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# "CFD analysis on heat transfer characteristics in ionic liquid-based nano-fluids flowing in a double-helical coiled tube heat exchanger"

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**Abstract**

In many industrial applications heat has to be transferred from one flowing fluid to another through a solid barrier separating these fluids. The equipment used for this purpose are called Heat Exchangers. The application of convection studies is mainly in the field of design of heat exchangers

At present study circular cross-sectional double tube with different number of turns and outside diameter keeping constant helix angle was employed with comparison of circular cross section straight tube in a double pipe heat exchanger. The number of turns varies from 1 to 6, keeping the helix angle and total length of tube constant to examine the effect in heat transfer performance.

The aim of this study is

***"To evaluate the heat transfer rate with structural modification of double-helical coiled tube heat exchanger by changing the helical geometry i.e. number of turns and outside helical dia using ionic liquid different weight percentage boron nanofluids based (io-nanofluids) considering the numerical simulation of ε-NTU analysis for both fluids passages*."**

Keywords; Heat exchanger, nano fluids, NTU analysis, heat transfer rate etc.

## I-Introduction

### Basic Types of Heat Exchangers

A heat exchanger is a device in which heat is transferred between a warmer and a colder substance, usually fluids. There are three basic types of heat exchangers:

- Recuperators
- Regenerators
- Direct Contact Heat Exchangers.

**Construction of Heat Exchangers**

A heat exchanger consists of heat-exchanging elements such as a core or matrix containing the heat transfer surface, and fluid distribution elements such as headers or tanks, inlet and outlet nozzles or pipes, etc. Usually, there are no moving parts in the heat exchanger; however, there are exceptions, such as a rotary regenerator in which the matrix is driven to rotate at some design speed and a scraped surface heat exchanger in which a rotary element with scraper blades continuously rotates inside the heat transfer tube. The heat transfer surface is in direct contact with fluids through which heat is transferred by conduction. The portion of the surface that separates the fluids is referred to as the primary or direct contact surface. To increase heat transfer area, secondary surfaces known as fins may be attached to the primary surface.

**Classification According to Construction**

According to constructional details, heat exchangers are classified as follows:

1. Tubular heat exchangers—double pipe, shell and tube, coiled tube
2. Plate heat exchangers (PHEs)- Gasketed, brazed, welded, and spiral, panel coil, and lamella
3. Extended surface heat exchangers—tube-fin, plate-fin
4. Regenerators—fixed matrix, rotary matrix

**Tubular Heat Exchanger- Double-Pipe Exchangers**

A double-pipe heat exchanger has two concentric pipes, usually in the form of a U-bend design. Double pipe heat changers with U-bend design are known as hairpin heat exchangers. The flow arrangement is pure counter-current. A number of double-pipe heat exchangers can be connected in series or parallel as necessary. Their usual application is for small duties requiring, typically, less than 300 $ft^2$ and they are suitable for high pressures and temperatures and thermally long duties. This has the advantage of flexibility since units can be added or removed as required, and the design is easy to service and requires low inventory of spares because of its standardization. Either longitudinal fins or circumferential fins within the annulus on the inner pipe wall are required to enhance the heat transfer from the inner pipe fluid to the annulus fluid. Design pressures and temperatures are broadly similar to shell and tube heat exchangers (STHEs). Figures 1 shows double-pipe heat exchangers.

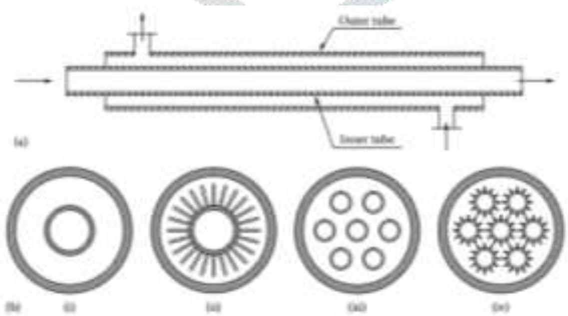


Figure 1 Double pipe/twin pipe hairpin heat exchanger. (a) Schematic of the unit, (b): (i) double pipe with bare internal tube, (ii) double pipe with finned internal tube, (iii) double pipe with multibare internal tubes, and (iv) double pipe with multi-finned internal tubes. (fig 1 Courtesy of Peerless Mfg. Co., Dallas, TX, Makers of Alco and Bos-Hatten brands of heat exchangers).

## II-Literature Review

Due to the wide application of heat exchangers in various industries, improving the heat transfer and increasing the efficiency are very important. Accordingly, a lot of researches have been performed to increase heat transfer.

***P.C. Mukesh Kumar et. al. (2019) )*** investigated the heat transfer and pressure drop of the double helically coiled heat exchanger handling MWCNT/water nanofluids which have been analyzed by the computational software ANSYS 14.5 version.

The MWCNT/water nano-fluids at 0.2%, 0.4%, and 0.6% volume concentrations have been taken for this investigation and it was found that the heat transfer rate and pressure drop increase with increasing volume concentrations of MWCNT/water nano-fluids

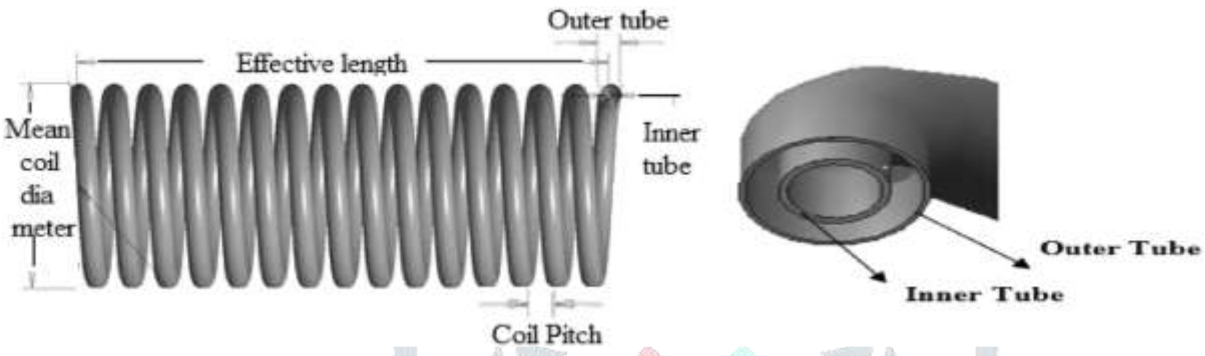



Figure 2- Double helically coiled heat Exchanger ( Courtesy P.C. Mukesh Kumar Research paper)

***Iman Bashtani*** et. al. (2019) has numerically investigated about a double pipe heat exchanger with a simple and corrugated tube assuming three different wave amplitudes. The simulation is performed using ANSYS package, considering turbulent flow and k-ω SST turbulence model. Accordingly, the heat exchanger type is considered to be water-to water and the corresponding flow is parallel so that the hot and cold fluids pass through the inner tube and the shell, respectively. The results show that, in the similar Reynolds number, corrugating increases Nusselt number so that at the maximum state the average Nusselt number of the corrugated heat exchanger is about 1.75 times as compared to the simple heat exchanger.

***Xue Chen et. al. (2019)*** reported for numerical investigation is performed to analyse the high-temperature heat transfer behaviour in a double-pipe heat exchanger filled with open-cell porous foam. The Forchheimer-extended Darcy equation and the local thermal non-equilibrium model were utilized to simulate the flow and thermal transport inside the foam regions, considering the coupling effects between the inner and annular spaces. The results indicate that thermal radiation promotes the thermal exchange between the two fluid sides. The heat exchanger effectiveness is improved by decreasing the porosity or increasing the pore density, exchanger length and annulus dimension, however, the potential increase in the total pressure drop should be seriously considered.

***C. Gnanavela et. al. (2019)*** investigated the thermal performance with respect to the laminar to turbulence flow with various nano-fluids in the heat exchanger pipe with insert of twisted tape with rectangular cut on its rib. The results are compared and best nanofluid was suggested.

## III-Research Methodology

ANSYS Workbench (Student Version) 18.0 is used for Finite element analysis. In ANSYS software the Computational Fluid Dynamics (CFD) is used as platform for the study.

### CFD Analysis

Computational fluid dynamic study of the system starts with building desired geometry and mesh for modelling the domain. Generally, geometry is simplified for the CFD studies. Meshing is the discretization of the domain into small volumes where the equations are solved by the help of iterative methods. Modelling starts with defining the boundary and initial conditions for the domain and leads to modelling the entire system domain. Finally, it is followed by the analysis of the results.

### Geometry

Heat exchanger geometry is built in the design modular of ANSYS workbench design module. Geometry is simplified by considering the plane symmetry. For the analysis counter current heat exchanger in helical shape with concentric tubes are considered. The figure 3.1 and Table 3.2 shows the geometry and dimensions respectively of the heat exchanger.

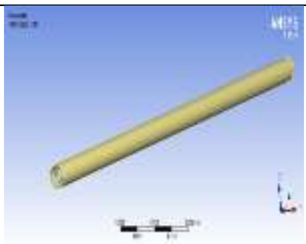
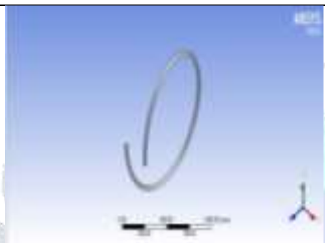
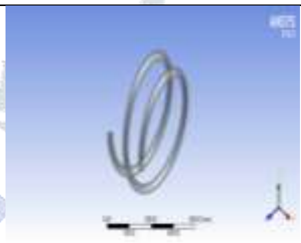
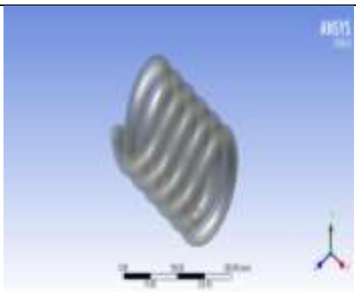
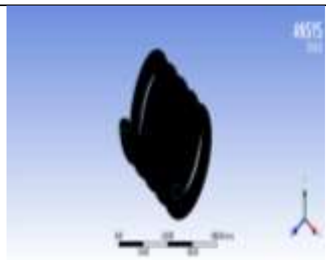
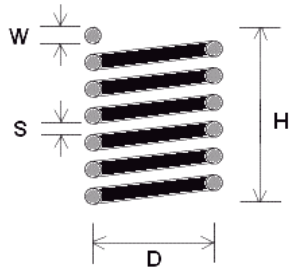
| | | |
|---|---|---|
|  (a) Straight Tube |  (b) Number of Turns=1 |  (c) Number of Turns=2 |
|  (d) Number of Turns=3 |  (e) Number of Turns=4 |  (f) Number of Turns=5 |
|  (g) Number of Turns=6 |  (h) Straight Tube(Meshing) |  (i)Number of turns=6 (Meshing) |

Figure 3.1 Geometry of Heat Exchanger

Table 3.2 Heat Exchanger Dimensions

| No. of Turns | Length of Tubes (Constant) | Outside Dia of Spring D (mm) | Outside Spring Radius R (mm) | Height (free Length) (H) (mm) | Pitch (S) | Geometrical Representation |
|---|---|---|---|---|---|---|
| 1 | 3140 | 1000 | 500 | 300 | 300 |   |
| 2 | 3140 | 500 | 250 | 300 | 150 | |
| 3 | 3140 | 333.3 | 166.6 | 300 | 100 | |
| 4 | 3140 | 250 | 125 | 300 | 75 | |
| 5 | 3140 | 200 | 100 | 300 | 60 | |
| 6 | 3140 | 166.6 | 83.3 | 300 | 50 | |

## IV-Result Analysis

The analysis has been carried out for water and Io-nano fluid with boron nitride nanoparticles at different weight fraction. The number of turns has been varied from 1 to 6. As more than 6 turns are not possible as the pitch will be less than the diameter. For the analysis the three different weight fractions are considered i.e. 0, 0.5, 1 and 3%. A straight tube also considered for the study i.e. number of turns 0.

To design or to predict the performance of a heat exchanger, it is essential to relate the total heat transfer rate to quantities such as the inlet and outlet fluid temperatures, the overall heat transfer coefficient, and the total surface area for heat transfer. Two such relations may readily be obtained by applying overall energy balances to the hot and cold fluids.

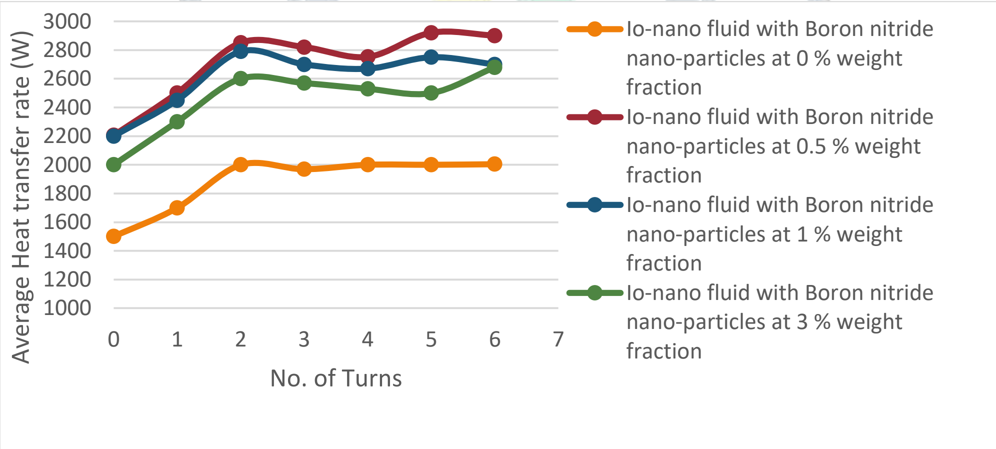



Figure 4.1 Average Heat Transfer (W) variation for different Io-nano Fluid with Boron Nitride Nanoparticles at 0,0.5, 1 and 3% Weight Fraction for different number of turns

The heat exchanger effectiveness depends on the flow geometry and pass arrangement. For a given flow geometry, the effectiveness is a function of two dimensionless quantities, UA/Cmin = NTU and Cmin/Cmax = R. The effectiveness equation is obtained by algebraic manipulation of the equations developed in calculation of the LMTD.

Figure 4.2 shows the Effectiveness variation for different Io-nano Fluid with Boron Nitride Nanoparticles at 0,0.5, 1 and 3% Weight Fraction for different number of turns. It can be observed that the Ionano fluid with 0.5% Boron Nitride particles shows the higher effectiveness. When considering the number of turns, the 5 turn tubes helical heat exchanger shows the better effectiveness.

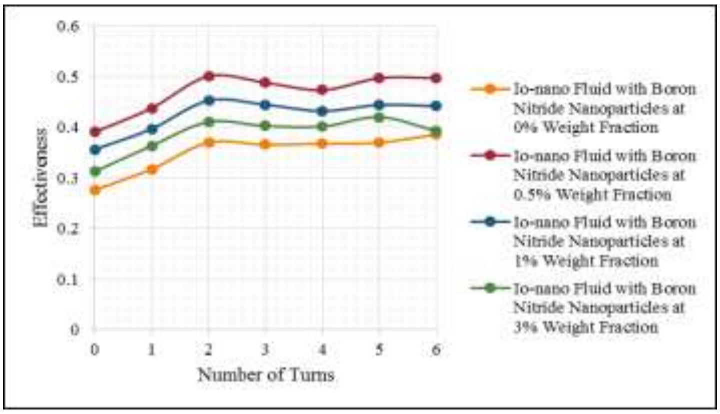



Figure 4.2 Effectiveness variation for different Io-nano Fluid with Boron Nitride Nanoparticles at 0,0.5, 1 and 3% Weight Fraction for different number of turns

The existence of the secondary flow in helical coiled heat exchangers results in a higher heat transfer rate which makes it more special. Dean, a British applied mathematician and fluid dynamist solved the fluid flow for curved tubes and introduced the Dean number (De) which portrays the magnitude of the secondary flow. The secondary flow is induced due to the centrifugal forces which act on the flowing fluid which is caused by the curvature of the tube. This secondary flow is perpendicular to the main axial flow. The fluid is basically transferred from the inner wall of the tube to the outer wall of the tube across the center and it is forced back to the outer wall again.

$$\mathbf{De = Re}\sqrt{\frac{d}{D}}$$

De= Dean number

Re= Reynolds number

d = inner tube diameter

D= Helical/curvature diameter

**Variation of Dean number with number of turns:**

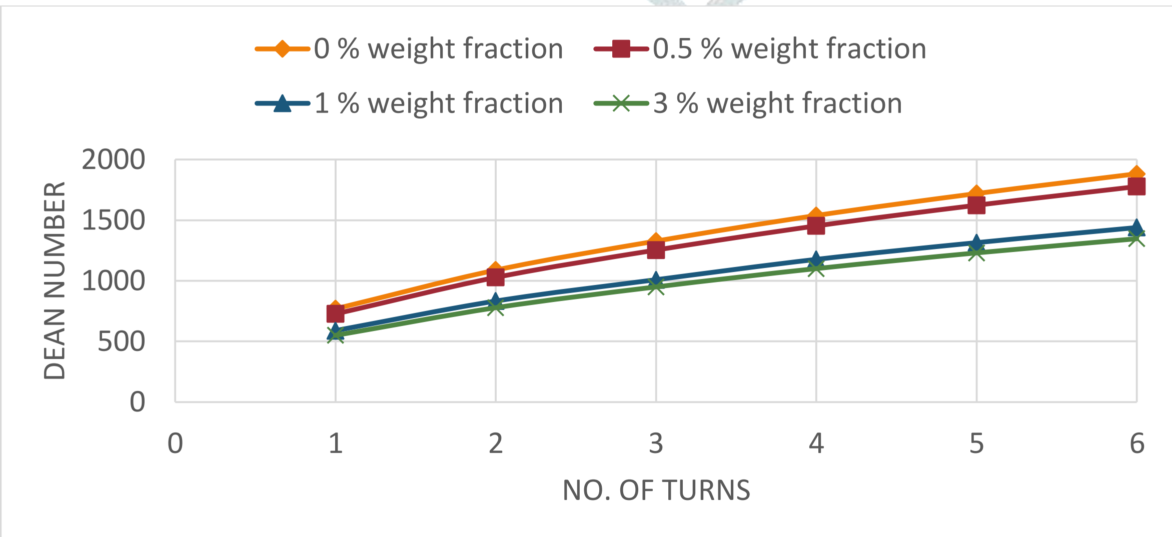



Figure 4.3 Shows Variation for Dean number with different number of turns with Boron Nitride Nanoparticles at 0,0.5, 1 and 3% Weight Fraction.

## V- Grid Independency

Through analyzing grid independency, we can find the minimum number of grid cells that is needed to get grid-independent results. Such strategy can save computational resource while ensure a rational computational result.When considering grid-independent issue, in principle a very dense grid can avoid this problem but the calculational resource may be wasted unnecessarily. In practice, we usually increase the grid resolution according to a certain ratio, for example 1/3, and then compare the results of two neighbourhood results. If the results tend towards identical, the grid can be considered as grid-independent. Such strategy can utilize computational resource most efficiently as well as obtain reasonable results.

| No. of Turns | Number of Nodes | Number of Elements |
|---|---|---|
| Straight Tube | 419094 | 314628 |
| 1 | 424853 | 316951 |
| 2 | 449723 | 337962 |
| 3 | 456707 | 345104 |
| 4 | 471225 | 357554 |
| 5 | 483499 | 360831 |
| 6 | 498839 | 375886 |

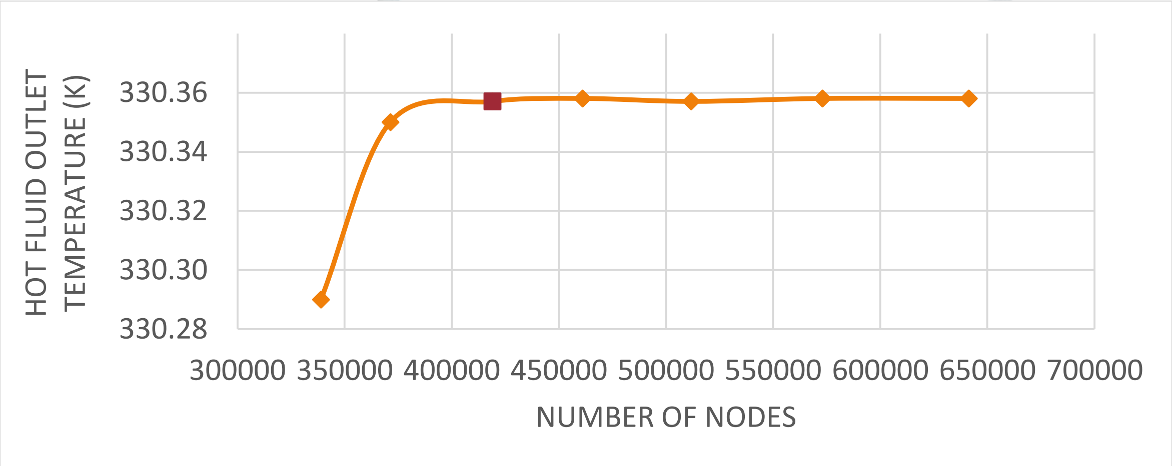



Fig 5 Shows the Grid independecy test of the work done on Ansys software.

## VI- Validation of Results

For the validation the method is adopted as adopted by E.J. Onyiriuka et al;

A plot for the variation of Nusselt number with Reynolds number for water is obtained from the present study and this plot is superimposed over the results from Gnielinski's equation. An average deviation of 8.64% was observed. This shows a very good agreement with Gnielinski's correlation.

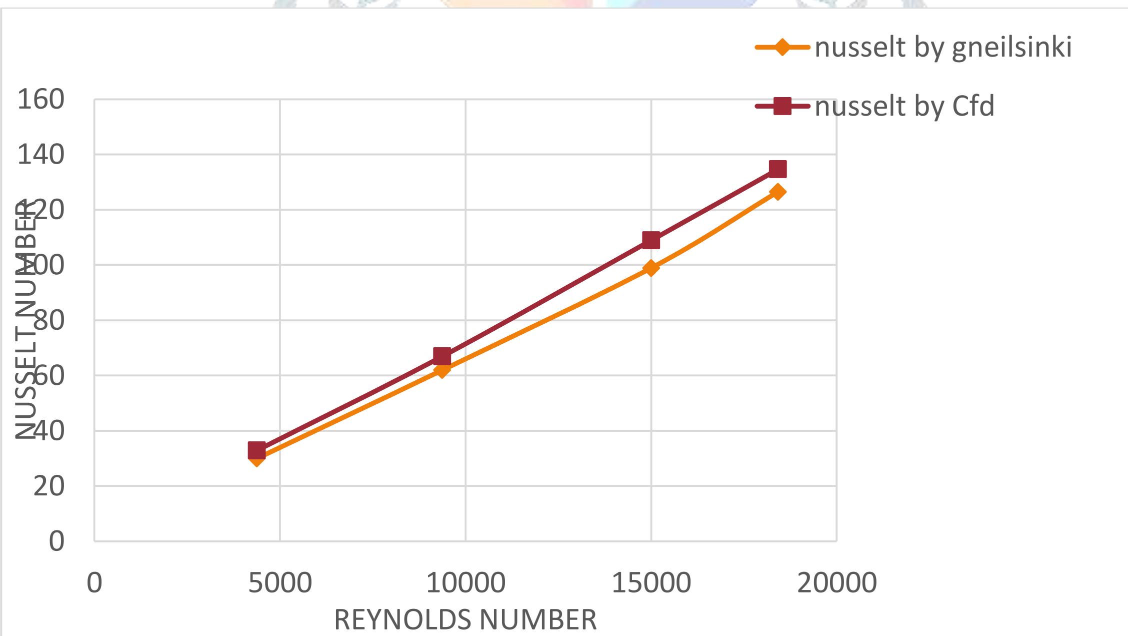
The Gnielinski's correlation is given by:

$$Nu_{Dh} = \frac{\left(\frac{f}{8}\right)(Re_{Dh}-1000)Pr}{1+12.7\left(\frac{f}{8}\right)^{1/2}\left(Pr^{\frac{2}{3}}-1\right)}$$

Where

- Dh is the hydraulic diameter
- Re is the Reynolds Number also f ={(0.79*ln*Re 1.64)}^-2
- Pr is the Prandtl Number
- Nu is the Nusselt Number
- F is the Darcy friction factor.

| **Re** | **Nusselt number by Gnielinski equation** | **Nusselt number (CFD anaysis)** | **% difference** |
|---|---|---|---|
| 4375.872 | 29.9800 | 32.8900 | 8.8 |
| 9376.869 | 61.9703 | 66.9870 | 7.46 |
| 15002.99 | 98.89 | 108.988 | 10.09 |
| 18420.34 | 126.456 | 134.6775 | 8.22 |




## VII-Conclusion

In this work circular cross-sectional double tube with different number of turns and outside diameter keeping constant helix angle was employed with comparison of circular cross section straight tube in a double pipe heat exchanger. The number of turns varies from 1 to 7, keeping the helix angle and total length of tube constant to examine the effect in heat transfer performance. Finite element analysis has been carried out for the analysis. It is observed that the Io-nano fluid with 0.5% Boron Nitride particles shows the higher effectiveness. When considering the number of turns, the 5 turn tubes helical heat exchanger shows the better effectiveness. The heat transfer rate is maximum for the 0.5% weight fraction boron nitride particle Io-nano fluid and 5 number turns heat exchanger.

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