CFD ANALYSIS FOR CONE HELICALLY COILED TUBE HEAT EXCHANGER BY VARYING PITCH

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ABSTRACT

Now-a-days heat exchangers have become indispensable in various fields of engineering such as in air conditioning, power stations, chemical plants, automobiles, etc. It necessitates the compact size along with the high performance of the heat exchangers. For the improvement in heat transfer performance of heat exchangers, heat transfer coefficient has an important role to play. Generally modifications which are made to enhance heat transfer coefficient leads to increase in pressure drop in heat exchangers. Hence the selection of most appropriate configuration is an important consideration in design of a heat exchanger. Secondary flow pattern formed in curved tubes plays an important role in mixing of fluid which leads to an increase in heat transfer coefficient along with an increase in pressure drop also.

Helically coiled exchangers offer certain advantages. Compact size provides a distinct benefit. Higher film coefficients—the rate at which heat is transferred through a wall from one fluid to another— and more effective use of available pressure drop result in efficient and less-expensive designs. Heat transfer rate of helically coiled heat exchangers is significantly larger because of the secondary flow pattern in planes normal to the main flow than in straight pipes.

This work aims to study on passive technique of heat transfer enhancement by some variation in geometry of helical coil tube heat exchanger. In this work the heat transfer and pressure drop analysis has been done for conical coil with varying pitch. The pitch number taken for the study are 18mm, 20mm and 22mm. The nanofluid of 0.5% volume concentration are supplied for cone helically coiled tube and hot water is supplied to the shell side. The mass flow rate of shell side is maintained constant at 0.15 Kg/s.The inlet temperature of hot fluid (shell) is 338 K whereas the inlet temperature of cold fluid (for cone helically coiled tube) is 305 K. The flow rate of the cone tube which handled nanofluid is varies from 0.05-0.07 Kg/s. It is found that the maximum overall heat transfer coefficient for pitch=22 mm is 32.23% higher than the pitch=18mm and maximum Nusselt number for pitch=22 mm is 14.91% higher than the pitch=18mm.

Keywords: *Cone coiled helical tube, Heat Exchanger, Nusselt number, Reynold's number, Pressure drop, Nano-fluids, CFD.*

I. INTRODUCTION:

Heat exchangers are an essential part in an assortment of mechanical settings, for example, cooling frameworks, force plants, refineries, and in this way ceaseless endeavour are made to expand their heat transfer efficiencies.

The design procedure of heat exchangers is quite complicated, as it needs exact analysis of heat transfer rate and pressure drop estimations apart from issues such as long-term performance and the economic aspect of the equipment. The major challenge in designing a heat exchanger is to make the equipment compact and achieve a high heat transfer rate using minimum pumping power. Techniques for heat transfer augmentation are relevant to several engineering applications. In recent years, the high cost of energy and material has resulted in an increased effort aimed at producing more efficient heat exchange equipment. Furthermore, sometimes there is a need for miniaturization of a heat exchanger in specific applications, such as space application, through an augmentation of heat transfer. Heat transfer enhancement is one of the most promising methods to optimize heat transfer equipment and to increase heat recovery in industrial processes. Heat transfer enhancement techniques have been extensively developed to improve the thermal performance of heat exchanger systems with a view to reducing the size and cost of the systems. Swirl flow is the one of the enhancement techniques widely applied to heating or cooling systems in many engineering applications.

Heat transfer enhancement techniques are classified as the - Passive Methods, Active Methods, and Compound Methods. These methods are commonly used in areas such as process industries, heating and cooling in evaporators, thermal power plants, air-conditioning equipment, refrigerators, radiators for space vehicles, automobiles, etc. The rate of heat transfer can be increased passively by increasing the surface area, roughness, and by changing the boundary conditions. The active method involves addition of nano sized, high thermal conductivity, and metallic powder to the base fluid, to increase the heat transfer rate.

Passive techniques, where inserts are used in the flow passage to enhance the heat transfer rate, are best suited compared to active techniques. Because the insert manufacturing process is simple and these techniques can be easily applied in an existing application.

A. Active Technique

The active method involves external power input for the enhancement in heat transfer; for examples it includes mechanical aids and the use of a magnetic field to disturb the light seeded particles in a flowing stream, etc.

B. Passive Technique

The Passive heat transfer methods does not need any external power input. In the convective heat transfer one of the ways to enhance heat transfer rate is to increase the effective surface area and residence time of the heat transfer fluids. By Using this technique causes the swirl in the bulk of the fluids and disturbs the actual boundary layers which increase effective surface area, residence time and simultaneously heat transfer coefficient increases in an existing system. Methods generally used are, extended surface, displaced enhancements devices, rough surfaces surface tension devices, Inserts etc.

C. Compound method

A compound method is a hybrid method in which both active and passive methods are used in combination. The compound method involves the complex designs and hence it has limited applications.

Helically coiled-tube heat exchangers

Helically coiled-tube heat exchangers are one of the most common equipment found in many industrial applications ranging from solar energy applications, nuclear power production, chemical and food industries, environmental engineering, and many other engineering applications. Heat transfer rate of helically coiled heat exchangers is significantly larger because of the secondary flow pattern in planes normal to the main flow than in straight pipes.

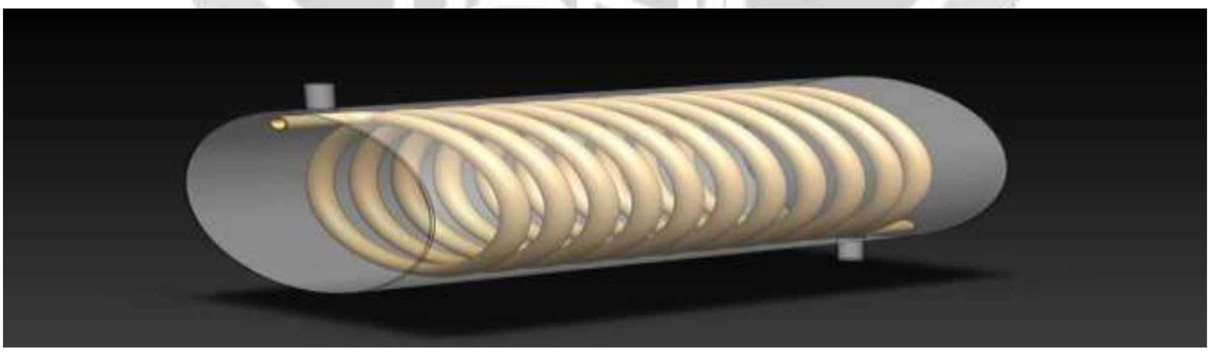
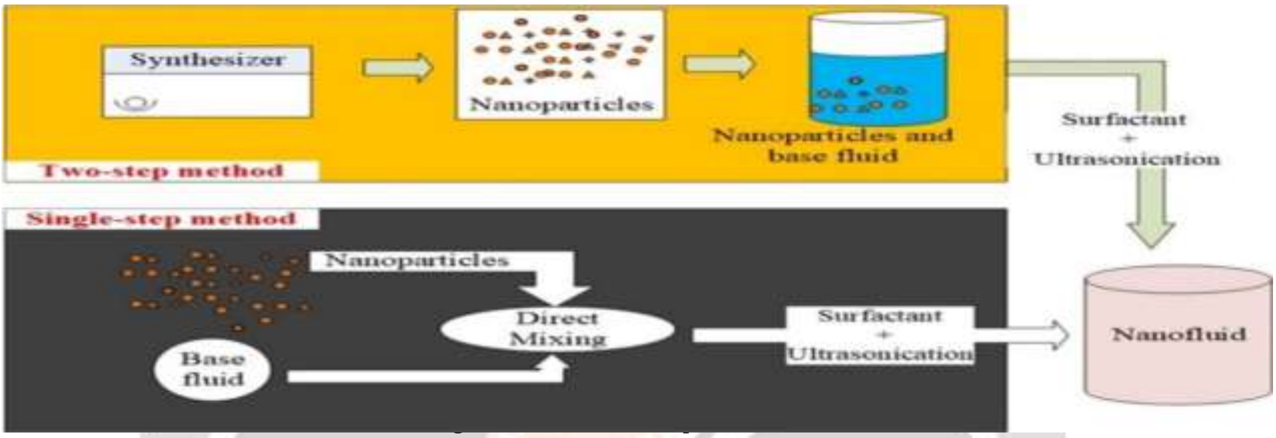


Figure 1. Helically coiled-tube heat exchanger.

Helically coiled exchangers offer certain advantages. Compact size provides a distinct benefit. Higher film coefficients—the rate at which heat is transferred through a wall from one fluid to another— and more effective use of available pressure drop result in efficient and less-expensive designs. True counter-current flow fully utilizes available LMTD (logarithmic mean temperature difference). Helical geometry permits handling of high temperatures and extreme temperature differentials without high induced stresses or costly expansion joints. High-pressure capability and the ability to fully clean the service-fluid flow area add to the exchanger's advantages. Although various configurations are available, the basic and most common design consists of a series of stacked helically coiled tubes. The tube ends are connected to manifolds, which act as fluid entry and exit locations.

1.6 Nanofluids

Nanofluids have some unique features which are quite different from dispersions of mm or μm sized particles. Compared to conventional cooling liquids such as water, kerosene, ethylene glycol and micro fluids, nanofluids have been shown to exhibit higher thermal conductivities. There are mainly two techniques of nanofluids production, namely two-step technique and single-step technique. In the two-step technique, the first step is the production of nanoparticles and the second step is the mixing of the nanoparticles in a conventional base fluid.



Computational Fluid Dynamics Analysis
This is a computer-based analysis by which we analyse the various things like fluid flow, pressure distribution, heat transfer, and related to the phenomenon in the chemical reactions.

There are the three main elements for the processing of the CFD simulations discussed below;

1. **Preliminaries processing:** this is the first step where the geometry of the issues to be solved are analyzed A pre-processor is defined to the geometry regarding the problem. They are fixed into the domain for the computational analysis and then yields the mesh associated with geometry. Here also put the nomenclature like inlet, outlet, wall, etc. Usually, the finer the mesh associated with geometry into the CFD analysis offers more solution that is accurate. The choice of computer hardware and the time for calculations are dictated by the fineness of the grid.

2. **Solver: -** The calculations are done by using the numerical solution methods in the solver processor. You will find the countless numerical practices that are utilized for the computations for example:-the finite factor method, finite amount technique, the finite huge difference technique additionally the spectral strategy. Most of them in computer codes use the finite volume method into the following steps:
   • Firstly the fluid movement equations are integrated on the control volumes (leading to the actual preservation of appropriate properties for every finite amount),
   •Then these key equations tend to be discretized (creating algebraic equations through converting of the fundamental fluid movement mathematical expressions)
   • Finally, mathematical relations and equations are fixed using the iterative method.
   • Pressure based paired option method CFD rule is used for resolving the simulations in this task.

3. **Post Processing**: This is done to visualize the total link between the solutions. It includes the ability to display the mesh and geometry also. As well as in this processor we could create the vectors, contours, and 2D and surface that is 3D of the issue solutions. Right Here the model can also be manipulated. In this method, we could also look at the cartoon of the problem.

II. LITERATURE REVIEW

It has been widely reported in literature that heat transfer rates in helical coils are higher as compared to a straight tube. Due to the compact structure and high heat transfer coefficient, helical coil heat exchangers are widely used. Striving to ensure high performance of the heat exchangers, HX, nowadays is a source of universal trend both to the miniaturization of these devices for both industrial and domestic applications, while maintaining the highest possible size to thermal energy ratio. As is well known, in the case of Recuperators the heat transfer coefficient has a decisive influence on their efficiency. Overall heat transfer coefficient, depends mainly on the lower value of heat transfer value (HTC) from working media.

It is, therefore, most significant to improve the heat transfer with special attention on the side of the medium with lower heat transfer coefficient. Helical coils are widely used in applications such as heat recovery systems, chemical processing, food processing, nuclear reactors, and high temperature gas cooling reactors. Helical coils have been widely studied both experimentally and numerically.

A considerable amount of experimental as well as analytical and computational research has been carried out on the enhancement of heat transfer. In this chapter, a brief survey of the relevant literature is presented to indicate the extent of work already reported in open literature pertaining to the enhancement of heat transfer by introducing nano fluid and helical coil in the heat exchanger.

2.1 Previous work

G. Rahul Kharat et. al. [2009], carried out a comparative study between helical coil heat exchanger and straight tube heat exchanger, and found that the effectiveness of heat exchanger is greatly affected by hot water mass flow rate and cold water flow rate. When cold water mass flow rate is constant and hot water mass flow rate increased the effectiveness decreases. Increase in cold water mass flow rate for constant hot water mass flow rate resulted in increase in effectiveness. For both helical coil and straight tube heat exchangers with parallel and counter flow configuration this result obtained. Helical coil counter flow is effective in all these conditions than the straight tube parallel flow heat exchanger. Overall heat transfer coefficient on other hand increases with increase in hot water mass flow rate and cold water mass flow rate. Use of a helical coil heat exchanger was seen to increase the heat transfer coefficient compared to a similarly dimensioned straight tube heat exchanger [3].

Ghadimi et al. [2011] suggested that the two-step method gives higher stability and low agglomeration with a better nanostructure. The MWCNT water-based nanofluids have been synthesized at 0.1%, 0.3%, 0.5%, volume concentration. The morphological characters of MWCNT in base fluid nanofluid are obtained by Transmission Electron Microscopy (TEM). TEM Image clearly illustrates that the MWCNT core is hollow with multiple layers almost parallel to the MWCNT axis [4].

E. Jung-Yang San et. al. [2012], Heat transfer characteristics of a helical heat exchanger", found that the impact of coil curvature is to suppress turbulent fluctuations arising within the flowing fluid and smoothing the appearance of turbulence. Thus it will increase the value of the Reynolds number (Re) needed to attain a fully turbulent flow, as compared to it of a straight pipe. The impact of turbulent fluctuations suppression enhances as the curvature ratio of coil increases [5].

Wang et al. [2013] investigated the heat transfer and pressure drop of working fluids as water-based CNT nanofluids in a circular tube as a horizontal position. They concluded that the enhancement of average convective heat transfer increases with increase in volume concentration of nanoparticles at constant Reynolds number [6].

Ellahi et al. [2016] carried out the particle shape effects on Marangoni convection boundary layer flow of a nanofluids with the blend of numerical and analytical studies. They suggested that the interface velocity reduces by increasing particle volume fraction and the spherical shape is better for heat transfer point view [11].

Bahiraei et al. [2018] applied a novel hybrid nanofluid containing graphene – platinum nanoparticles in twisted geometry in a miniature devices. They proposed that the heat transfer and pumping power in the channel increase by increasing pressure drop and Dean Number. The ratio of heat transfer to the power in the chaotic channel is greater than 1.5 [17].

Bahiraei et al. [2019] numerically inverted the hydro thermal and energy efficiency of a hybrid nanofluids (graphene – platinum nanofluid) in a tube connected by twisted tapes. They have taken the twisted angle, twin co – twisted tape and counter twisted tape for co-swirling flows recommended to use the counter twisted tapes with higher twisted ratio to enhance the heat transfer with reduced energy consumption [18].

K. Palanisamy et al. [2019] numerically investigated the heat transfer and the pressure drop of cone helically coiled tube heat exchanger using (Multi wall carbon nano tube) MWCNT/water nanofluids. The tests was conducted under the turbulent flow in the Dean number range of 2200 < De < 4200. The experiments was conducted with experimental Nusselt number is 28%, 52% and 68% higher than water for the nanofluids volume concentration of 0.1%, 0.3% and 0.5% respectively. It was found that the pressure drop of 0.1%, 0.3% and 0.5% nanofluids are found to be 16%, 30% and 42% respectively higher than water. It is also studied that there is no immediate risk of handling MWCNT and studied that there is no significant erosion of coiled tube inner wall surface even after several test runs. Therefore the MWCNT/water nanofluids are the alternate heat transfer fluids for traditional fluids in the cone helically coiled tube heat exchanger to improve the heat transfer with considerable pressure drop [21].

It is studied from the literature review that most of the experimental works on double helically coiled tube heat exchanger have been done by using oxide nanofluids. Very little works have been done on cone helically coiled tube heat exchanger by using MWCNT/water nanofluids with CFD software. Therefore this investigation deals with the thermal and flow behaviour of cone helically coiled tube heat exchanger handling MWCNT/water nanofluids at three different pitch number by varying pitch of helical coil.

III. RESEARCH OBJECTIVES

The objectives of this study are:

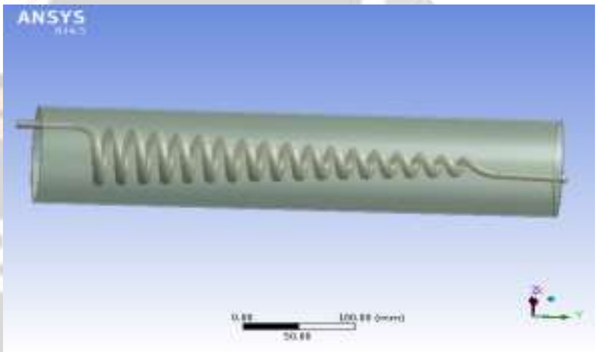
(i) Investigating the thermal and flow behaviours of MWCNT/water nanofluids with higher volume concentration at different Dean number in cone helically coiled heat exchanger by varying pitch size.
(ii) To observe which configurations and parameters that gives the best results.
(iii) To study and modeling the heat transfer of cone helically coiled tube heat exchanger using CFD simulation.

IV. METHODOLOGY

Table 1. Dimensions of cone coil tube

Cone coil angle (θ)	8 degree
Cone inner tube dimeter(d_i)	0.08 cm
Cone outer tube diameter (d_o)	0.1 cm
Diameter of the shell	11.4 cm
Effective length of the coil	470 cm
Pitch of the coil	1.8, 2.0, 2.2 cm
Calming section length	11 cm
Cone coil diameter	6.4 cm
Number of turns	16

Figure 3 Cone helically coiled tube heat exchanger.



The designed model of Cone helically coiled tube heat exchanger is meshed in ICEM Meshing.

Model Selection

The governing equations are discretized by finite volume method and solved in steady-state implicit format. The SIMPLE algorithm is used to couple the velocity and pressure fields. The second order upwind scheme is applied and standard k-ε turbulent model with standard wall function is selected.

Boundary Conditions

Flow is turbulent and counter flow conditions. The nanofluid of 0.5% volume concentration are supplied for cone helically coiled tube and hot water is supplied to the shell side. The mass flow rate of shell side is maintained constant at 0.15 Kg/s.The inlet temperature of hot fluid (shell) is 338 K whereas the inlet temperature of cold fluid (for cone helically coiled tube) is 305 K. The flow rate of the cone tube which handled nanofluid is varies from 0.05-0.07 Kg/s.After putting the boundary conditions, the solution is initialized and then iteration is applied so that the values of all parameters can be seen in a curve or line graph. After the iteration gets completed final result could be seen.

V. RESULTS AND DICUSIONS

Here in this section nanofluid of 0.5% volume concentration for cone helically coiled tube flowing at Dean Number 2200. While the mass flow rate of shell side is maintained constant at 0.15 Kg/s.

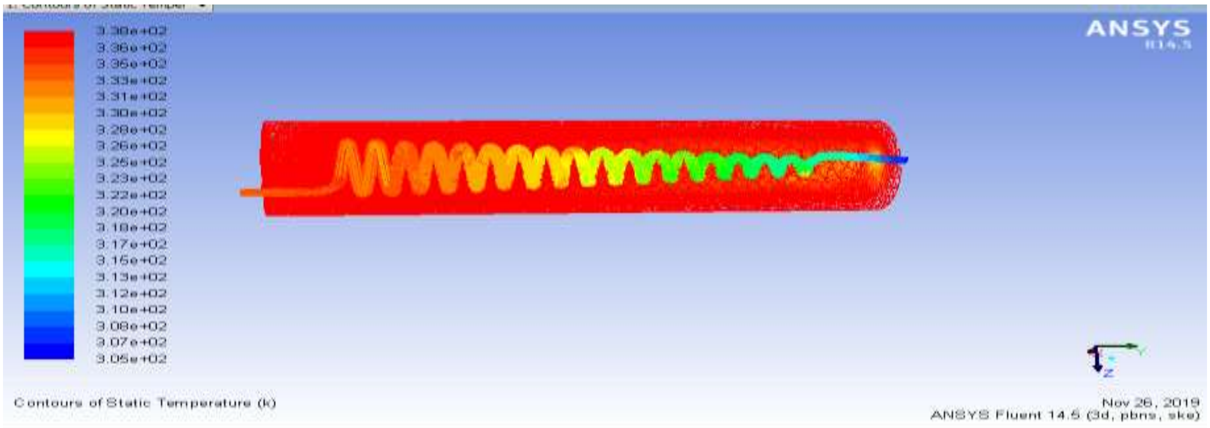


Figure 4. Contours of static temperature at Dean number 2200 for pitch= 20 mm.

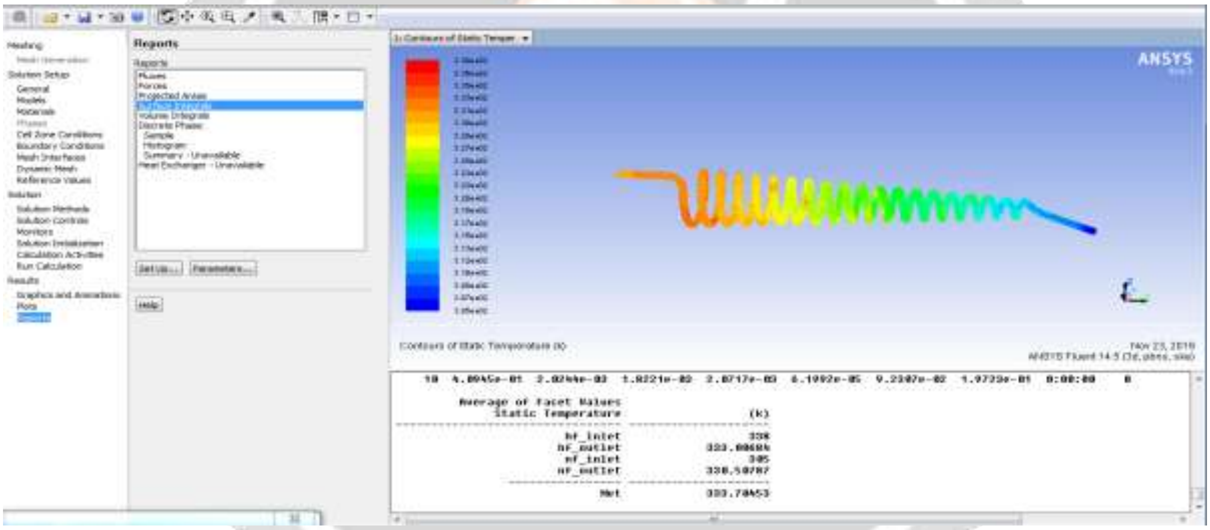


Figure 5. Contours of static temperature at Dean number 2200 for pitch= 18mm.

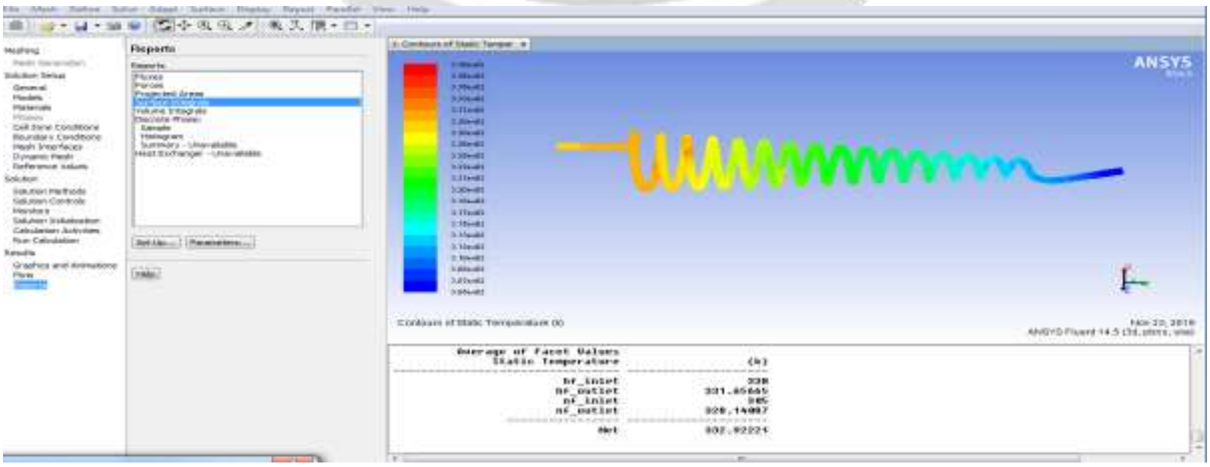


Figure 6. Contours of static temperature at Dean number 2200 for pitch= 22mm.

Table 2. Comparison of values of Nusselt no. at different Dean No. for different pitch number

S.No.	Dean Number	Nusselt Number			
		Pitch=20 mm(Experimental)	Pitch=20 mm(CFD)	Pitch=18mm mm(CFD)	Pitch=22 mm(CFD)
1.	2200	74	74.84	72.67	85.36
2.	3025	97	97.9	94.47	98.85
3.	4200	119.5	126.99	114.57	131.88

Table 3. Comparison of values of Overall heat transfer coefficient at different Dean No. for different pitch number

S.No.	Dean Number	Overall heat transfer coefficient (W/m^2-K)			
		Pitch=20 mm(Experimental)	Pitch=20 mm(CFD)	Pitch=18mm mm(CFD)	Pitch=22 mm(CFD)
1.	2200	860	872	860.87	885.54
2.	3025	970	983	969.32	1001.20
3.	4200	1140	1156	1141.56	1179.80

Table 4. Comparison of values of Pressure drop at different Dean No. for different pitch number

S.No.	Dean Number	Pressure drop (Pascal)			
		Pitch=20 mm(Experimental)	Pitch=20 mm(CFD)	Pitch=18mm mm(CFD)	Pitch=22 mm(CFD)
1.	2200	10520	11180	12443	10120
2.	3025	14750	15717	16116	14320
3.	4200	16950	17469	18965	16732

VI. CONCLUSIONS

In recent years a lot of attention has been paid to improving the Thermal performance of heat exchanger. In this work a heat exchanger of cone helical coil tube type was first designed in CFD. Helical coil heat exchangers of three different coil pitches were investigated for counter flow configuration. The mass flow rate of the hot fluid was kept stable at 0.15 kg/s and the values of the MWCNT/water fluid were altered between 0.05 kg/s up to 0.07 kg/s. From the outcomes of the present study, it is found that at higher mass flow rate of the MWCNT/water fluid an increased heat transfer in the heat exchanger was achieved. It is also found that maximum heat transfer characteristics are exhibited by coil of pitch 22mm as compared to other two coils of pitch 18mm and 20mm.

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