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Comparative analysis of thermal and fluid flow behaviour of diverse nano fluid using Al_2O_3, ZnO, CuO nano materials in concentric spiral tube heat exchanger

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Present paper based on computational and experimental study, in which diverse parameters have been investigated for observing the fluid flow, thermal and performance attributes like thermal performance factor, NTU, effectiveness and fluid flow attributes like Reynolds number, Nusselt number, Friction factor, HTR etc of diverse composition of nanofluids in spiral tube having insert, CTHE with insert diameter and pitch distance 2 mm and 20 mm. During present investigation water used as the base fluid associated with diverse additives or nano particles in single and combined form like Zinc Oxide, Aluminium Oxide and Cupric Oxide to form diverse composition of nano fluids with 10 nm particle size and 0.08% volume fraction like Zinc Oxide with water, Aluminium Oxide with Zinc Oxide with water, Aluminium Oxide with water and Aluminium Oxide with Cupric Oxide with water to improve the thermal conductivity. Experimentation has been performed for diverse nanofluids at 31 ^{O}C with flow range 0.721 to 2.941 L/min, which flows in the spiral tube whereas, the hot fluids as water flows at 4.02 L/min across the shell side of test set up at 50 ^{O}C. Here comparative investigation has been drawn for diverse nanofluids for observing its fluid flow, thermal and performance attributes at diverse flow rate with turbulent flow under counter flow condition with Reynolds Number 4236 to 18540. The result predicted that out of four diverse nano fluids Aluminium Oxide and Cupric Oxide with water as base fluid shows best results for fluid flow, thermal and performance attributes, for flow rate range 0.721 to 2.941 L/min and Reynolds Number 4236 to 18540. It has been evaluated that from minimum to maximum Reynolds Number, HTR, Nusselt number, Friction factor and effectiveness and NTU varies from 1228.3 to 3316.4, 88.28–160, 0.0438–0.0306, 0.84–0.55, 4.66–1.96 for Aluminium Oxide and Cupric Oxide nano fluid.

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1. Introduction

In present scenario, there are wide range of research opportunities in solar area and nano technology in terms of enhancement in thermal performance and efficiency of solar collectors, thermal exchanger devices, radiators, thermal reservoir and hybrid micro solar collector equipments for diverse application like water cooling, water heating, heat exchange, space heating etc. Past studies focused on geometrical parameters aspect like different shape and size of inserts like triangular perforated twisted tape with V cut [9], fins, and baffles etc, longitudinal spacing and angular spacing of their proposed inserts, fins and baffles etc, for observing the effects of thermal performance of devices and fluid peculiarities, study showed little bit enhancement but it has some limitation due to shape and size complexities in solar based devices [10,11,12,13,14,17,19]. Recently researchers pay specific attention on nano fluid science due to its effective chemical and physical properties and diverse nano fluids [15,16,18] in thermal based devices as per selected applications mentioned above where heat transfer enhancement were major focusing areas and for achieving it, parametric study has been investigated out through various researches, which plays an important role in heat transfer enhancement like effect of particle size with varying volume frac-

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tion, use of different surfactant for gaining better stability of nano fluids with different ultra sonication timing were majorly studied [15,18]. Now researchers collaborate these both areas to overcome from past problems and provide a feasible solving for the problem statements related like poor efficiency, poor thermal performance of solar collectors, heat exchanger devices, hybrid micro solar collectors and solar space heating devices etc, by using optimum shape and size of geometry with optimum blend of nano fluid composition in these devices to improve its efficiency, thermal performance etc. More effective and versatile heat exchanger devices can be constructed through proper methodology, thermal enhancement and economical consideration, to bring the heat exchanger designs in lower size or up to some micro level size with high performance factor. [1] Garimella et al. observed the effect of HTR and fluid flow in coiled type annular ducts under laminar flows and transition flow condition, the result depicts an enhancement under laminar and transition flow. [2] Similarly, Prabhanjan et al. [3] has been observed the effect of HTR in HCHE and straight tube and result achieved effective heat transfer rate. Ho et al. [4–6] derived the model/correlations for HTC of tube-side and air-side and results show a close agreement with proposed model/correlations for HTR. S. Krishn. [7] conducted a review on the parameters that effects or influence the CHF and investigates the effects of pool boiling over nanofluid. Investigation depicted that as the concentration of volume, orientation of particle increases, it positively affects CHF, wettability and surface roughness of nano fluid and with lower size and shape of particle HTC increases. R. Kumar. et. al. performed an investigation for depicting the effects of triangular perforation and side V cuts in twisted tape with PTT having pitch ratio of 50 mm and the results has been shows an increment in the TPF and fluid flow behavior for TPTTV than PTT [9] A. A. Bachchan. et. al. [8] shared a review on methods that improves the distillation rate through PCM, selection of geometrical shape over absorber plate, nano particles etc, and the results shows an enhancement in distillation rate with PCM, fins over absorber plate and nano particles. Kumara. et al. [18] performed experimental investigation on fluid flow behavior of Al_2O_3 with diverse base fluid like water, paraffin and ethylene glycol as nano fluid for diverse volume fraction varies from 0.01 to 0.1% the results showed an increment near about 13–28% for Al_2O_3 + Water, for 12%-26% Al_2O_3 + Ethylene Glycol and for 09%-25%(Al_2O_3 + Paraffin), as the volume concentration of nano particle increases, increment in friction factor value were observed, but with an increase in flow rate slight decrement in f were observed. For the Nusselt number good Results were observed at 0.06 vol% of Al_2O_3/water nanofluid.

2. Governing Equations:

The governing equations for calculating the fluid flow, thermal and performance attributes through experimental test set up were determined by following steps, for calculating flow rate of hot fluid as water and cold fluid as nano fluid, governing equations are as follows,

$$Q_{fds} = \frac{Vol.}{t} \tag{1}$$

$$Q_{fds} = A.V \tag{2}$$

$$m_{rf} = \rho.A.V \tag{3}$$

Here, m_{fr} is the flow rate of hot fluid as water and cold fluid as nano fluid which is used to obtain HTR. Heat transfer rate are governed by equation,

$$Q_{hf} = m_{rhf}.C_{phf}(T_{in} - t_{out}) \tag{4}$$

$$Q_{cf} = m_{rcf}.C_{pcf}(T_{out} - t_{in}) \tag{5}$$

Where, T_{in} = Inlet temperature of GI tube shell side, T_{out} = Outlet temperature of GI tube shell side, t_{in} = Inlet temperature of spiral tube (tube side) and t_{out} = Outlet temperature of spiral tube (tube side). Next step based on LMTD method for calculating convective heat transfer coefficient (h_{cc}) and overall heat transfer coefficient (U_{ohtr}) based on governing equation:

$$Q_{rf} = h_{cc}.A.\Delta T \tag{6}$$

$$\Delta T = \frac{(\Delta T1 - \Delta T2)}{\ln(\frac{\Delta T1}{\Delta T2})} \tag{7}$$

$$\Delta T_1 = (T_{out} - t_{in}) \tag{8}$$

$$\Delta T_2 = (T_{in} - t_{out}) \tag{9}$$

$$U_{ohtr} = \frac{1}{(\frac{1}{hi} + \frac{1}{ho})} \tag{10}$$

After calculating above parameters next step is used to evaluate the fluid flow attributes of cold fluid as nano fluid based on governing equation:

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

$$Re = \frac{\rho.A.D}{\mu} \tag{12}$$

$$f = \frac{\Delta P}{\left(\frac{L}{D}\right)\left(\frac{\rho.v^2}{2}\right)} \tag{13}$$

After calculating above parameters next step is used to evaluate the performance attributes of cold fluid as nano fluid based on governing equation:

$$\varepsilon = \frac{Q_{actual}}{Q_{max}} \tag{14}$$

$$Q = m_{rcf}.C_{pcf}(t_{out} - t_{in}) = m_{rhf}.C_{phf}(T_{in} - T_{out}) \tag{15}$$

$$Q_{max.f} = C_{min}(T_{in} - t_{in}) \tag{16}$$

$$T_{out} = T_{in} - \frac{Q_{max}}{C_{max}} \tag{17}$$

$$t_{out} = t_{in} + \frac{Q_{max}}{C_{min}} \tag{18}$$

$$NTU = \frac{U.A_s}{C_{min}} \tag{19}$$

$$C_{min} = m_{rf}.C_{cpf}$$

$$NTU_{counter} = \frac{1}{c-1}\ln(\frac{\varepsilon - 1}{\varepsilon c - 1}) \tag{20}$$

$$NTU_{parallel} = -\ln(\frac{1 - \varepsilon(1+c)}{1+c}) \tag{21}$$

$$\eta_{thpf} = \frac{\left(\frac{Nu}{Nu_s}\right)}{\left(\frac{f^{0.33}}{{f_s}^{0.33}}\right)} \tag{22}$$

$$Nu_s = 0.023Re^{0.8}Pr^{0.4} \tag{23}$$

Fig. 1. Isometric view of spiral tube having clock wise flow [19].

Table 1
Dimensions of spiral tube heat exchanger. [19]

Parameters	Dimensions
Inner diameter of the spiral coil tube (inner tube), mm	10.6
Outer diameter of the spiral coil tube (inner tube), mm	12.6
Number of turns in coil of spiral tube and Number of coils in spiral tube	3 & 6
Distance between spiral tube (inner tube),, mm	11.4
Outer diameter of outer Galvanized Iron tube (shell tube), mm	162
Inner diameter of outer Galvanized Iron tube (shell tube), mm	154
Length of the Galvanized Iron tube (shell tube),mm	850
Pitch of Insert, mm	20
Diameter of Insert, mm	2

$$f_s = 0.316Re^{-0.25}(\text{BlasiusEquation}) = [0.79Ln(Re) - 1.64]^{-2}(\text{PetukhovEquation}) \quad (24)$$

$$f_s = [0.79Ln(Re) - 1.64]^{-2}(\text{PetukhovEquation}) \quad (25)$$

3. Experimental test set up layout and Instrumentation:

Fig. 2 shows layout of experimental testing setup for spiral tube type heat exchanger whereas, Fig. 1 shows the plane spiral tube geometrical model . The experimental test set up consists of a outer tube made of GI material namely shell side tube, which is fully insulated with glass wool, spiral copper tube is installed inside the outer GI shell pipe and fixed with flanges, rubber packing, nut and bolts with 04 RTD thermocouples, 02 pressure transmitters and 02 mass flow meters each were attached at inlet and outlet of the GI shell tube and spiral copper tube with data acquisition system.

Testing rig was designed and fabricated in such a way or manner that it's each and every element or components can be easily assembled and disassembled. Including this measuring unit like data logger, pressure transmitter, mass flow meter, rota meter,

Table 2
Operating conditions of diverse fluids [19]

Parameters	Hot Water	Nano Fluid 1 (Cold Fluid) $ZnO + H_2O$	Nano Fluid 2 (Cold Fluid) $Al_2O_3 + ZnO + H_2O$	Nano Fluid 3 (Cold Fluid) $Al_2O_3 + H_2O$	Nano Fluid 4 (Cold Fluid) $Al_2O_3 + CuO + H_2O$
Inlet nano fluids temperature, (K)	323	304	304	304	304
Flow rate, (L/min)	4.021	0.721-0.2.941	0.721-0.2.941	0.721-0.2.941	0.721-0.2.941
Specific heat c_p, (KJ/kg. °C)	4.185	3.571	3.145	3.827	3.089
Thermal conductivity K, ($W/m^2.K$)	653	762	763	765	767
Viscosity μ, (Ns/m^2)	0.000547	0.00095	0.00095	0.00095	0.00095
Density ρ, (g/m^3)	0.983	1.140	1.295	1.071	1.324

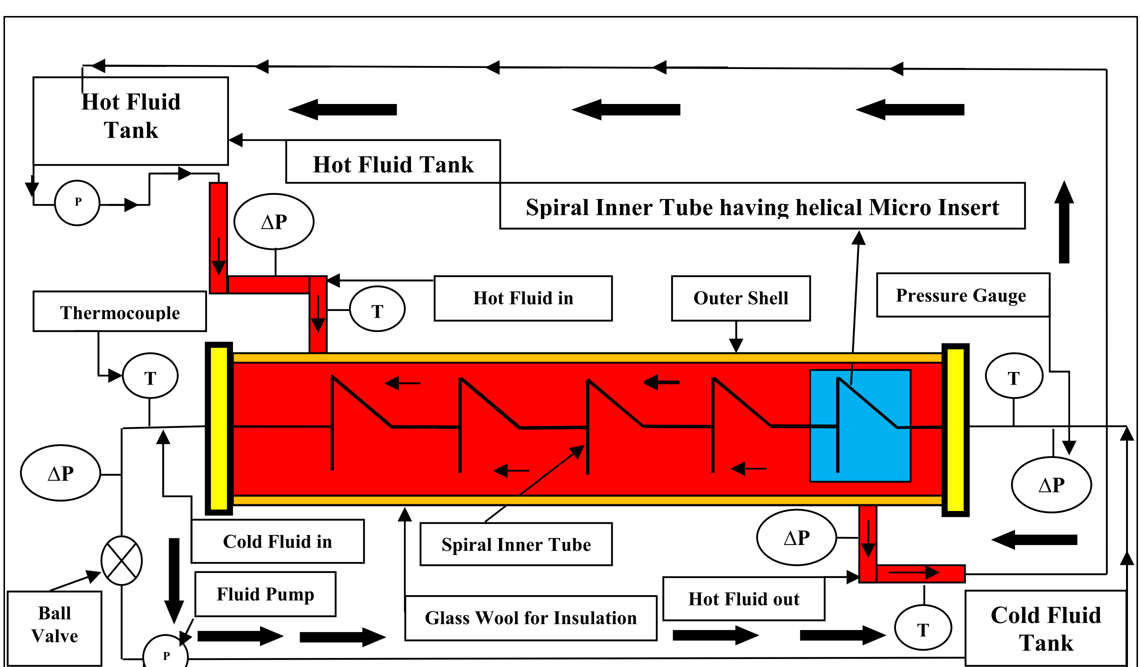


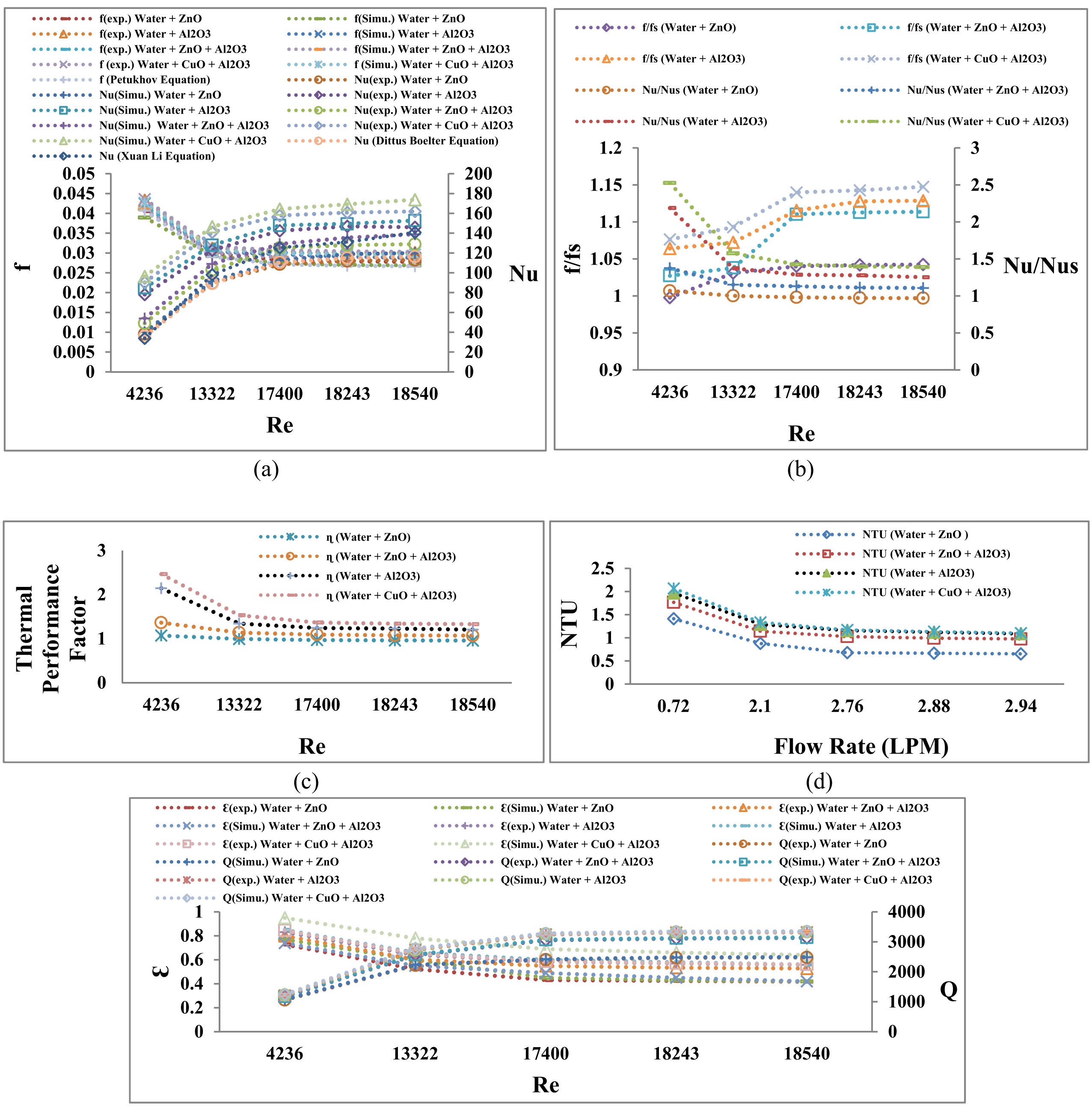
Fig. 2. Schematic diagram of the experimental test set up. [19].

were used to calculate temperature pressure drop and flow rate, flow controlling unit for maintaining flow rate of fluids like pumps, valves and variac, temperature controlling unit for maintaining the temperature of hot and cold nano fluid at desirable operating temperatures like contractor, temperature logger, heating element etc, were installed properly.

Experimental test set up have 08 RTD thermocouples T1, T2, T3, T4, T5, T6, T7 and T8 attached on the outer surface of GI shell tube with data acquisition system. Hot fluid as water moves from hot water tank to GI shell tube and cold fluid as nano fluid moves from cold nano fluid tank to spiral tube with the help of peristaltic pump at test section. Table 1 shows dimensions of experimental test set up and Table 2 shows operating parameters and values of diverse fluids.

4. Result and discussion

The proposed research has been investigated for acknowledging the fluid flow, thermal and performance attributes of diverse nanofluids inside spiral tube having insert as shown in figure number 3(a), 3(b), 3(c), 3(d) and 3(e) with varying Reynolds Number from 4236 to 18,540 with turbulent flow under counter flow condition, friction factor varies from 0.0406 to 0.0278 for Water + ZnO nano fluid, 0.0418 to 0.0297 for Water + ZnO + Al_2O_3 nano fluid, 0.0433 to 0.0301 for Water + Al_2O_3 nano fluid, 0.0436 to 0.0303 for Water + CuO + Al_2O_3 nano fluid and here all nano fluids show decreasing trend as Reynolds number and flow rate is increasing as shown in Fig. 3(a) whereas, it has been observed that the friction factor simulated result for diverse types of nano fluids also show



(e)

Fig. 3. (a) Variation between Friction Factor and Nusselt Number for varying Reynolds Number. (b) Variation between Nu/Nu_s and f/f_s with varying Reynolds Number. (c) Variation between Thermal Performance Factor and Reynolds Number for diverse Nano Fluids. (d) Variation between Number of Transfer Unit (NTU) and Mass Flow Rate for diverse Nano Fluids. (e) Variation between Effectiveness and Heat Transfer Rate for varying Reynolds Number.

decreasing trend as Reynolds number and flow rate is increasing and the friction factor result varies from 0.0390 to 0.0269 for Water + ZnO nano fluid, 0.0411 to 0.0286 for Water + ZnO + Al_2O_3 nano fluid, 0.0425 to 0.0288 for Water + Al_2O_3 nano fluid, 0.0427 to 0.0296 for Water + CuO + Al_2O_3 nano fluid as shown in Fig. 3(a) on other hand, an enhancement in Nusselt number has been observed with respect to Reynolds number range as shows in Fig. 3(a) for diverse types of nano fluids and their values varies from 38.25 to 113 for Water + ZnO nano fluid, 49.15 to 129 for Water + ZnO + Al_2O_3 nano fluid, 78.18 to 146 for Water + Al_2O_3 nano fluid, 90.28 to 162 for Water + CuO + Al_2O_3 nano fluid. While comparing the above experimental values for these diverse types of nano fluid compositions, Water + CuO + Al_2O_3 nano fluid shows best result as compared to other types of nano fluids, due to high thermal conductivity of both particles, more heat transfer occur during fluid flow and because of extra fluid particle surface area occurred by addition of nano particles, best and optimum results obtained for Water + CuO + Al_2O_3 nano fluid where optimum values for Nusselt number, friction factor is 162 and 0.00303 for suitable and effective flow rate i.e. 2.94 L/min with Reynolds number range 4236 to 18540. whereas, it has been observed that the Nusselt number simulated result for proposed nano fluids with varying material composition of nano fluid also show increasing trend as Reynolds number and flow rate is increasing and the Nusselt number result varies from 40.25 to 120 for Water + ZnO nano fluid, 54.08 to 139 for Water + ZnO + Al_2O_3 nano fluid, 84.95 to 151.85 for Water + Al_2O_3 nano fluid, 96.45 to 173.85 for Water + CuO + Al_2O_3 nano fluid as shown in Fig. 3(a). Thus, it has been computed after comparing all results that the experimental and simulated results shows a close agreement and validates the values came from simulation and experimentally for Nusselt number & friction factor. Again Nusselt number and Friction factor experimental values for Water + ZnO nano fluid were validated through Blasius equation, Petukhov equation and Dittus–Boelter as shown in equation number 23, 24, 25.

When the simulation and experimental results compared with each other for diverse nano fluids such as Water + ZnO nano fluid, Water + ZnO + Al_2O_3 nano fluid, Water + Al_2O_3 nano fluid and Water + CuO + Al_2O_3 nano fluid etc, it has been noted, that the experimental values were smaller than simulation values because some amount of heat loss occurred from the proposed experimental test set up, but the error % between simulation and experimental values, which varies from 3% – 5% for all the proposed attributes. Thus, lower error % range validated this proposed research work. Now, it is clearly shown from the Fig. 3(d) that as the flow rate is increasing from 0.72 to 2.94 L/min, NTU values is decreasing from 1.41 to 0.65 for Water + ZnO nano fluid, 1.76 to 0.97 for Water + ZnO + Al_2O_3 nano fluid, 1.96 to 1.088 for Water + Al_2O_3 nano fluid, 2.06 to 1.102 for Water + CuO + Al_2O_3 nano fluid. Out of four diverse nano fluid samples, Water + CuO + Al_2O_3 nano fluid shows best and optimum results because Water + CuO + Al_2O_3 nano fluid have larger particle surface area, contact area and high thermal conductivity, due to high thermal conductivity of both nano material particles, more heat transfer occur during fluid flow and because of extra fluid surface area achieved by addition of nano particles than other types of nano fluid, this phenomenon influences NTU. From Fig. 3(e) it has been observed that the effectiveness is decreasing with increasing rate of Reynolds number where as heat transfer rate is increasing with Reynolds number range 4236 to 18540. It is clearly shown from Fig. 3(b) and Fig. 3(c) that as f/f_s factor is increasing when Reynolds number is increasing 4236 to18540, but Nu/Nu_s factor is decreasing as well as thermal performance factor is also decreasing but among other types of nano fluids, only Water + CuO + Al_2O_3 nano fluid show best and promising results.

4.1. Conclusions

The results based on fluid flow, thermal and performance attributes for diverse nano fluids flow through spiral tube type heat exchanger under turbulent flow for counter flow condition, which shows similarity and close agreement between experimental and simulation results. Thus, the above results validated this present work and these results will helpful to improve the performance and enhance the heat transfer rate of normal heat exchanger designs/devices, hybrid electronic equipments, biomedical equipments etc having diverse shapes & size of inserts or micro inserts and micro channel. The improved designs with effective nano fluids will be used or applicable in several devices like hybrid and micro solar collectors, heat exchangers, for cooling & heating purpose and for increasing the life cycle of hybrid, electronic and biomedical devices. Nano fluids have only one limitation that is, it requires timely ultrasonication, otherwise it faces coagulation, sedimentation and stability issues which decreases its performance level. From the above results, following points has been identified which are as follows:

It has been observed that out of four nano fluids, i.e. Water + ZnO nano fluid, Water + ZnO + Al_2O_3 nano fluid, Water + Al_2O_3 nano fluid and Water + CuO + Al_2O_3 nano fluid, which flows through spiral tube having helical coil micro inserts, Water + CuO + Al_2O_3 nano fluid showed best results for fluid flow attributes, thermal and performance attributes, with varying flow rate and Reynolds number ranges i.e. 0.72 to 2.94 L/min and 4236 to 18540.

The maximum and optimum value of for Water + CuO + Al_2O_3 nano fluid for HTR, Nu , f and effectiveness and NTU are 1228.3–3316.4, 88.28–160, 0.0438–0.0306, 0.84–0.55, 4.66–1.96.

Water + Al_2O_3 nano fluid and Water + ZnO + Al_2O_3 nano fluid shows second and third best results than Water + ZnO nano fluid.

Enhancement in the fluid flow attributes, thermal and performance peculiarities like HTR, heat transfer coefficient, NTU, Nu, TPF has been observed for various types of nano fluids for diverse flow rate under turbulent flow for counter flow condition. This is because the addition of diverse nano particles for making diverse nano fluids increases the particle surface area of base fluid for heat-transfer and the addition of nano particle in base fluid as water increases more thermal conductivity in overall nano fluid and hence, increases the heat transfer.

The experimentation was carried out for diverse range of Reynolds's numbers and flow rate. The experimentation results has been showed an improvement in the fluid flow, thermal and performance attributes of diverse types of nano fluids as Reynolds's number range and flow rate were increased and shows best results in higher range.

Pressure drop has been studied in diverse nano fluids. An increment has been observed in fiction factor for diverse nano fluids as compared to plain water but there is no significant increment occurs in plain water.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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