Comparative Analysis of Fluid Flow Attributes in Rectangular Shape Micro Channel having External Rectangular Inserts with Hybrid Al_20_3+ZnO+H_20 Nano Fluid and (H_20) Base Fluid

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バージョン：

Comparative Analysis of Fluid Flow Attributes in Rectangular Shape Micro Channel having External Rectangular Inserts with Hybrid $Al_2O_3+ZnO+H_2O$ Nano Fluid and (H_2O) Base Fluid

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Abstract: Comparative analysis is conducted between nano fluid (nf) $Al_2O_3+ZnO+H_2O$ and water (H_2O) as base fluid through experimental and simulation result. The effect of nano fluid and (base) fluid flowing inside rectangular micro channel with or without insert were acknowledge, for analysis the behavior of fluid flow, heat transfer and performance characteristics 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 preparation of nano fluid 0.01% volume fraction, 10-20 nm size nano particles were taken with 0.5ml CTAB (cetyl-2 tri-methyl, ammonium-bromide) surfactant. Experimentation was conducted for different operating parameters under counter flow conditions, where nano fluid is flowing inside micro channel of 0.081mm 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 base fluid due to better thermal conductivity and extra molecular area gain in nanofluid due to addition of nano particle with base fluid. It improves the results 21% approximately. Better optimum results were observed in case of rectangular micro channel with micro insert compared with other geometry because of rich turbulency gain and extra exposed area due to micro insert. It affects optimum results in terms of better performance up to 9%-18% compared with simple micro channel without inserts.

Keywords: Micro channel; Rectangular strip micro insert; Nano-fluid, Thermal Behavior.

1. Introduction

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, green bio-glycol nano fluid[23, 24, 25, 26)], 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 ater 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] 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].

1.1. Objective:

The main aim of this research work is to enhance the fluid flow, thermal attributes and performance of thermal device and predict the operating range for pumping cost. 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 micro channel and nano fluid simultaneously, in its best way with modified form to determine heat termination rate, performance factor, NTU, Ɛ, Nu and f etc.

1.2. Novelty:

The novelty of this research work is the unique design of micro channel and the micro insert mounted above the surface of rectangular micro 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[39, 10, 40]. 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 2. It could be seen that the CuO Nano fluid showed linear behavior in their conductivity. While changing the size and concentration of Al_2O_3 the thermal conductivity changes non-linearly (Natalia Sizochenko). Al_2O_3 and ZnO has shown more diversity in its properties.

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, 12)]	40	880	3700
ZnO [1 12)]	29	544	5600
CuO [1, 12)]	77	540	6800
TiO_2 [1, 12)]	11.2	650	3900
Al_2O_3+ZnO+H_2O [48)]	0.6690	3725.51	1108.4

2.1. Nanofluid Preparation

Preparation of Al_2O_3 + ZnO + H_2O nano fluid sample is based on technique of ultrasonication process. Where, Al_2O_3 and ZnO were mixed in water at 0.005% volume fraction each with 0.51 ml of CTAB surfactant[8, 3)] after preparing the available powder form of 25 gm CTAB first mixed with 250 ml ethanol through mechanical string process. As the mechanical string of sample is done, transfer the sample 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:

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

Here, $\rho_{\mathrm{b\ fd}}$ is the base fluid density and $\rho_{\mathrm{n\ pt}}$ is the hybrid nano particles density.

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

Here, $\mu_{\mathrm{b\ fd}}$ is the base fluid viscosity and $\mu_{\mathrm{n\ pt}}$ is the hybrid nano particles viscosity.

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

Here, $K_{\mathrm{b\ fd}}$ is the base fluid thermal conductivity and $K_{\mathrm{n\ pt}}$ is the hybrid nano particles thermal conductivity.

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

Here, $C_{\mathrm{p\ (b\ fd)}}$, $\rho_{\mathrm{b\ fd}}$ 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.

Table 2: Diverse Condition used during Simulation

Boundary Condition	
Shell (External micro channel tube) Temperature (^{O} C)	30
Tube side (micro channel tube)Temperature (^{O} C)	50
Velocity of Shell (External micro channel tube) Fluid (m/s)	0.0000252
Velocity of Tube side (micro channel tube) Fluid (m/s)	0 to 8
Solution Initialization	Hybrid
Initial Gauge Pressure	Constant
Parameters	
Thermal Conductivity 'K' (W/m.k)	0.669
Specific heat 'Cp' (J/kg.k)	3725.51
Density 'ρ' (kg/m^3)	1108.4
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)

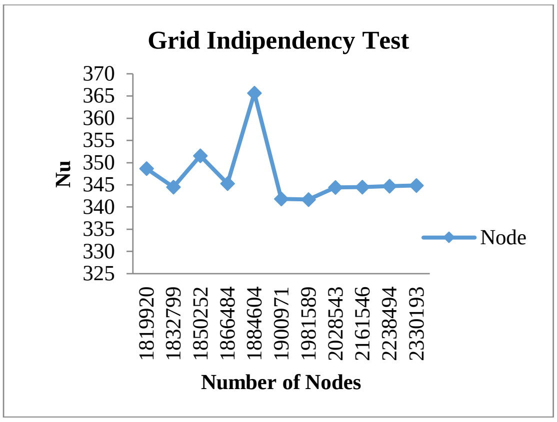

Fig. 1: Graphical representation of Grid Indipendency Test

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. Some boundary, initial condition and parameters have been selected for achieving accurate results through simulation as shown in table 2.

2.3. Fabrication of test set-up

Experimental test set up of this research consist of following parts namely centre plate, heater plate and micro 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 micro 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 micro 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 micro channel which is located at 79 mm apart from semi cylindrical groove of micro channel inlet having length 79 mm, diameter 2mm. Micro channel having length 104 mm, breath 10 mm, thickness 3 mm and micro channel diameter 0.081mm is fixed over rectangular groove which is located at the starting edges of semi cylindrical groove of shell for micro channel placement.

Both Centre plates tied up nicely with heater plate having and nut & bolts which is placed at back side of both centre plate having length 280 mm, breath 120 mm and thickness 20 mm after fixing thermocouples over micro channel which is passed from side way semi cylindrical groove for thermocouples placement having slot length 50 mm, wire diameter 2 mm as shown in figure 4.

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 micro channel surface, inlet and outlet section of shell side and micro 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 micro channel side connected from cold water tank and outlet is connected to chiller tank where as 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. Complete assemble setup is shown in figure 2 and 3. Details of peristaltic pump are mentioned in table 4.

2.4. Experimental Procedure

First of all, φφplain 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 micro channel with the help of peristaltic pump with the fixed mass flow rate indicator details are mention in table number 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.

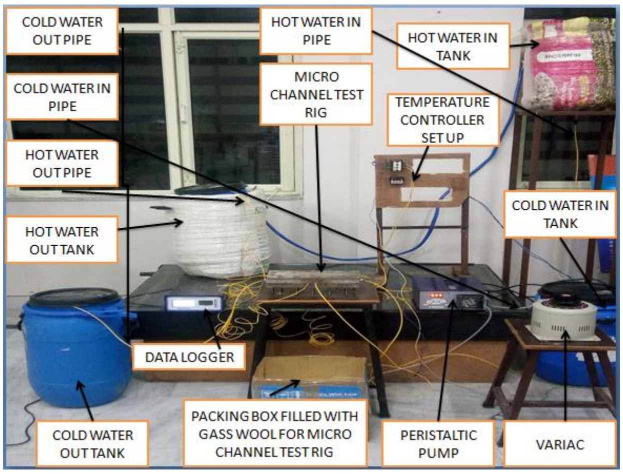

Fig. 2: Photographic View of Experimental Setup.

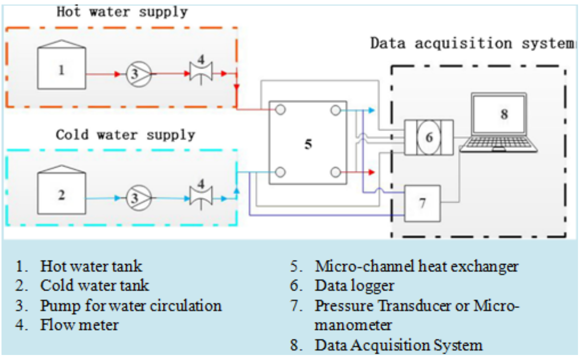

Fig. 3: Line Diagram of Experimental Setup.

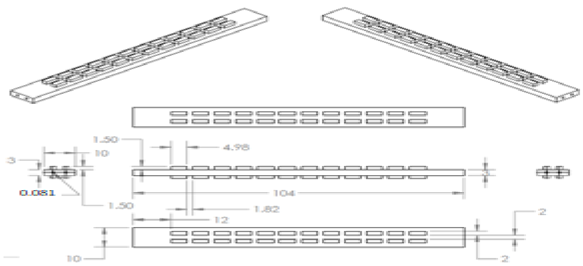

Fig. 4: Micro Insert

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 [29].

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

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, f, and heat flow rate were 0.89%, 3.93%, 1.07% and 5.33% 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 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,

$$Q_{ds} = \frac{Volume}{t} \quad (6)$$

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

$$m_{rf} = \rho_f . A V_f \quad (7)$$

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. Q is obtained by governing equation as,

$$Q_{hf} = m_{hf} . C_{phf} \left(T_{in} - t_{out} \right) = Q_{cf} = m_{cf} . C_{pcf} \left(T_{out} - t_{in} \right) \quad (8)$$

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:

$$Q_r = h.A.\Delta T \quad (9)$$

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

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

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

$$Nu = \frac{h.D}{k} = 0.023\Re^{0.8}\,\mathrm{Pr}^{0.4} \quad (11)$$

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

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

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

$$\varepsilon = \frac{Q_{actual}}{Q_{\max}} \quad (13)$$

$$NTU = \frac{U.A_s}{Q_{\max}} \quad (14)$$

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

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

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

$$Nu_s = 0.023\Re^{0.8}\,\mathrm{Pr}^{0.4} \quad (17)$$

$$f_s = 0.316\Re^{-0.25} \quad (18)$$

3. Result and Discussion

It has been observed from figure 4 and 5 that the micro channel with rectangular strip micro insert performing well than micro channel without rectangular strip micro insert.

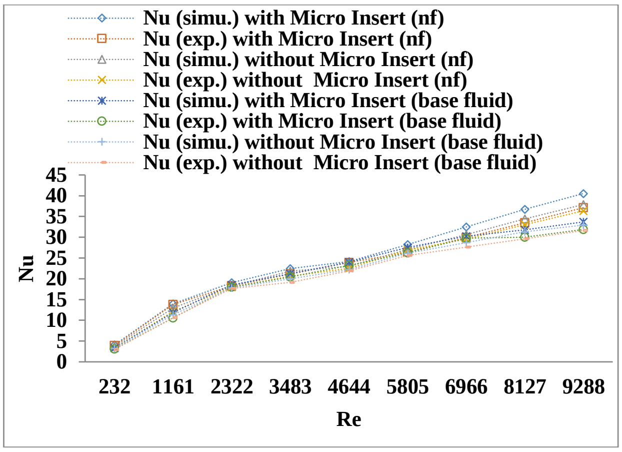

Fig. 5: Graphical variation between Nu v/s Re for proposed nano fluid (Al_2O_3+ZnO+H_2O @0.03 vol.%) and base fluid

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. On the other hand, from figure 6 and 7 Nu/Nus and f/fs factor varies from 0.11-0.086 and 0.00085-0.00178 (experimental), 0.12-0.089 and 0.00077-0.00177 (simulation) in laminar case whereas, 0.065-0.063 and 0.00285-0.00353 (simulation) 0.064-0.057 and 0.00286-0.00354 (experimental) in turbulent case. While comparing the above results, an increment was acknowledged for Nu and f/fs parameters whereas, a decrement showed by Nu/Nus and f parameters with respect to Re number.

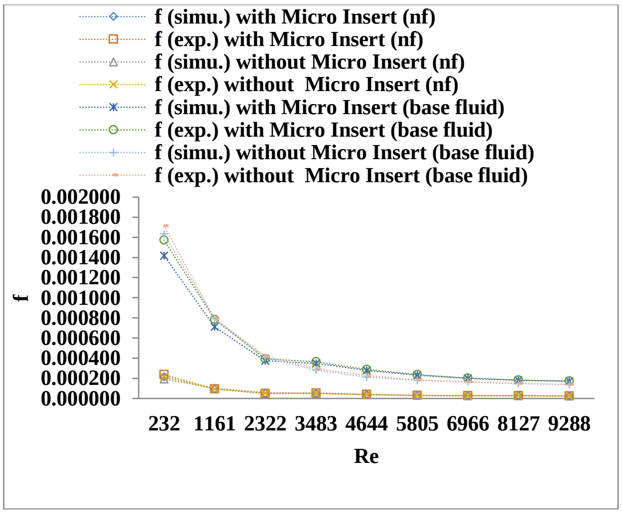

Fig. 6: Graphical variation between f v/s Re for proposed nano fluid (Al_2O_3+ZnO+H_2O @0.03 vol.%) and base fluid

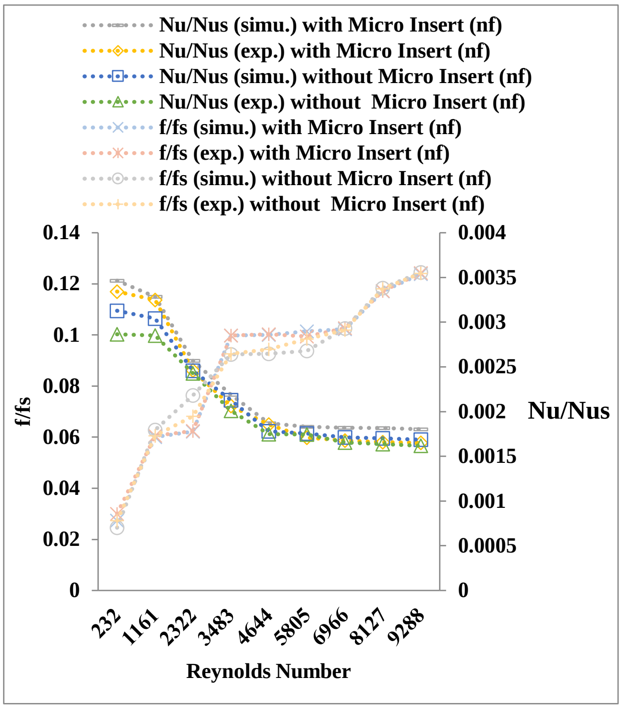

Fig. 7: Graphical variation between f/fs and Nu/Nus v/s Re for proposed Nano Fluid (Al2O3 + ZnO + H2O) @0.03 vol.%

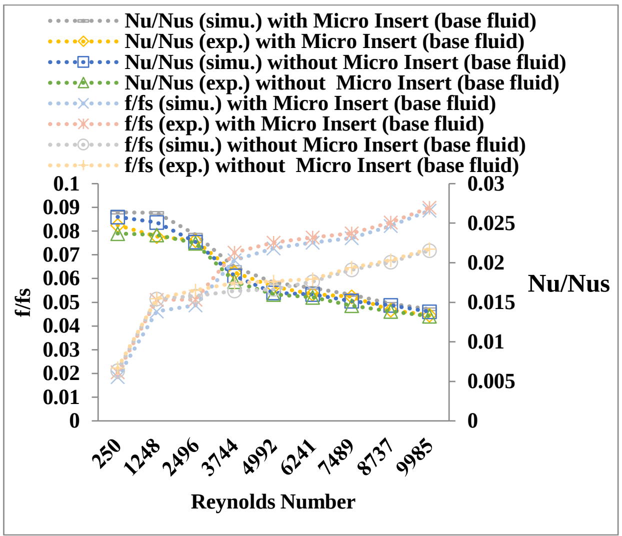

Fig. 8: Graphical variation between f/fs and Nu/Nus v/s Re for base fluid.

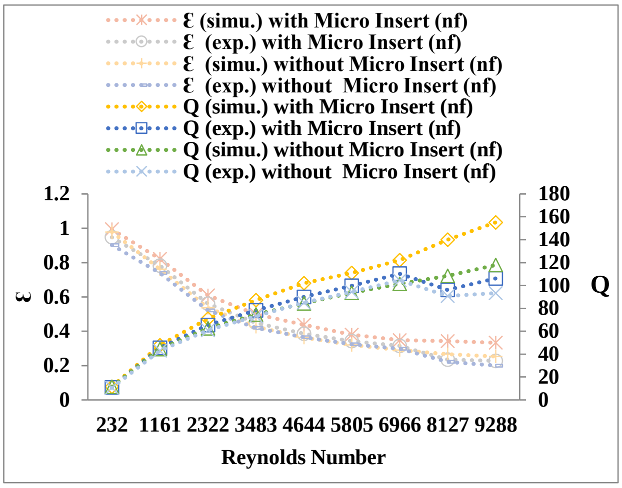

Fig 9: Graphical variation between Ɛ v/s Q with respect of Re of nano fluid (Al_2O_3+ZnO+H_2O @0.03 vol.%)

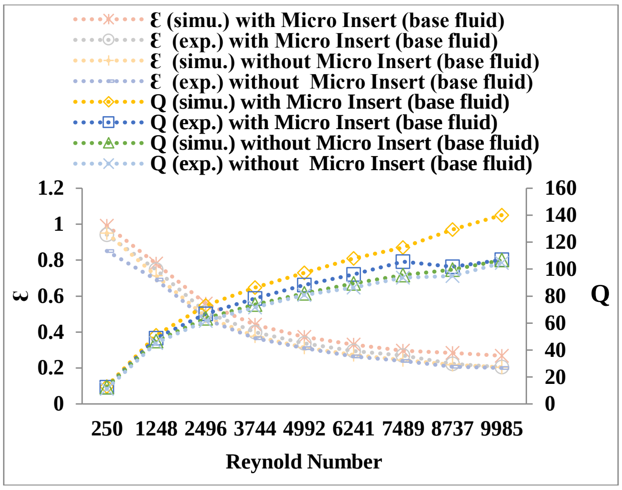

Fig. 10: Graphical variation between Ɛ v/s Q with respect to Re for base fluid.

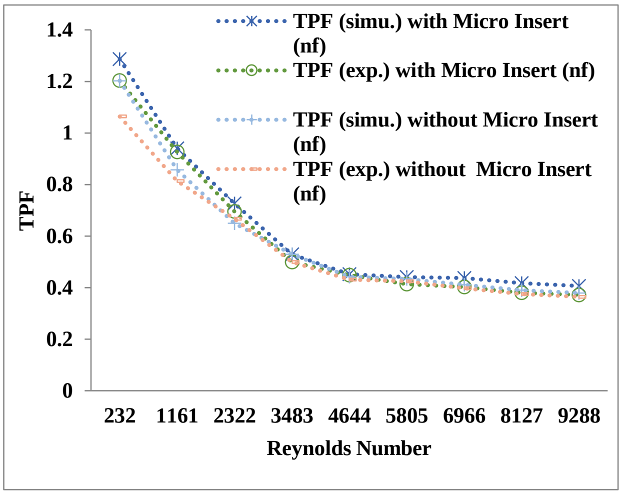

Fig. 11: Graphical variation between TPF v/s Re for proposed nano fluid (Al_2O_3+ZnO+H_2O @0.03 vol.%)

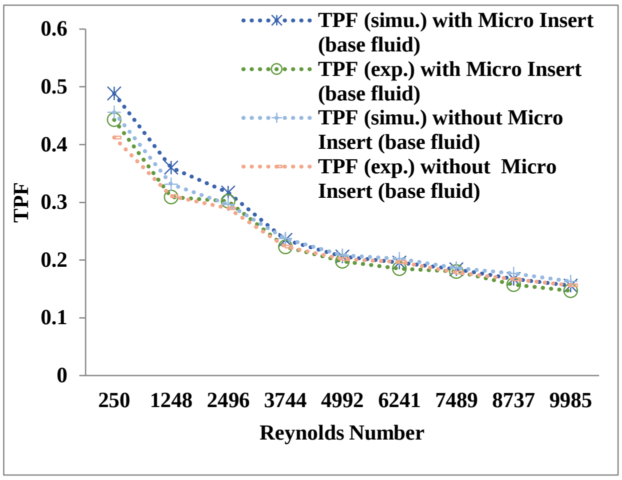

Fig. 12: Graphical variation between TPF v/s Re for base fluid.

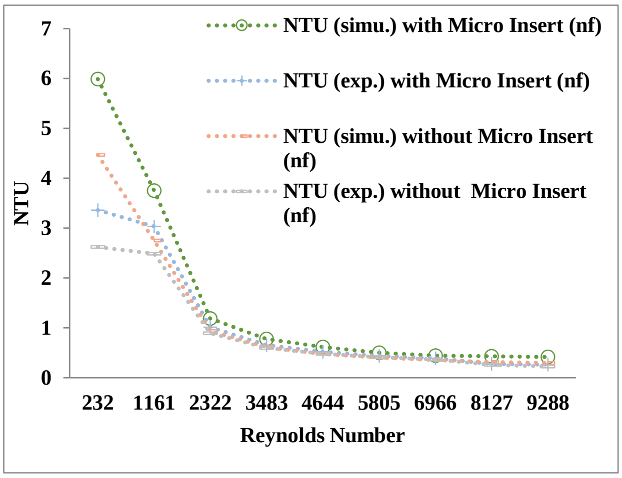

Fig. 13: Graphical variation between NTU v/s Re for proposed nano fluid (Al_2O_3+ZnO+H_2O @0.03 vol.%)

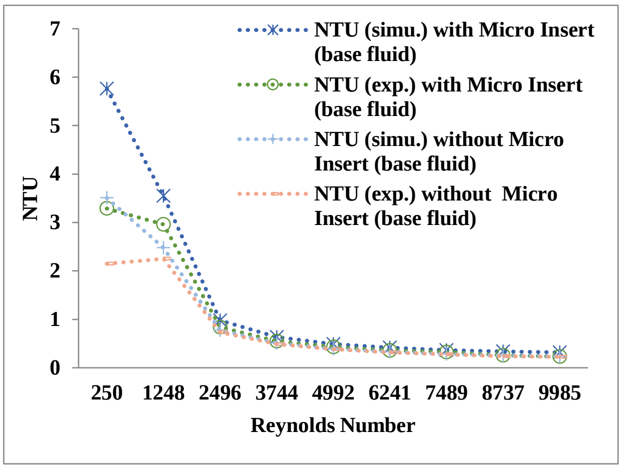

Fig. 14: Graphical variation between NTU v/s Re for base fluid.

It is because of better turbulent property of the geometry. From figure 9, 10, 11, 12 13 and 14 it is clearly seen that the rate of heat transfer is increasing whereas, Ɛ TPF and NTU is gradual decreasing with respect to Re number for thermal behavior of proposed nano fluid than base fluid (water) [7, 8, 30]. Because thermal conductivity of base fluid (water) was lower than the proposed nanofluid. The thermal behavior of micro channel with rectangular strip micro insert has showing better performance compared with other geometry. The Nu/Nus and f/fs ratio plays significant role to compute thermal performance of the micro channel with insert compared with smooth micro channel as per given equation 16. Figure 7 and 8 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. The better results range for rate of heat transfer, Ɛ, TPF and NTU varies from 11.03-65.30, 0.9475-0.5605, 3.36-1.012 and 1.20-0.69 (experimental), 11.58-70-89, 0.994-0.6085, 5.98-1.184 and 1.28-0.72 (simulation) in laminar case whereas, 101.94-155.19, 0.3865-0.228, 0.1519-0.263 and 0.44-0.37 (simulation), 90.06-106.25, 0.4375-0.333, 0.617-0.415 and 0.45-0.40 (experimental) in turbulent case. 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 micro channel was computed at rich laminar-regime and lower turbulent-regime for an average pumping cost.

3.1. Validation:

Figure 15 and 16 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. 3.6%-7.5% 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.

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

Re	f Exp. (Al_2O_3+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	0.05512	0.05127	0.057	0.06
2000	0.02756	0.02563	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. (Al_2O_3+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	8120.84	6545.31	7750	8600
2000	12044.36	10870.8	9750	10500

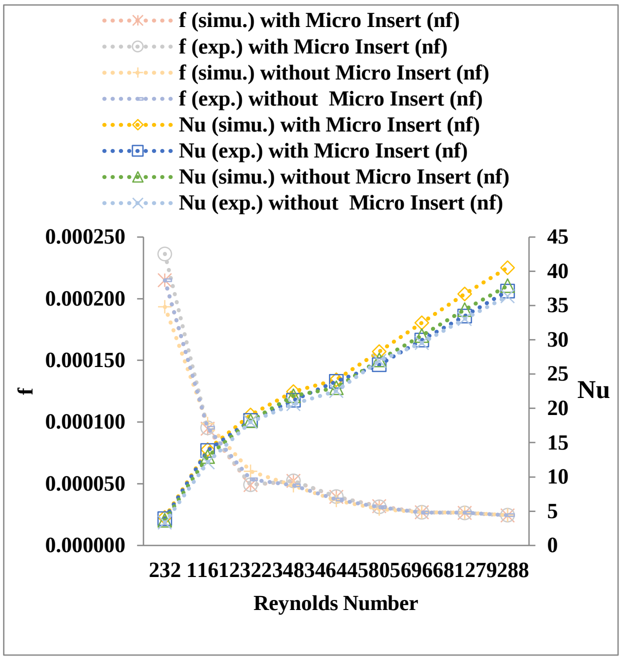

Fig. 15: Graphical Variation for Validation between f v/s Nu experimental-simulated values with respect of Re for proposed nano fluid (Al_2O_3+ZnO+H_2O @0.03 vol.%)

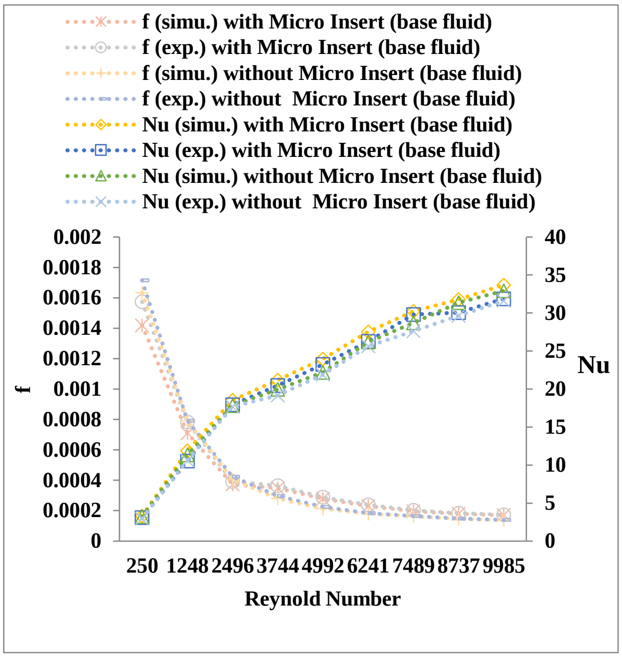

Fig. 16: Graphical Variation for Validation between f v/s Nu experimental-simulated values with respect of Re for base fluid.

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.

4. Conclusion

It is analysed from the results that nanofluids Al_2O_3+ZnO+ water showing better results in terms of performance, fluid flow, thermal behaviour and heat transfer parameters as compared to base fluids (water). It is happened because of following reasons:

1- Nano fluid achieved higher thermal conductivity compared with the (base) fluid.

2- Extra molecular area gain due to addition of nano particles in base fluid and thus increased thermal conductivity rate of nanofluid, improved the results 21% approximately.

3- On the other hand, the effect of geometrical profile also acknowledged where rectangular strip micro insert based micro channel show better performance in term of fluid flow, thermal parameters as compared with micro channel without micro insert because of higher 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 micro inserts over rectangular micro channel.

5- Enhanced area of micro inserts effects optimum results in terms of better performance up to 9%-18% compared with simple micro channel without inserts.

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