per governing equation:

$$\varepsilon = \frac{Q_{actual}}{Q_{\max}} \tag{13}$$

$$NTU = \frac{U.A_s}{Q_{\max}} \tag{14}$$

where $C_{\min} = m.C_{cp}$ and

$$\text{NTU}_{counter} = \frac{1}{c-1}\ln\left(\frac{\varepsilon-1}{\varepsilon_c-1}\right) \tag{15}$$

$$\eta_{tpf} = \frac{\left(\frac{Nu}{Nu_s}\right)}{\frac{f^{0.33}}{f_s^{0.33}}} \tag{16}$$

$$Nu_s = 0.023\Re^{0.8}\,\text{Pr}^{0.4} \tag{17}$$

$$f_s = 0.316\Re^{-0.25} \tag{18}$$

3. Result and Discussion

It has been observed from figure 5, 6, 7 and 8 that the mini channel with rectangular strip mini insert performing well than mini channel without rectangular strip mini insert.

The fluid flow behavior of proposed nanofluid showing better enhancement than base fluid (water) for both the regions laminar and turbulent, where Nu and f factor varies from 14.8005-53.03 and 0.0002-0.000051 (simulation), 70.152-108.998 and 0.000041-0.000025 (simulation) in laminar case whereas, 11.710-50.25 and 0.000244-0.00051 (experimental), 65.609-94.5215 and 0.000041-0.000025 (experimental) in turbulent case.

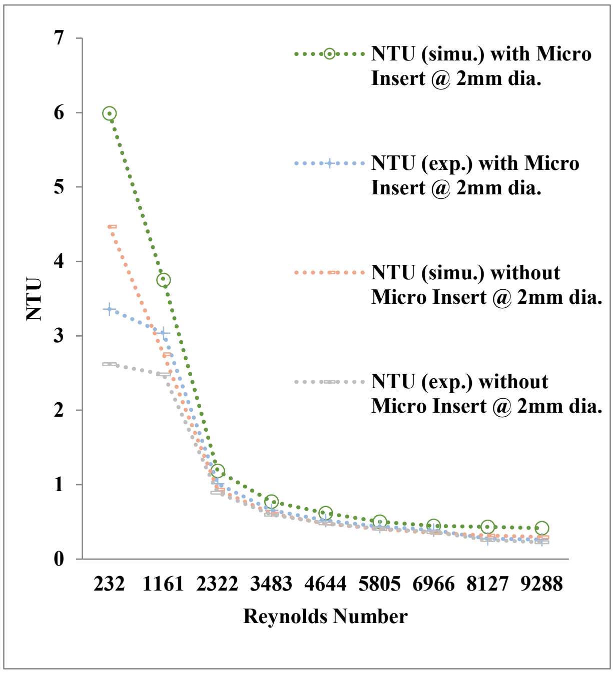

Fig. 5: Variation between effectiveness and quality factor for CuO + ZnO+H_2O nano fluid in mini- channel having with or without mini insert @0.03 vol.%)

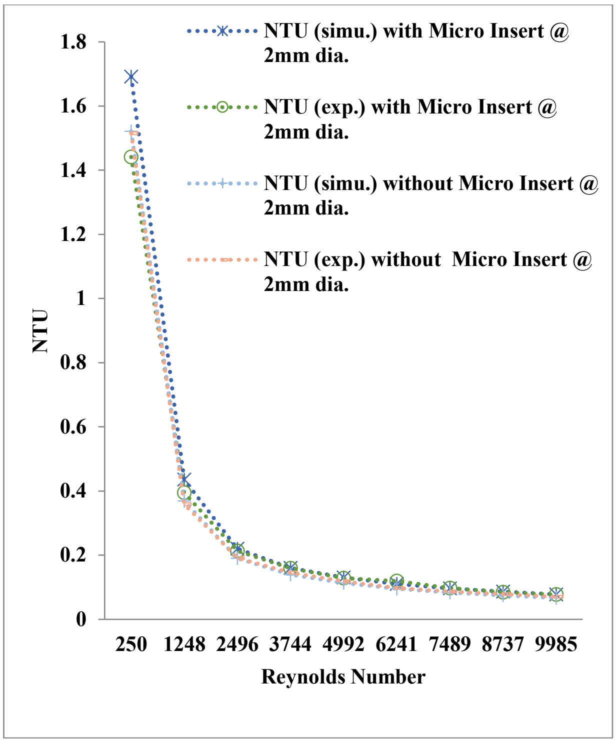

Fig. 6: Variation between effectiveness and quality factor for water mini- channel having with or without mini insert

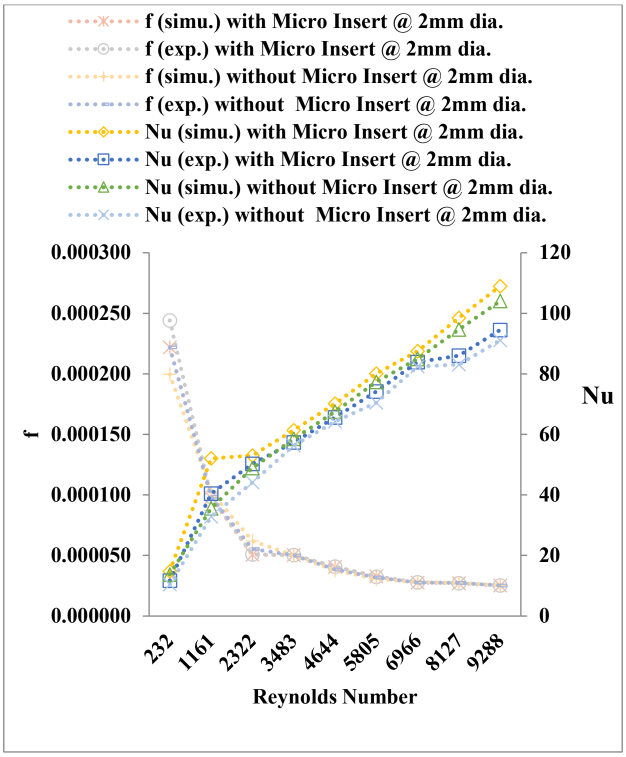

Fig. 7: Variation between TPF and Reynolds number for CuO + ZnO+H_2O nano fluid in mini- channel having with or without mini insert @ 0.03 vol.%

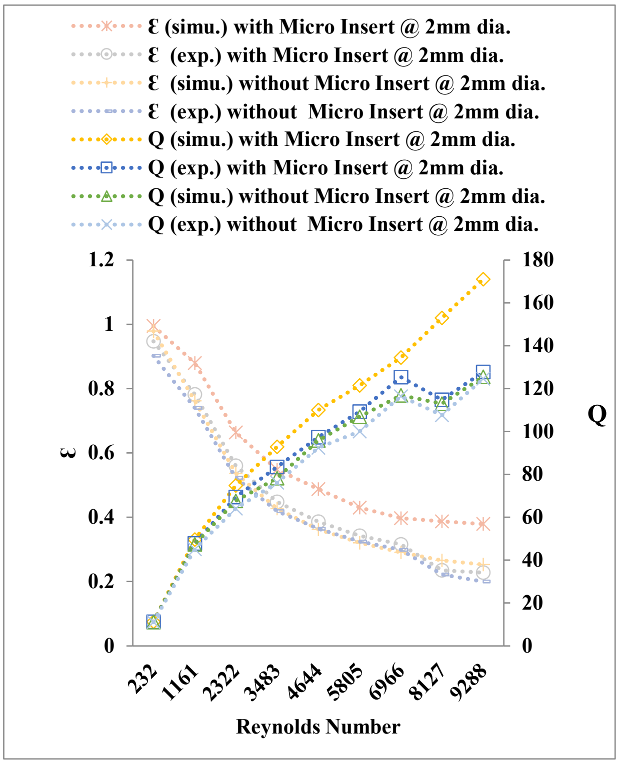

Fig. 9: Variation between effectiveness and quality factor for CuO + ZnO+H_2O nano fluid in mini- channel having with or without mini insert @0.03 vol.%)

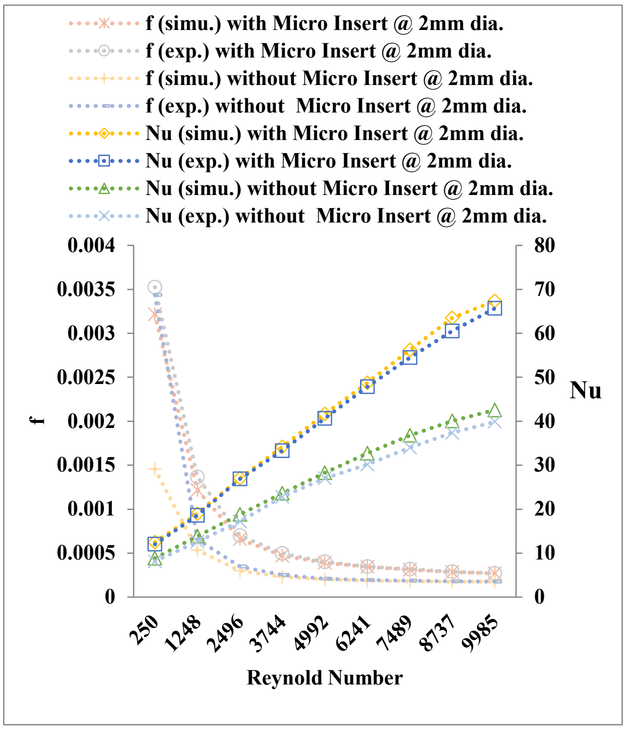

Fig. 8: Variation between TPF and Reynolds number for water mini-channel having with or without mini insert

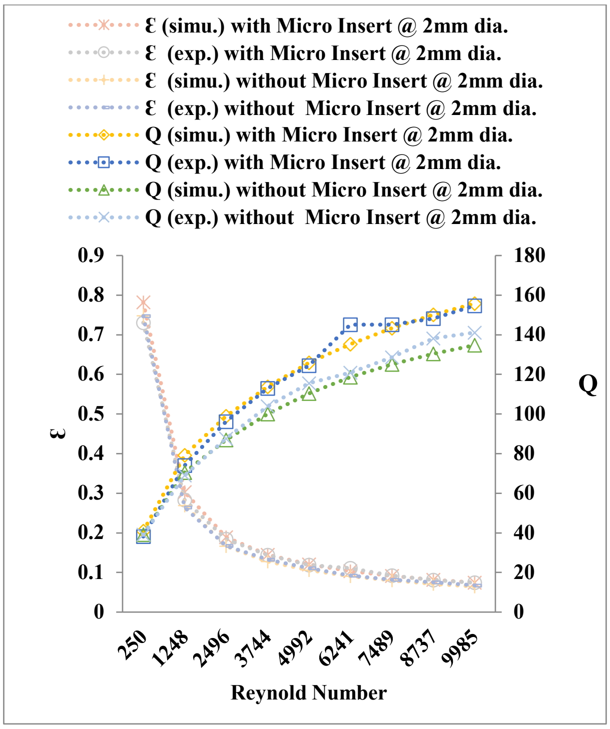

Fig. 10: Variation between effectiveness and quality factor for water mini- channel having with or without mini insert

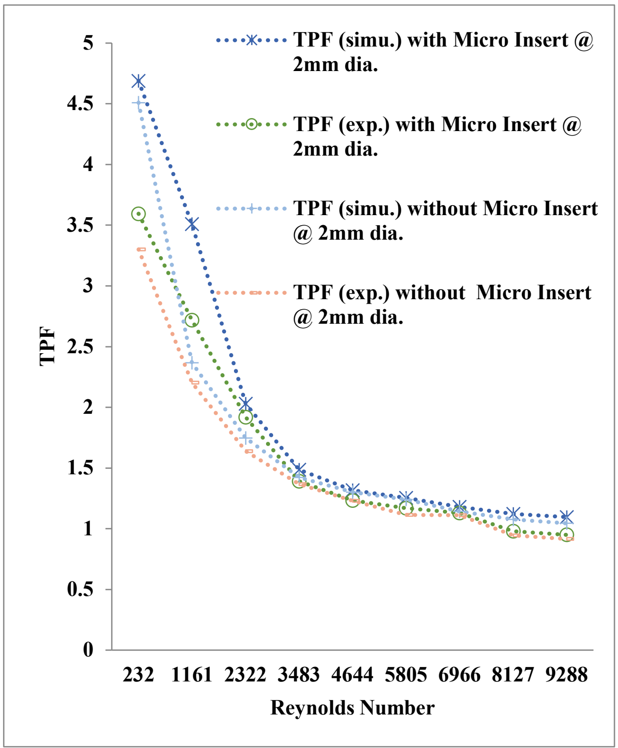

Fig. 11: Variation between TPF and Reynolds number for CuO + ZnO+H_2O nano fluid in mini- channel having with or without mini insert @ 0.03 vol.%

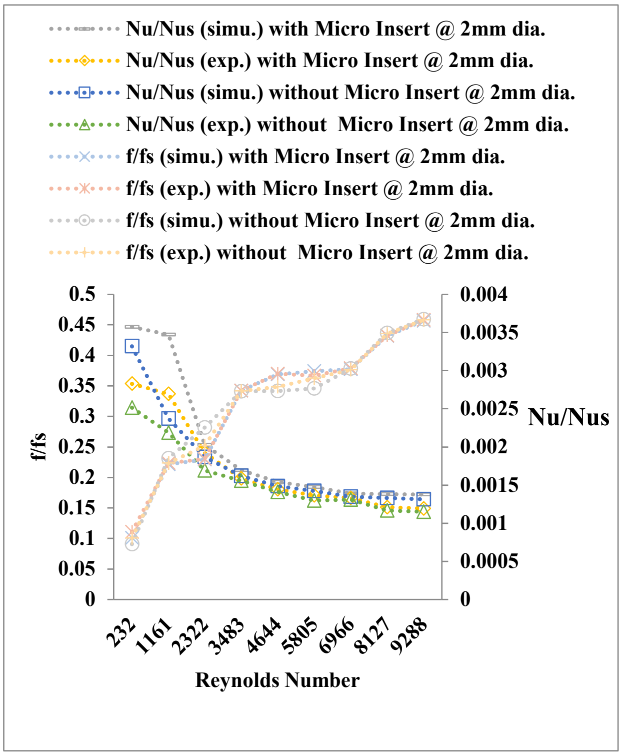

Fig. 13: Variation between friction factor and Nusselt number for CuO + ZnO+H_2O nano fluid in mini- channel having with or without mini insert @ 0.03 vol.%

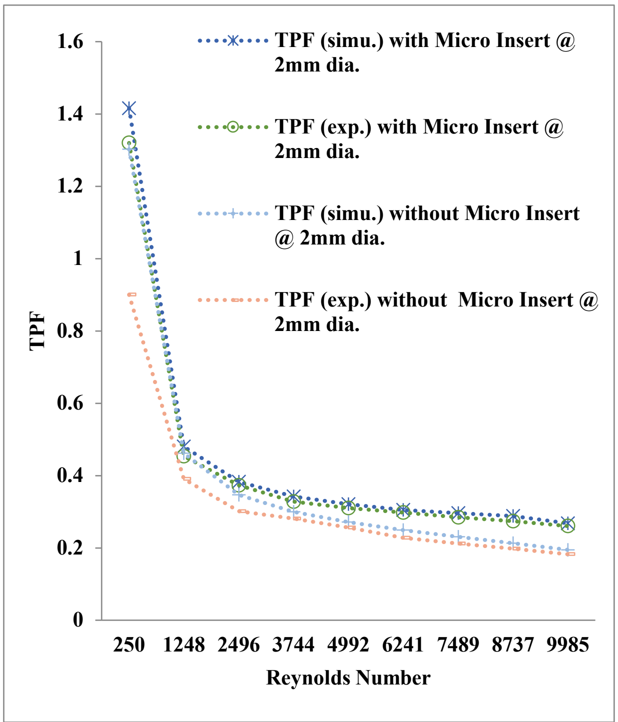

Fig. 12: Variation between TPF and Reynolds number for water mini-channel having with or without mini insert

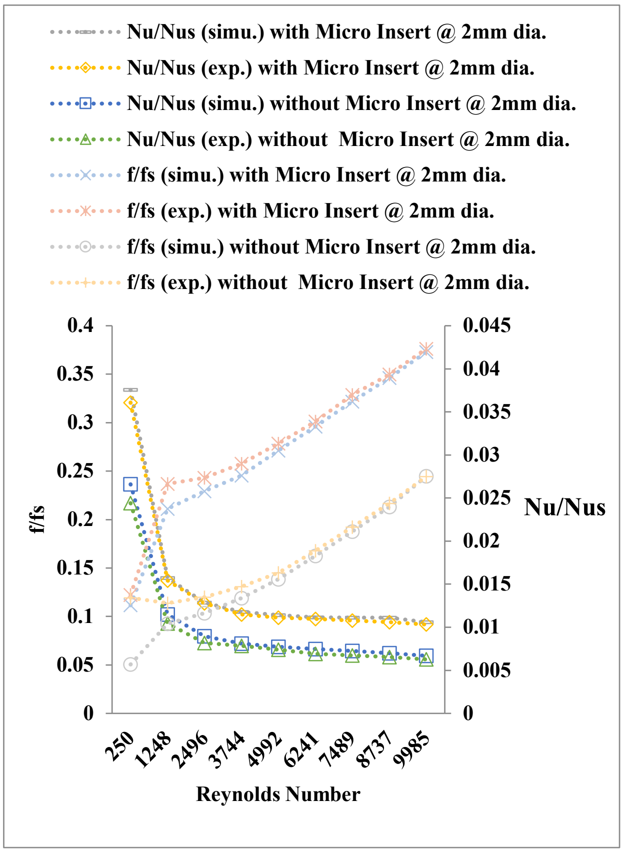

Fig. 14: Variation between friction factor and Nusselt number for water mini- channel having with or without mini insert

It has been observed from figure 5 and 6 that the mini channel with rectangular strip mini insert performing well than mini channel without rectangular strip mini insert. The fluid flow behavior of proposed nanofluid showing better enhancement than base fluid (water) for both the regions laminar and turbulent, where Nu and f varies from 3.92-18.25 and 0.000236-0.0000492 (experimental), 4.07-19.04 and 0.000215-0.0000490 (simulation) in laminar case whereas, 24.15-40.53 and 0.0000394-0.0000244 (simulation), 23.93-37.12 and 0.0000395-0.0000245 (experimental) in turbulent case. From figure 9, 10, 11, 12, 13 and 14 it is clearly seen that the rate of heat transfer is increasing whereas, effectiveness TPF and NTU is gradual decreasing with respect to Re number for thermal behavior of proposed nano fluid than base fluid (water).

Because thermal conductivity of base fluid (water) was lower than the proposed nanofluid. The thermal behavior of mini channel with rectangular strip mini insert has showing better performance compared with other geometry. The better results range for rate of heat transfer, Ɛ, TPF and NTU varies from 11.228-74.878, 0.995-0.663, 5.988-1.184 and 4.688-2.028 (simulation) 11.2120-69.461, 6.9475-0.5605, 3.360-1.012 and 3.594-1.919 (experimental) in laminar case whereas, 110.0324-171.086, 0.4875-0.379, 0.617-0.415 and 1.317-1.095 (simulation), 97.392-127.75, 0.3865-0.228, 0.519-0.263 and 1.231-0.949 (experimental) in turbulent case.

On the other hand Nu/Nus and f/fs factor varies from 0.44668-0.25 and 0.000805-0.001836 (simulation), 0.192725-0.1719 and 0.00295-0.00365 (simulation) in laminar case where as, 0.35-0.240 and 0.000885-0.018 (experimental) 0.185-0.164 and 0.00295-0.0036 (experimental) in turbulent case.

The closest performance has been achieved for flow characteristics between experimental and CFD results i.e. 6%-8.2% in terms of error percentage. While comparing the above results, an increment was acknowledged for Nu and f/fs parameters whereas, a decrement showed by Nu/Nus and f factor parameters with respect to Re number. It is because of better turbulent property of the geometry.

The Nu/Nus and f/fs ratio plays significant role to compute thermal performance of the mini channel with insert compared with smooth mini channel as per given equation 16. Figure 13 and 14 evidently indicates that at lower flow rate or fluid velocity in laminar-regime, fiction factor is too high due to low turbulency and high pressure drop. It leads to low heat dissipation of fluid because of smooth stream flow of fluid. At higher flow rate or fluid velocity in turbulent-regime, fiction factor is too low due to low turbulency and high temperature drop, which leads to high heat dissipation of fluid because of disrupted flow stream of fluid. Here NTU signify the amount of heat dissipation in a flow regime which is helpful to predict the optimum thermal performance region, result indicates that laminar-regime have high heat conduction not convection but turbulent-regime have high convection not conduction due to high flow rate. Thus the optimum range for better heat dissipation in terms of thermal performance of mini channel was computed at rich laminar-regime and lower turbulent-regime for an average pumping cost.

3.1. Validation:

Figure 7 and 8 represents validation curves for flow characteristics i.e. Nu and f of present work. Thus closest performance has been achieved between experimental and CFD simulation results i.e. 6%-8.2% in terms of error percentage. Comparative validation data of present work and previous work as shown in table 5 and 6 has been observed for Roughness factor (f) and Thermal attribute (h) with respect to Reynolds Number.

As per previous available data and present evaluated data, it is evidently seen that results It is clearly visible from the data that the results are coming within an ace of acceptance limit.

Table 5: Comparison Data of Present Work and Previous Work for Roughness factor with respect to Reynolds Number.

Re	f Exp. (CuO+ZnO +H_2O) @ 0.01% Vol. Present work	f (H_2O) Exp. Present work	f (Al_2O_3+H_2O) @ 0.1% Vol. Previous work [10]	f (Al_2O_3+H_2O) @ 2% Vol. Previous work [10]
1200	0.055	0.0512	0.057	0.06
2000	0.0275	0.0256	0.033	0.035

Table 6: Comparison Data of Present Work and Previous Work for Thermal attribute with respect to Reynolds Number.

Re	h Exp. (CuO+ZnO +H_2O) @ 0.1% Vol. Present work	h Exp. (H_2O) Present work	h (Al_2O_3+H_2O) @ 0.1% Vol. Previous work [10]	h (Al_2O_3+H_2O) @ 2% Vol. Previous work [10]
1200	13551.13	5716.41	7750	8600
2000	16836.58	8263.71	9750	10500

4. Conclusions

It is studied from the outcomes that nano fluid CuO+ZnO+H_2O display finer result in terms of fluid flow, thermal behavior and heat convey parameter as compared to base fluid (water). It is happened because of following reasons:

1- CuO and ZnO nano particle have greater thermal conductivity compare with the based fluid

2- Extra molecular areas gained due to inclusion of nano particles in base fluid (water) and thus enlarge the thermal conductivity of nano fluid. Thus, it improved the results 18%-21% approximately.

3- The outcome of geometrical profile also admit where rectangular strip mini insert based mini channel show best performance in terms of fluid flow, thermal parameter as compared with mini channel without mini insert because of gain in turbulency.

4- The governing reason behind the optimum results was good turbulency, effective pressure drop and temperature drop, which has been gained by location of mini inserts over rectangular strip mini channel. It also depends on the increased area which effects in terms of better heat transfer.

5- Enhanced area of micro inserts effects optimum results in terms of better performance up to 9%-15% compared with simple micro channel without inserts.

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