Performance Improvement Research of Coil Heat Exchanger Using CFD

[1]Nithin V K

[1]Assistant Professor
[1]Department Of Mechanical Engineering,
[1]Universal Engineering College, Thrissur,India

Abstract—**The heat transfer coefficient of heat exchangers is improved by using nanofluids. Therefore, in recent years, researchers have paid more and more attention to the use of nanofluids in heat exchangers. Very few studies have been performed on multi-fin geometries using spiral heat exchangers loaded with nanofluids. In this review, we consider a study of numerical investigation of the heat transfer performance of coil heat exchangers using various water-based nanofluids with different numbers of coil turns. In order to identify the most efficient heat exchanger design under various heating conditions, a total of nine cases are first prepared and the numerical results are validated against experimental correlations. A two-head waveform and thirty spool rotations using various water-based nanofluids with a nanofluid concentration of four percentage was found to be the most effective of all cases[1]. The heat transfer coefficient increases with increasing coil turns and decreasing number of fin heads.**

IndexTerms— coil turn, helical heat exchanger, heat transfer coefficient, multi-fin shape, nanofluid, fin head

I. INTRODUCTION:

Heat exchangers are widely used in mechanical devices used to exchange heat from one type of fluid to another. Heat exchangers are commonly used in a variety of heat transfer applications such as power plants, refrigeration, electronics, air conditioning, and automotive equipment. Heat exchangers are available in a variety of shapes and sizes depending on the application in which they are used[2]. Shell and tube, double tube, spiral or straight, plate type, fin type, spiral, etc. By changing the geometry of the heat exchanger we can find the best fit for the heat transfer performance. Literature indicates that spiral coils can transport heat more efficiently than straight tubes. Adding nanoparticles to liquids improves the thermophysical properties of heat exchangers, allowing them to transfer more heat[2]. Nanofluids have become popular due to their high thermal conductivity compared to other conventional liquids.

Due to their exceptional thermophysical properties, nanofluids are used in applications such as solar energy, refrigeration, heat exchangers, heat pipes, electronics cooling, automotive, core system cooling, biomedical, coolants in machining and manufacturing. The wide range of applications of nanofluids has led researchers to integrate them into all types of heat transfer applications[3]. Significant improvements in heat transfer are observed using heat exchangers of different shapes and sizes with nanofluids, but the complexity of the design has led to the use of finned geometries with multiple heads and different coil turns. No one has considered using . Increased fluid mixing also improves the heat transfer coefficient of the coil-rotating finned geometry[4]. In this study, we study and describe the effects of geometry and coil rotation on heat exchanger performance given a particular common and effective design of heat exchangers. This efficient heat exchanger can be used in a variety of applications to reduce energy consumption by offering higher thermal performance

Also, in the chemical industry, heat is removed from a fluid, which is a heat exchanger, and transferred to another fluid. Improving heating or cooling can lead to energy savings, resulting in more efficient processes[4]. Heat transfer is enhanced using a variety of techniques and methods such as: It allows high heat transfer rates in small volumes by increasing the heat transfer area or heat transfer coefficient between the fluid and the surface. B. Spiral heat exchanger. In recent years, significant improvements in heat transfer coefficients have been observed with the use of nanofluids. Liquids with suspended nanoparticles are called nanoliquids. Adding nano-sized solid metal (Cu, Au, Fe) or metal oxide particles to the base liquid increases the thermal conductivity of the resulting liquid[5]. Various heat transfer enhancement techniques are used to improve the performance of heat exchangers. Among many heat transfer improvement methods, finned tubes are the most widely used technique to improve the heat transfer performance of tubes. Because the convective heat transfer coefficient of the fluid is low in conventional smooth tube heat exchangers, their thermal performance is known to be poor. The mechanism of heat transfer enhancement by internal finned tubes is based on flow separation and fin reattachment[6].

A literature survey is collected for a deeper understanding of a topic. We searched various research papers and compiled the information. Various sources have helped to better understand this topic and the following research papers have been reviewed.

Md. Jahid Hasan, Shams Forruque Ahmed, and Arafat A. Bhuiyan consider the fin head profile in the article "Geometric and Coil Rotation Effects on Performance Optimization of Helical Heat Exchangers Using Nanofluids" in[1]. to study the geometric effects of the helical heat exchanger. in a few spool turns. Numerical models were validated using experimental correlations and numerical simulations. Three different rib head profiles (2 head ribs, 3 head ribs, and 4 head ribs) and coil turns (10 turns, 20 turns, and 30 turns) were used to predict geometric effects. The low head fin geometry has a higher heat transfer coefficient than the 3 and 4 fin head geometry. It is also shown that the higher the number of turns in the fin profile, the higher the heat transfer coefficient, 30 turns, and the higher the local Nusselt number. The introduction of nanofluids ($Al2O3$, CuO, $SiO2$, ZnO) into the coil heat exchanger suggested that the water-based nanofluid $Al2O3$ provides the highest heat transfer coefficient across the tube.

II. OBJECTIVES AND MOTIVATION:

Heat exchangers (HX) are widely used in mechanical devices that transfer heat from one type of fluid to another. They are mainly used in heat transfer applications such as power plants, refrigeration, electronics, air conditioning, chemical processes and automotive equipment. Heat exchangers come in a variety of shapes and sizes depending on the application. Shell and tube, twin tube, spiral or straight, plate type, fin type, spiral, etc. Many researchers have tried to study the optimal heat transfer performance by changing the geometry of the heat exchanger. CFD Analysis of Coil Heat Exchangers for Various Geometries and Boundary Conditions Effect of Coil Rotation on Heat Transfer Effect of Heat Exchanger Geometry and Flow Motion Effect of Fin Profiles on Heat Transfer Improved Heat Transfer with Nanofluids Heat transfer coefficients vary by number increases as the fin head count decreases and the coil rotation speed increases. Therefore, we decided to use ANSYS fluent 2019 R1 to analyze how different properties affect the heat transfer coefficient through computational fluid dynamics.

II.1. MATERIALS & METHODS:

CFD code in FLUENT contains his three main elements: (i) pre-processor, (ii) solver, and (iii) post-processor. In this project the following assumptions are made in the CFD simulations: Wall thickness is neglected, wall temperature is assumed constant, gravity is ignored, steady state is chosen, steady state is chosen, flow is considered laminar for better results increase. and eddy investigations consider the RNG-k-ε model with eddy-dominated flow.

In this case, the study was conducted using a CFD solver. The flow field was analyzed using the Reynolds-averaged Navier-Stokes equation[7]. The basic equations for flow modeling are the continuity, momentum, and energy equations. A CFD study was created considering a constant wall temperature condition. All geometric parameters and fluid properties were used for heat exchanger design. A schematic of a specialized heat exchanger was first created to create the fluid domain of the 3D CFD model. Three different geometries were chosen for this study. B. Two ribs with 10 turns, 20 turns and 30 turns. The dimensions of the geometry profiles have changed slightly to keep the same hydraulic diameter as they each use the local Nusselt number.

The inner round tube has a diameter of 5 mm and the nanofluid moves while the water flows in the outer finned tube[5]. A thin wall was placed between the nanofluidic tube and the outer finned tube. All boundary conditions are kept the same to analyze the effects of nanofluids. Different inlet velocities of water flowing through corrugated tubes are combined with nanofluids flowing through circular tubes at different constant velocities.

Table. 1. Fluid properties and geometrical parameters used

Parameters	Magnitude	Units
T_{in}	293	K
T_{wall}	423	K
d	0.0113	m
h_c	0.02	m
R_c	0.04	m
L	1.26	m
V_{in}	1.5	ms^{-1}
P_{out}	0	Pa

Meshing was performed with a CFD meshing tool. A maximum tooth surface size of 30 mm was chosen. As mesh independence tests were run and the number of meshes continued to increase, the results fluctuated.

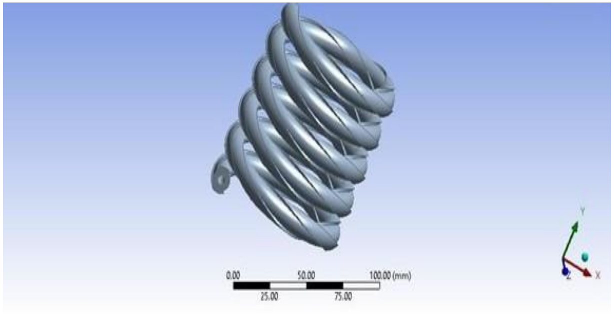


Fig. 1 Geometry of 2 ribs and 10 revolutions

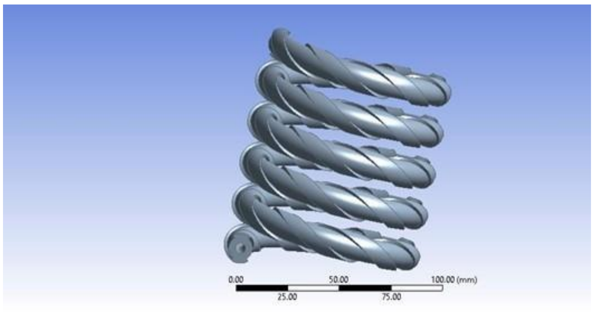


Fig. 2 Geometry of 2 ribs and 20 revolutions

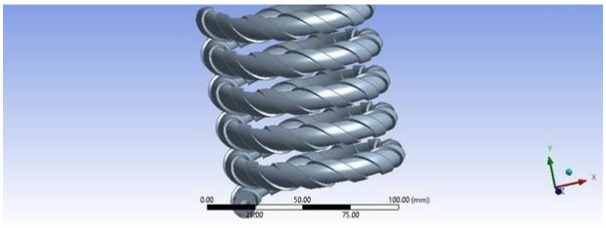


Fig. 3 Geometry of 2 ribs and 30 revolutions

Fig. 4 Meshing of heat exchanger

Fig. 5 Meshing of 2 ribs and 10 revolutions

Since this study only investigated the heating effect of the heat exchanger, it is likely that the wall temperature is much higher than the temperature of the liquid flowing inside the tube. The boundary conditions used to investigate the geometric effects on the nine shapes are described below. A uniform constant velocity is set at the entrance and applied to the boundary normal. The magnitude of the inflow velocity is Uin = 1.5 $ms{-1}$ in all cases. Anti-slip is also considered. An air inlet temperature Tin = 293 K is chosen[4], [8]–[10]. Also, the outlet pressure is zero gauge pressure, $Pout$ = 0 Pa. A constant wall temperature condition is applied in this study. A relatively high temperature of the wall temperature is taken to maintain a large temperature difference and ensure better analysis and observation of the effect. The constant wall temperature is 423 K. The k-ε turbulence model was chosen to evaluate turbulence effects in this study. To evaluate turbulence effects, the k-ε turbulence model was chosen in this study.In addition to consideration, the vortex effect RNG option with vortex-dominant flow is chosen. A SIMPLE pressure-velocity coupling based algorithm was chosen to perform the simulations. This is because it can solve a variety of heat transfer and fluid flow problems. A quadratic scheme was adopted to solve the pressure scheme. Additionally, cell-based least-squares gradients were considered to solve the computational model.

III.RESULTS AND DISCUSSION:

Geometric effects were analyzed by varying the number of rotations of the coil. Effects of velocity, temperature and geometrical changes indicating changes in local Nusselt number were shown. Several cases were considered to correctly evaluate the geometric effect. Four different nanofluids were later implemented in the heat exchanger of choice and introduced internal flow through circular tubes.

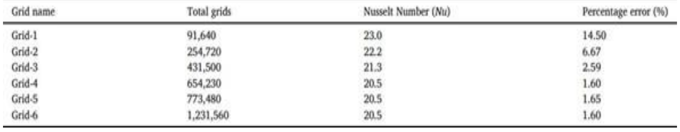
III.I Effect of heat exchanger geometry on flow motion[11]:

We numerically analyzed the effect of heat exchanger shape and flow movement on the heat exchanger. Significant variations were observed in the velocity and temperature distributions across the heat exchanger. Variation of axial velocity contours at these cross-sections. Velocity distributions for all nine cases of coiled-tube heat exchangers are also shown. Note that the larger the rib size, the higher the velocity due to the curvature. The axial velocity of the three finned headcasings is correspondingly higher than the other two finned headcasings due to the relatively high axial airflow momentum. As the spool rotation increases, the magnitude of the velocity across the tube increases. We also know that the higher the rib profile rotation, the higher the temperature at a particular location.

III.II Heat transfer by changing fin shape:

The larger the surface area of the heat exchanger, the higher the heat transfer coefficient, because the larger the cross-sectional area, the better the heat transfer coefficient. In order to increase the wetted area of the cross section, we introduce a rib profile and verify its performance. Fin profile implementation plays an important role in enhancing the heat transfer coefficient of both spiral and straight tubes. A similar trend was observed in this survey. Due to the existing curvature, the rib geometry also ensures considerable mixing within the heat exchanger.

Table. 3. Grid independence test results.



Grid independence test results at dean number of 300.

Grid name	Total grids	Nusselt Number (*Nu*)	Percentage error (%)
Grid-1	91,640	23.0	14.50
Grid-2	254,720	22.2	6.67
Grid-3	431,500	21.3	2.59
Grid-4	654,230	20.5	1.60
Grid-5	773,480	20.5	1.65
Grid-6	1,231,560	20.5	1.60

III.III Heat transfer by filament rotation[12]:

Rib profiles increase the heat transfer coefficient, and as the number of rib profile tips decreases, the heat transfer coefficient increases. The effect of the ribbed head and the spool rotation effect of the ribbed shape were studied. Higher curvature is guaranteed with increased spool rotation. A finned 30 turn with two heads provides the highest Nusselt numbers across the tubes. This indicates that the 30 highest turns provide the highest heat transfer coefficients for the 3-fin and 4-fin geometries respectively. The higher the rotation of the coil, the higher the heat transfer coefficient of both heat exchangers.

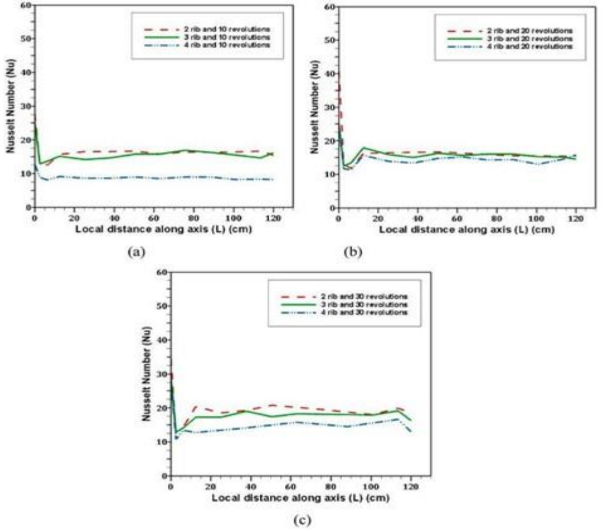


Fig. 6 . Nusselt number (Nu) versus local distance (L) (cm) for (a) 10-turn, (b) 20-turn, and (c) 30-turn heat exchangers.

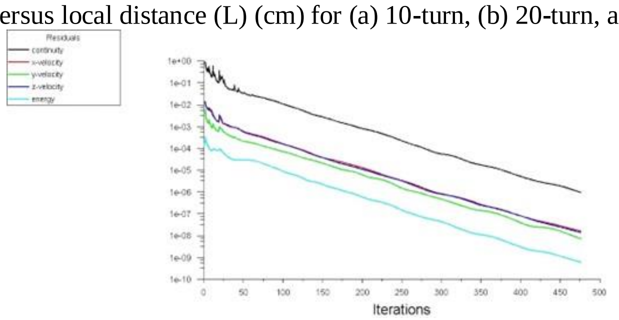


Fig. 7 Results of 10 repetitions of laminar flow

After the analysis results obtained for the heat transfer rate with various geometrical parameters are shown below; graphical results and contours are depicted for each case,Shown below are the analytical results obtained for the heat transfer coefficient using different geometric parameters. Graphical results and contour lines are displayed for each case.

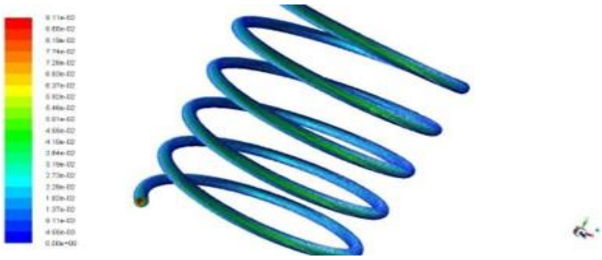


Fig. 8 Velocity contours for nanofluids (laminar flow)

Fig. 9 pace contour of water- laminar

Fig. 10 temperature contour of nano fluid - laminar

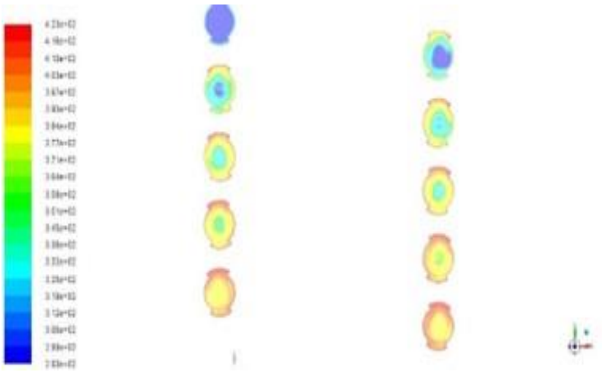


Fig. 11 temperature contour of water – laminar

Fig. 12 pace contour at sectional plane

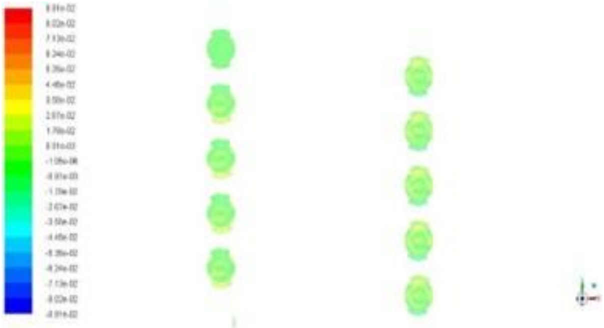


Fig. 13 velocitycontour at cross sectional plane

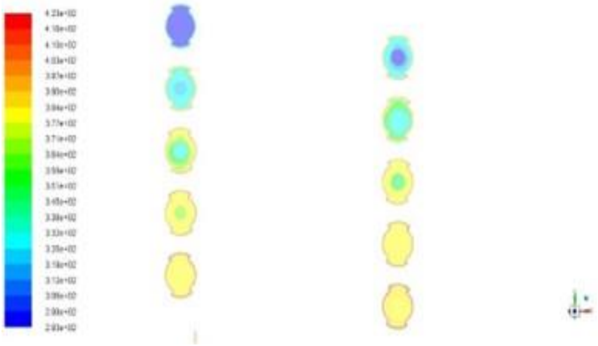


Fig. 14 temperaturecontour at cross sectional plane

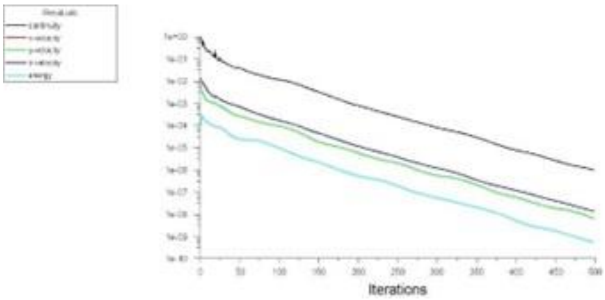


Fig. 1520revolutionsiterationsresults

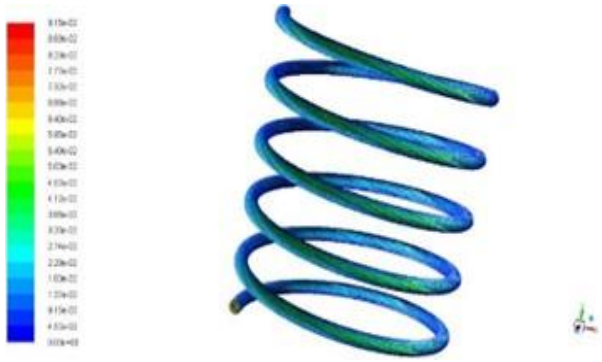


Fig. 16 Velocity contours of nanofluids

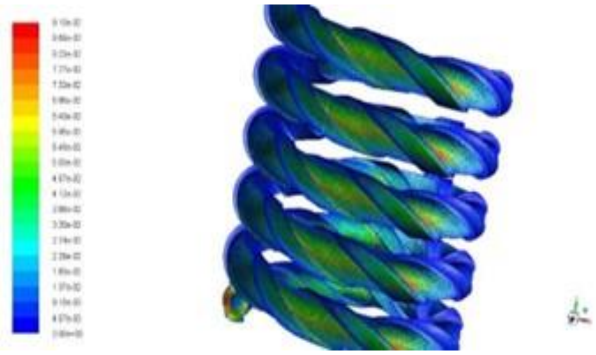


Fig. 17 velocitycontour ofwater

Fig. 18 temp. for nanofluids

Fig. 19 temp. contours for water

Fig.20 Velocity contours

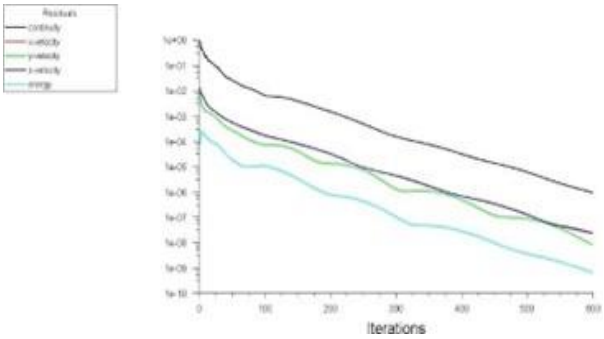


Fig. 2130revolutions iterations

Fig. 22 Velocity contours nanofluid

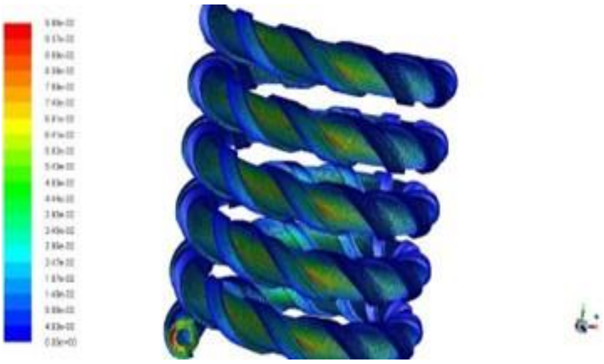


Fig. 23 Velocity contours water

Fig. 24 temp. contours nanoliquids

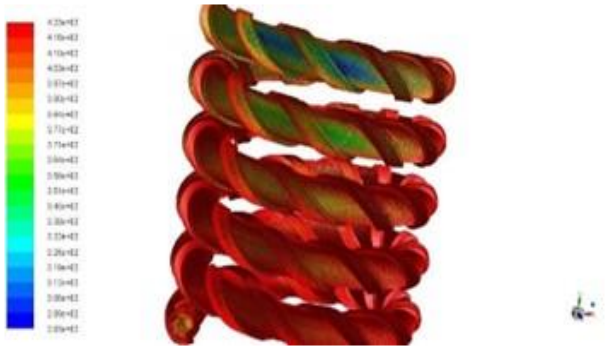


Fig. 25 temp. contours for water

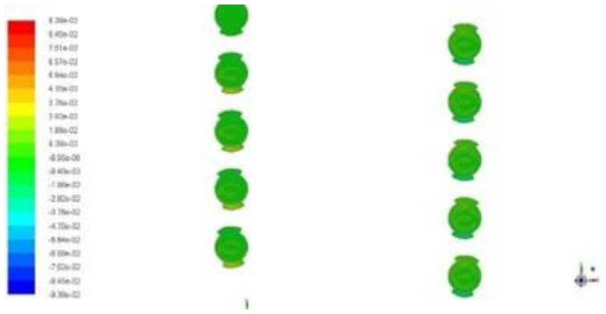


Fig. 26 Velocity contours

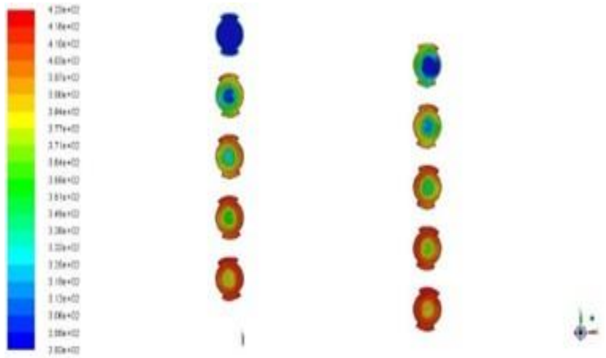


Fig. 27 temp. contours

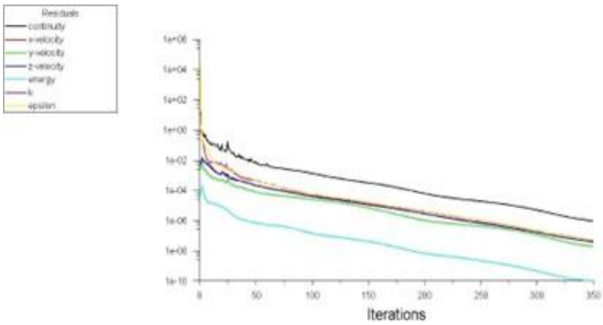


Fig. 28 iterations results by 0.1 velocity

Fig. 29 Velocity contours

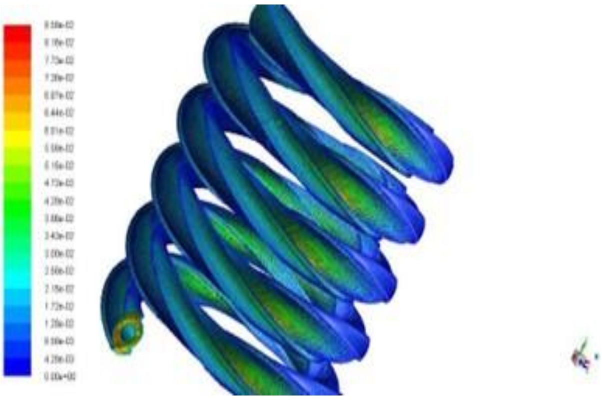


Fig. 30 Velocity contours for water

Fig. 31 temp. contours

Fig. 32 temp. contours for normal water

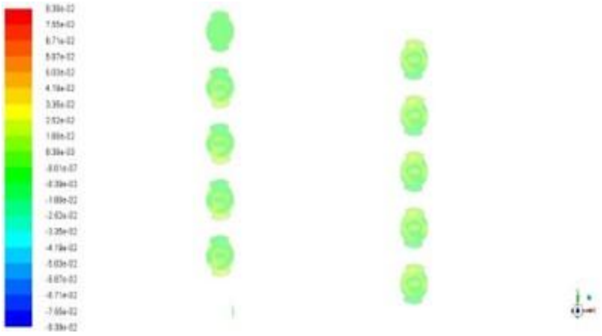


Fig. 33 Velocity contours

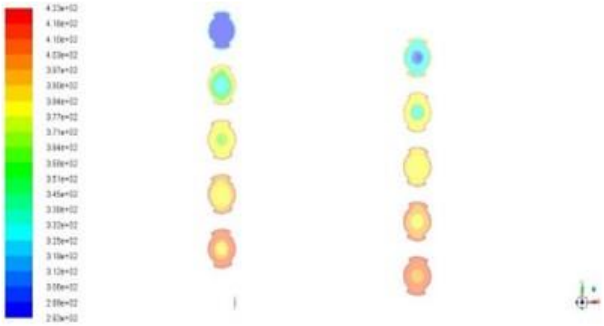


Fig. 34temp.cntours

Modifiedresult using modified flowconditionand velocityare:-

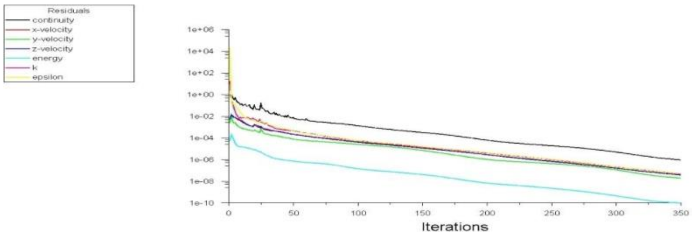


Fig. 3510 revolution iteration result using 0.05velocity

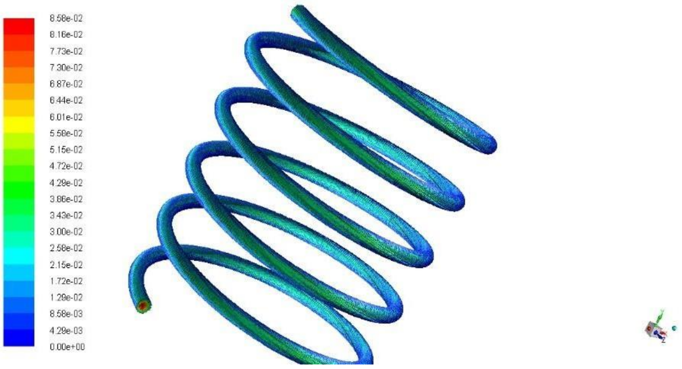


Fig. 36 velocity contour ofnano fluid

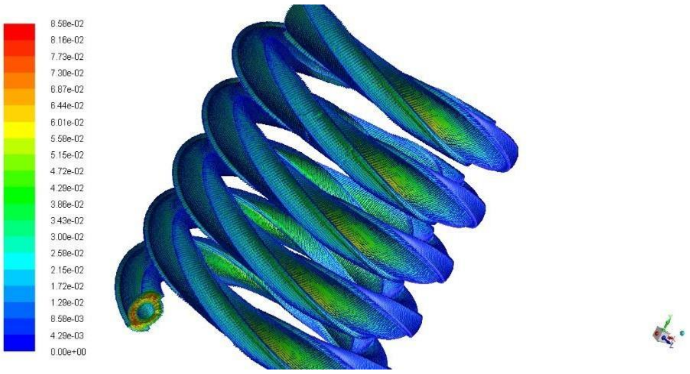


Fig. 37 velocity contour of water

Fig. 38 temperaturecontour ofnano fluid

Fig. 39 temperaturecontour ofwater

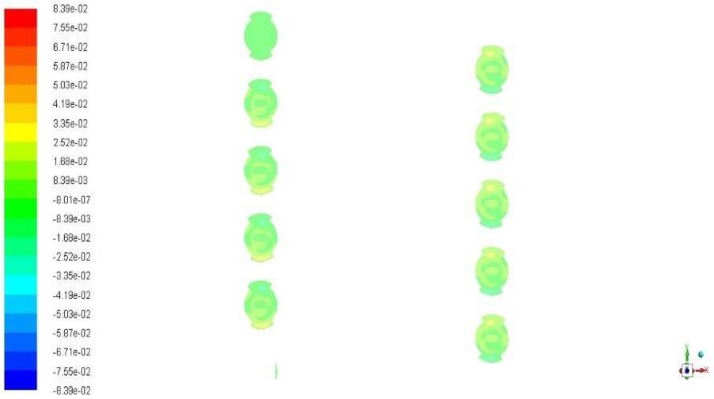


Fig. 40 velocity contour at cross sectional plane

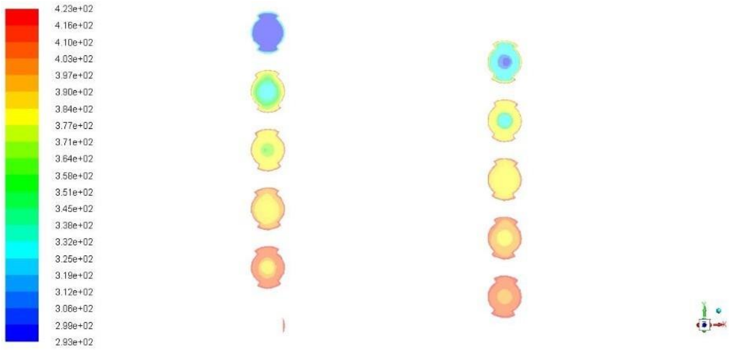


Fig. 41 temperaturecontour at cross sectional plane

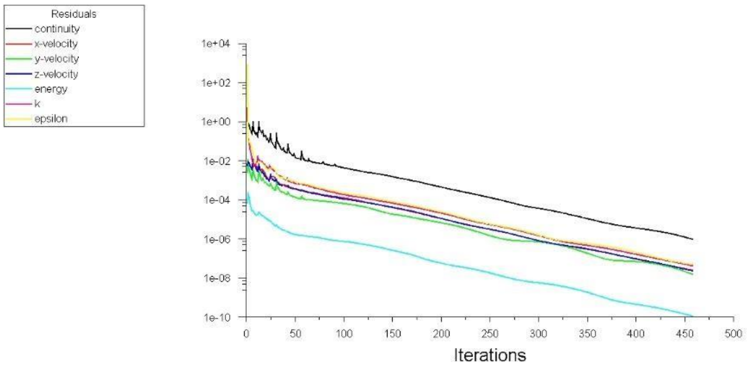


Fig. 42 10 revolution iteration result using 0.1 velocity

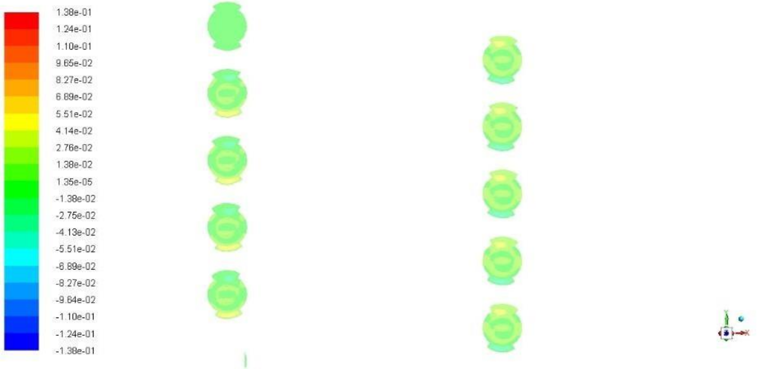


Fig. 43 velocity contour at cross sectional plane

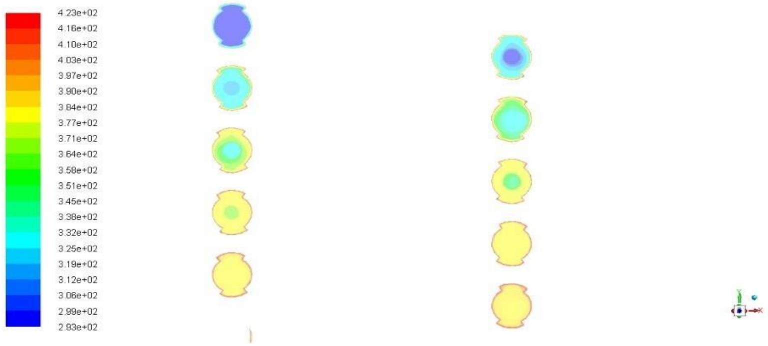


Fig. 44 temperaturecontour at cross sectional plane

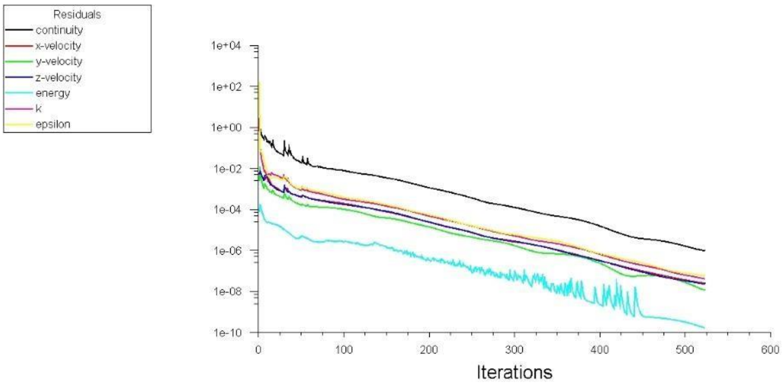


Fig. 45 10 revolution iteration result using 0.15 velocity

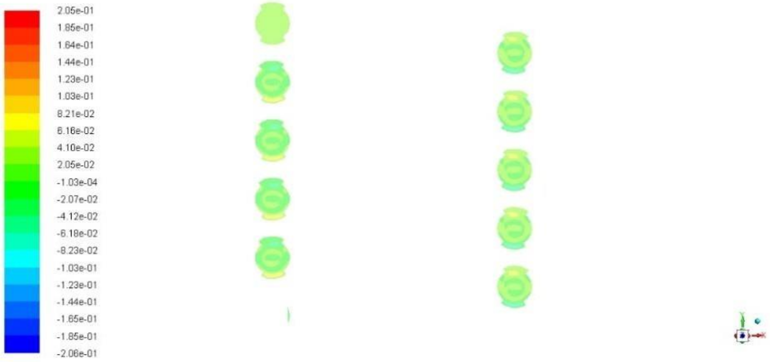


Fig. 46 velocity contour at cross sectional plane

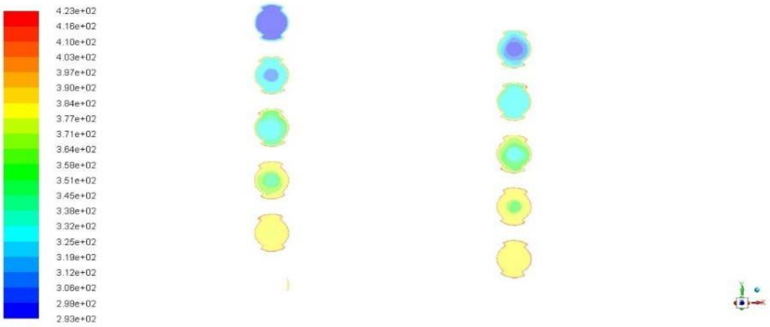


Fig. 47 temperaturecontour at cross sectional plane

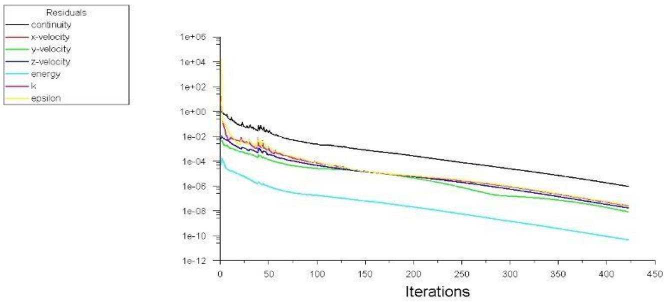


Fig. 48 20 revolution iteration result using 0.05 velocity

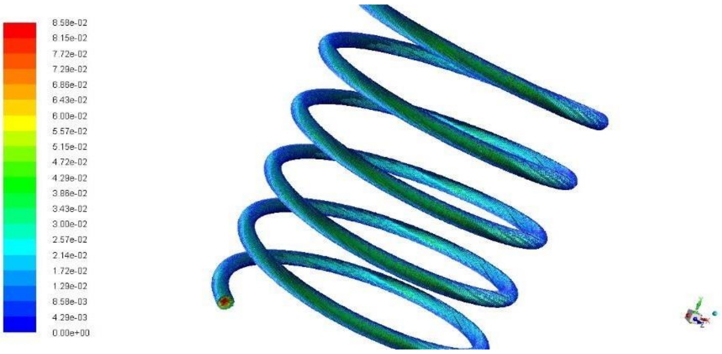


Fig. 49 velocity contourof nano fluid

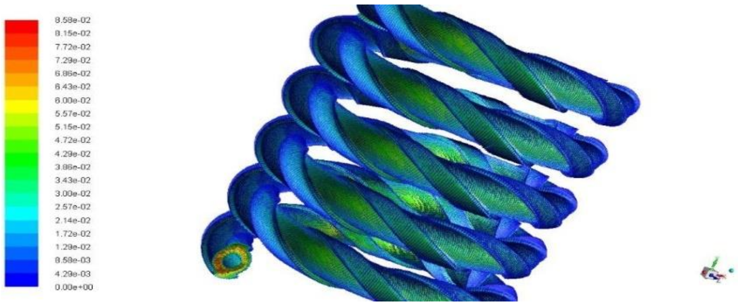


Fig. 50 velocity contour of water

Fig. 51 temperaturecontour ofnano fluid

Fig. 52 temperaturecontour ofwater

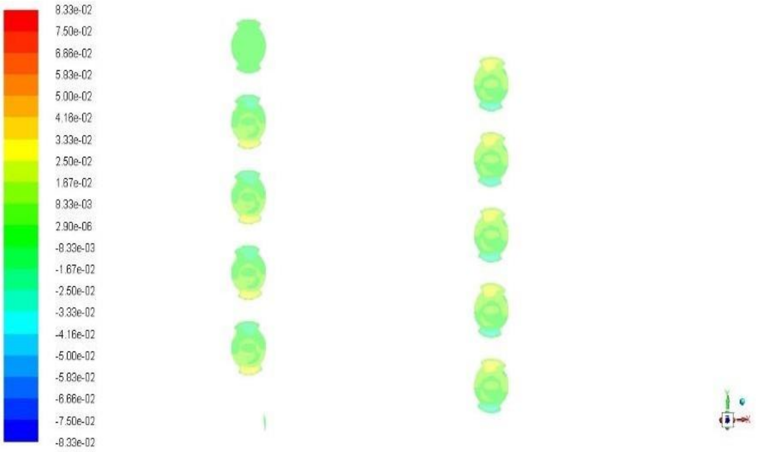


Fig. 53 velocity contour at cross sectional plane

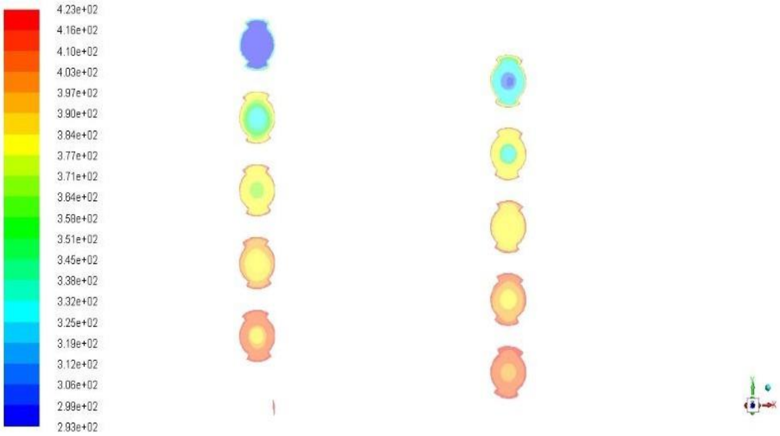


Fig. 54 temperaturecontour at cross sectional plane

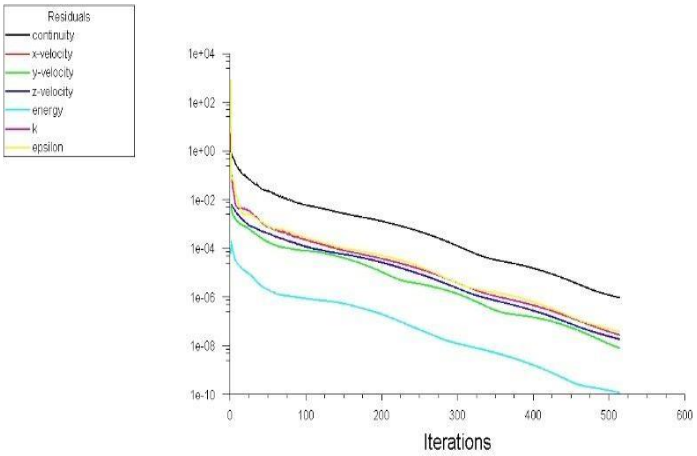


Fig. 55 20 revolution iteration using 0.1velocity

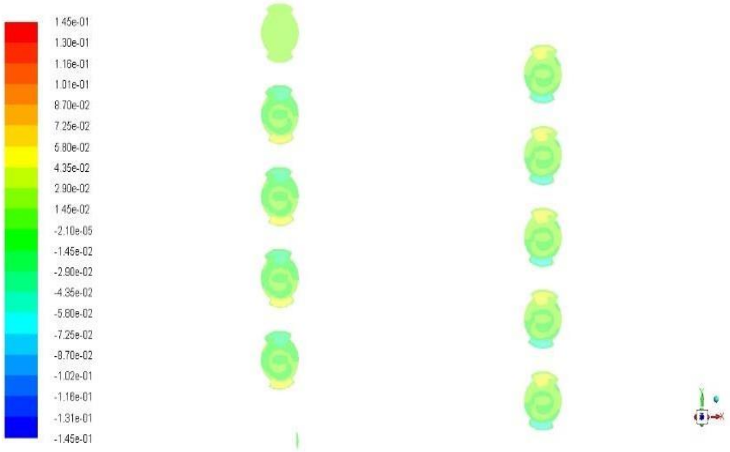


Fig. 56 velocity contour at cross sectionalplane

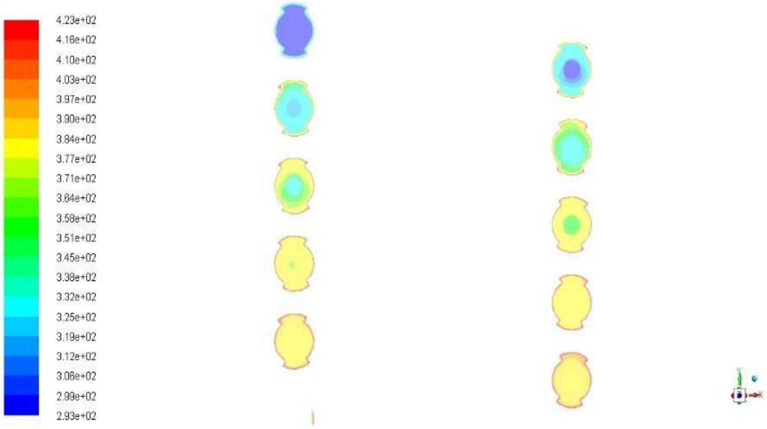


Fig. 57 temperaturecontour at cross sectional plane

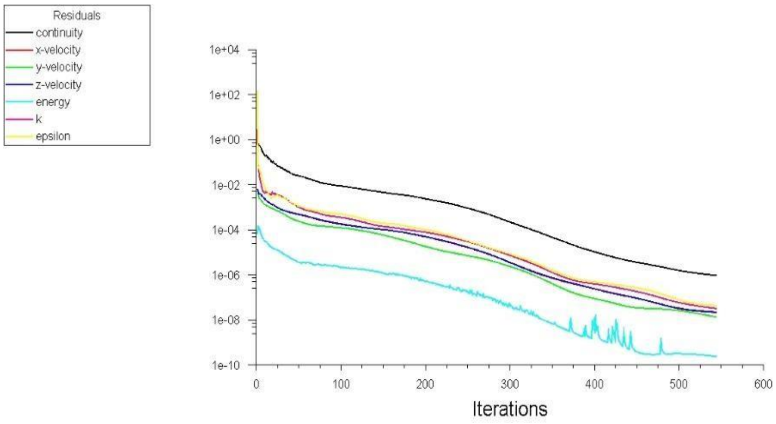


Fig. 58 20 revolution iteration result using 0.15 velocity

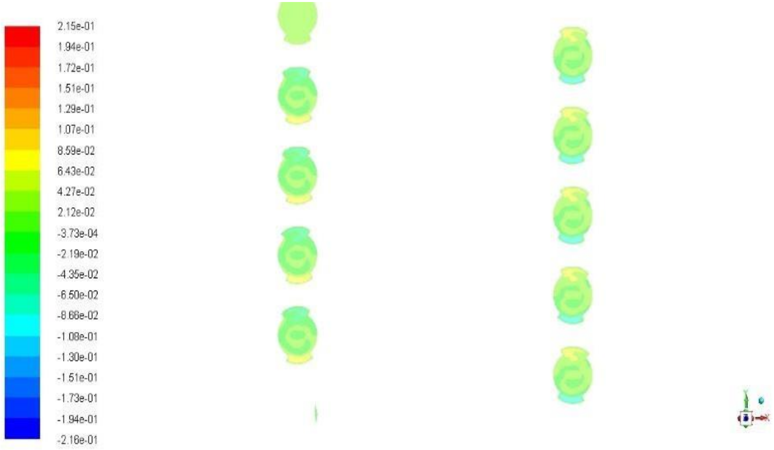


Fig. 59 velocity contour at cross sectional plane

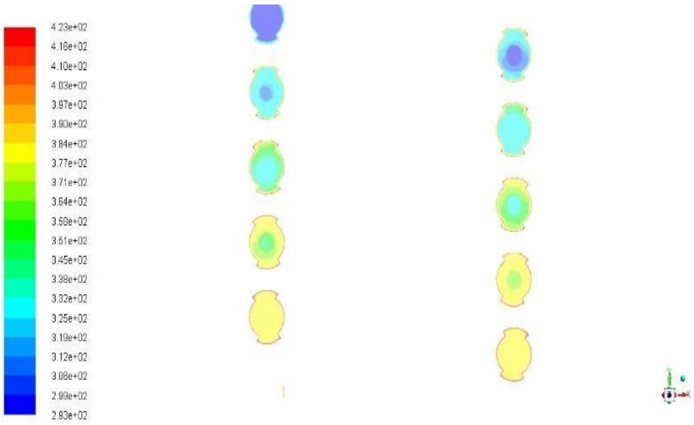


Fig. 60 temperaturecontour at cross sectional plane

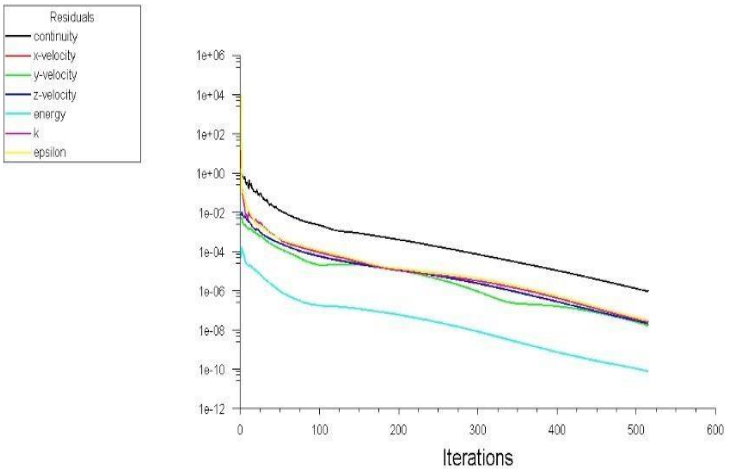


Fig 61 30 revolution iteration result using 0.05 velocity

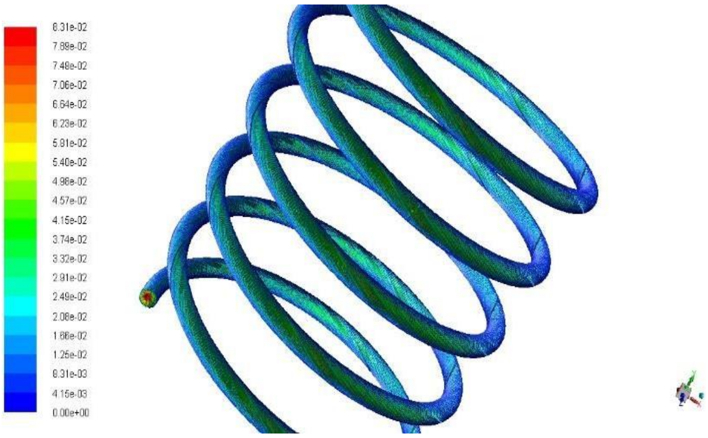


Fig. 62 velocity contourof nano fluid

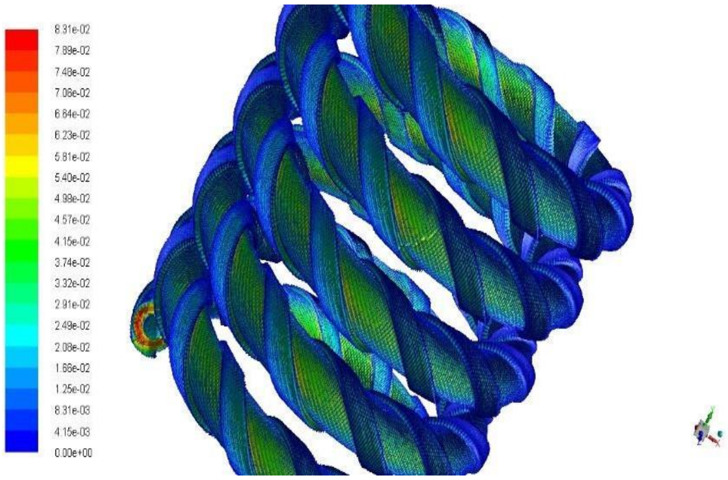


Fig. 63 velocity contour of water

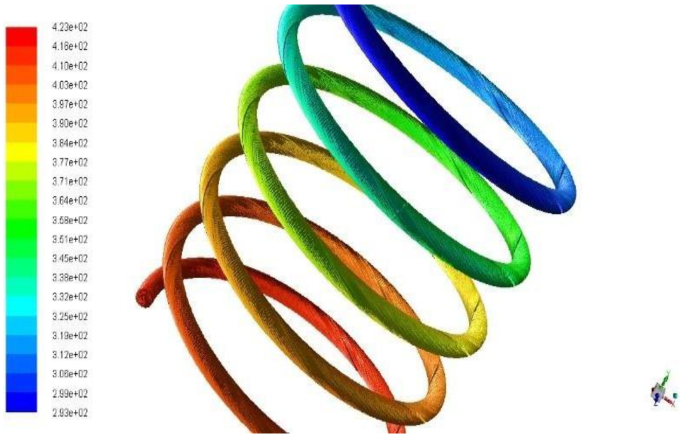


Fig. 64 temperaturecontour ofnano fluid

Fig. 65 temperaturecontour ofwater

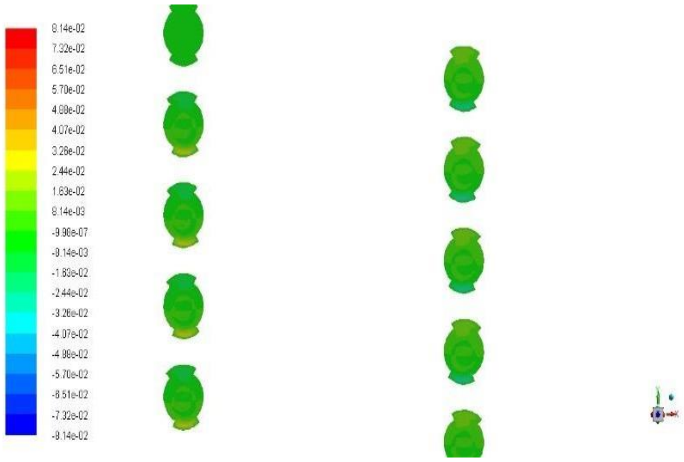


Fig. 66 velocity contour at cross sectional plane

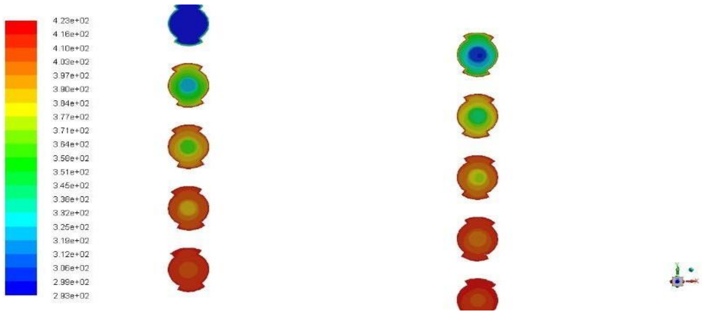


Fig. 67 temperaturecontour at cross sectional plane

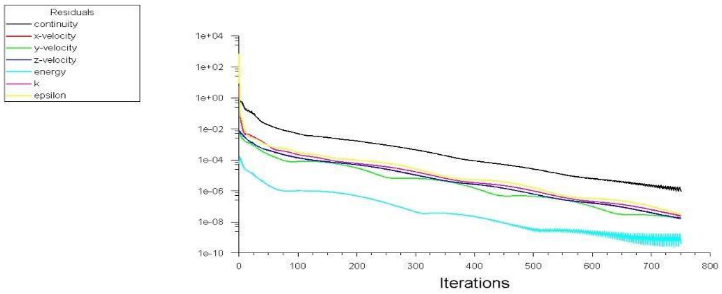


Fig. 68 30 revolution iteration result using 0.1 velocity

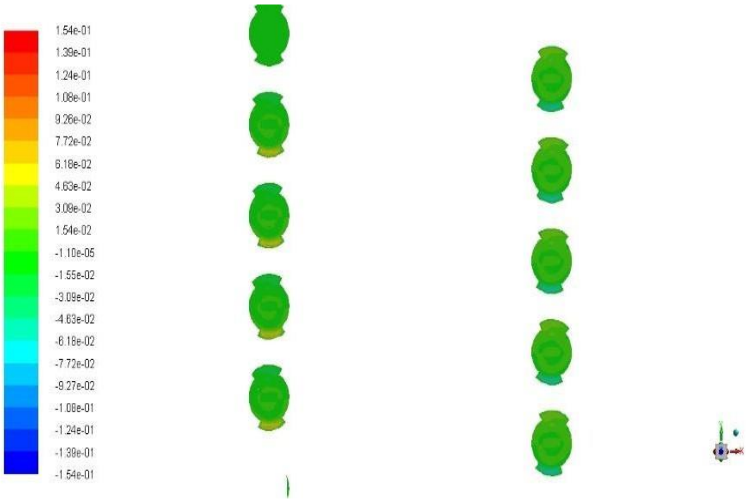


Fig 69 velocity contour at cross sectional plane

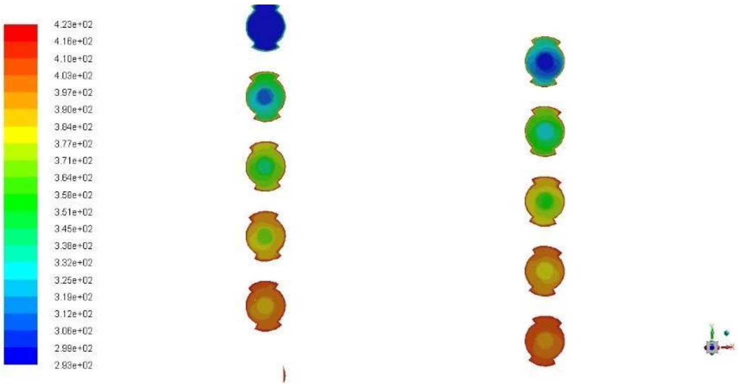


Fig. 70 temperaturecontour at cross sectional plane

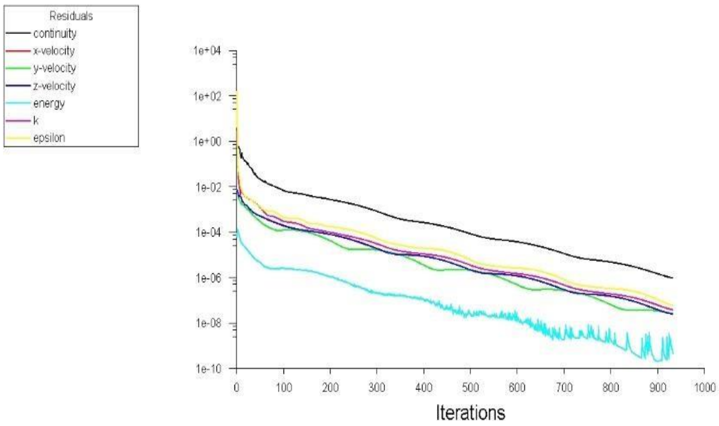


Fig. 71 30 revolution iteration result using 0.15 velocity

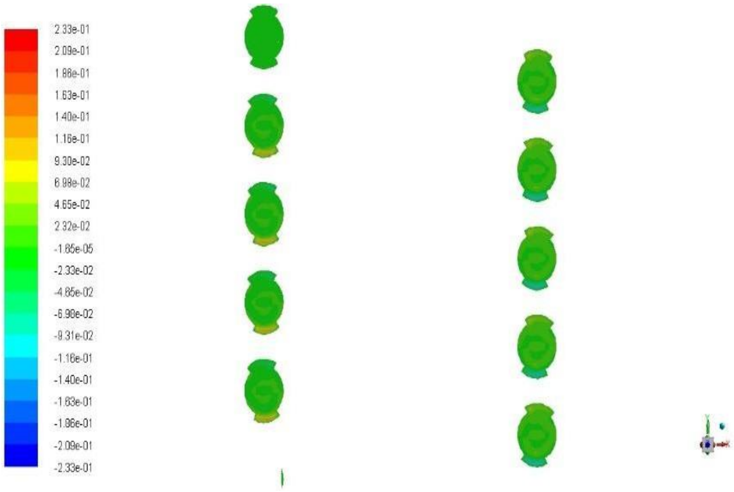


Fig. 72 velocity contour at cross sectional plane

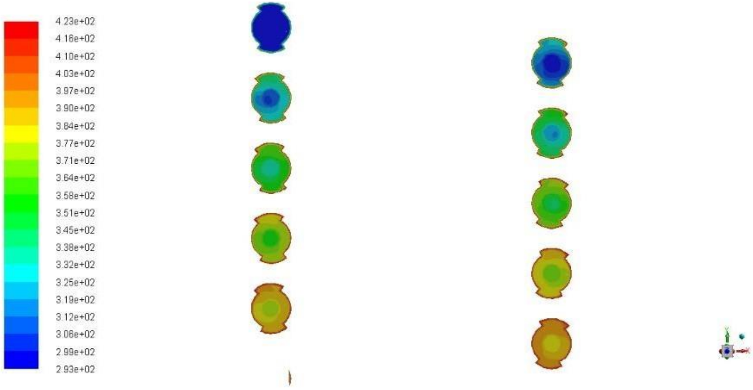
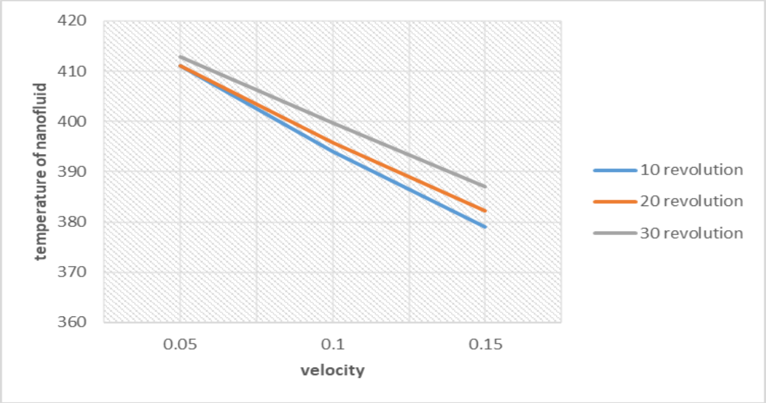


Fig. 73 temperaturecontour at cross sectional plane

Fig. 74 graphical result of nano fluid



IV CONCLUSIONS:

This work consisted of finding the geometric effects on the heat exchanger considering a ribbed head profile with multiple turns. Numerical models were validated using experimental correlations and numerical simulations. Three different fin head profiles and coil turns were used to predict geometric effects. Low head fin geometry has higher heat transfer coefficient than 3 and 4 fin head geometry[13]. The introduction of nanofluids into heat exchangers showed that water-based Al2O3 nanofluids provided the highest heat transfer coefficient across the tubes. In addition to this increased number of rotations, the rotations performed lead to higher heat transfer coefficients, which can be further analyzed with further changes in the boundary conditions.

References:

[1] M. J. Hasan, S. F. Ahmed, and A. A. Bhuiyan, "Geometrical and coil revolution effects on the performance enhancement of a helical heat exchanger using nanofluids," *Case Studies in Thermal Engineering*, vol. 35, Jul. 2022, doi: 10.1016/j.csite.2022.102106.

[2] H. Ayed*et al.*, "Experimental investigation on the thermo-hydraulic performance of air–water two-phase flow inside a horizontal circumferentially corrugated tube," *Alexandria Engineering Journal*, vol. 61, no. 9, pp. 6769–6783, Sep. 2022, doi: 10.1016/j.aej.2021.12.024.

[3] H. M. Maghrabie*et al.*, "Intensification of heat exchanger performance utilizing nanofluids," *International Journal of Thermofluids*, vol. 10, May 2021, doi: 10.1016/j.ijft.2021.100071.

[4] M. J. Hasan, S. F. Ahmed, and A. A. Bhuiyan, "Geometrical and coil revolution effects on the performance enhancement of a helical heat exchanger using nanofluids," *Case Studies in Thermal Engineering*, vol. 35, Jul. 2022, doi: 10.1016/j.csite.2022.102106.

[5] C. T. Muthiah, C. Arvind, S. Sekar, R. Giri, C. Devanathan, and S. Girisankar, "Analysis of heat transfer characteristics in helically coiled heat exchanger using Al2O3and CuO nanofluids," in *Journal of Physics: Conference Series*, Oct. 2021, vol. 2054, no. 1. doi: 10.1088/1742-6596/2054/1/012026.

[6] S. F. Ahmed *et al.*, "Data-driven modelling techniques for earth-air heat exchangers to reduce energy consumption in buildings: a review," *Environmental Chemistry Letters*, vol. 19, no. 6. Springer Science and Business Media Deutschland GmbH, pp. 4191–4210, Dec. 01, 2021. doi: 10.1007/s10311-021-01288-7.

[7] S. Alshahrani, E. I. Jassim, F. Ahmed, and B. I. Jasem, "Performance and environment interactivity of concentric heat exchanger practicing TiO2 nanofluid and operated near heat capacity ratio of unity," *Case Studies in Thermal Engineering*, vol. 28, Dec. 2021, doi: 10.1016/j.csite.2021.101702.

[8] R. N. Radkar, B. A. Bhanvase, D. P. Barai, and S. H. Sonawane, "Intensified convective heat transfer using ZnO nanofluids in heat exchanger with helical coiled geometry at constant wall temperature," *Mater Sci Energy Technol*, vol. 2, no. 2, pp. 161–170, Aug. 2019, doi: 10.1016/j.mset.2019.01.007.

[9] J. Luo *et al.*, "Profit and efficiency enhancement of a cylindrical solar collector by structural modification of helical tube," *Case Studies in Thermal Engineering*, vol. 34, Jun. 2022, doi: 10.1016/j.csite.2022.101982.

[10] G. Nobrega, R. R. de Souza, I. M. Gonçalves, A. S. Moita, J. E. Ribeiro, and R. A. Lima, "Recent Developments on the Thermal Properties, Stability and Applications of Nanofluids in Machining, Solar Energy and Biomedicine," *Applied Sciences (Switzerland)*, vol. 12, no. 3. MDPI, Feb. 01, 2022. doi: 10.3390/app12031115.

[11] S. F. Ahmed *et al.*, "Data-driven modelling techniques for earth-air heat exchangers to reduce energy consumption in buildings: a review," *Environmental Chemistry Letters*, vol. 19, no. 6. Springer Science and Business Media Deutschland GmbH, pp. 4191–4210, Dec. 01, 2021. doi: 10.1007/s10311-021-01288-7.

[12] N. H. Abu-Hamdeh*et al.*, "A detailed hydrothermal investigation of a helical micro double-tube heat exchanger for a wide range of helix pitch length," *Case Studies in Thermal Engineering*, vol. 28, Dec. 2021, doi: 10.1016/j.csite.2021.101413.

[13] A. Alimoradi, "Study of thermal effectiveness and its relation with NTU in shell and helically coiled tube heat exchangers," *Case Studies in Thermal Engineering*, vol. 9, pp. 100–107, Mar. 2017, doi: 10.1016/j.csite.2017.01.003.