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Thermal Analysis of Helical Coil Induction Heater

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ABSTRACT: Induction heating system has a number of inherent benefits compared to traditional heating systems based on application such as hardening, casting, welding, post-heating and water heating. Induction heating process is clean environmental due to a non-contact and time reducing heating process. Helical coil configuration is very effective for heat exchangers because they can accommodate a large heat transfer area in a small space with high heat transfer coefficients. This project deals with thermal analysis of different helical coil configurations through which water flows and it uses induction heating device i.e. induction cooker as a source of heat transfer to water.

In Computational Fluid Dynamics (CFD) analysis, various helical coils with different number of turns $N=3.25$, $N=4$ and $N=5$ are simulated using the appropriate boundary conditions and fluid properties specified to the system with suitable assumptions. The process in solving simulation consists of modelling and meshing the basic geometry of helical coil using CFD package ANSYS 14.5. The objective is to study the temperature field of water inside coil using ANSYS software tools. In this study, an attempt has been made to analyze the effect of flow rate on the heat transfer to water in helical coil from induction cooker. The temperature contours were plotted using Fluent in ANSYS 14.5. Steel was chosen as metal for the construction of the helical coil. Different helical coil configurations are analysed using CFD software intended for values of water outlet temperature; so as to develop energy efficient helical coil induction heater.

KEYWORDS: Induction Heating Process, Helical Coil, Induction Cooker, ANSYS and Computational Fluid Dynamics (CFD)

I.INTRODUCTION

Industry prerequisites of Electricity and especially water at certain temperature of 85^0-90^0C for different processes; to fulfill demands it required lot of Electricity or Fuel for hot water required at particular temperature using different techniques including Electric Heater, Gas Water Heater, Storage Heat Pump water heater, Heat Exchanger using burning of fuel etc. Due to degradable resources in environment it is necessary to find out alternative energy resources or use available resources effectively; so, for water heating process electricity should aimed at having effective use over the supplied electricity, the new technique of water heating using induction heating process is being developed. Typical applications of induction heating are melting of metals, heating of metals for design, Brazing, Welding and all sorts of Surface Treatments.

An Induction heating is able to generate joule heat to metal effectively and this induction heating has been recently applied to small thermal power plants and home appliances. [1] A green and renewable energy, high cost, thermal efficiency, safety and clean environmental are important issues that influenced the technology in home appliances recently such as in stove and water heating. Induction heating is a non-contact heating process and one of the new technologies in home appliance. There are some researches that discussed about induction heating process and implementation due to their clean and no pollution aspects. [2] The main advantages of using these processes when

compared to any other heating process (gas furnace) are their fast heating rate, good reproducibility and low energy consumption. Induction heating has been extended to the catering industry as currently; the induction cooker draws more and more attentions as one of the popular kitchen appliances instead of ordinary stove plates. [4] Also these induction cooker works with the suitable magnetic material pots such as Steel, Enamelled Steel, Cast Iron etc.; Instead of pot utilized in water heating process using induction cooker for continuous hot water requirement; it is suggested that helical coil is being used for water flow through it which placed on induction cooker where induction cooker acts as heat source to change the temperature of water. Helical coils are widely used in applications such as heat recovery system, chemical processing, food processing, nuclear reactors and high-temperature gas cooling reactors. [5] Because of helical coils have a compact configuration, more heat transfer surface can be provided per unit of space than by the use of straight tubes, ease of manufacture and longer operating life. Hence helical coil is used instead of Spiral or Pancake coil for heat exchange purpose.

With the utilization of all these individual benefits of total system includes induction cooker, helical coil especially thermal analysis which is of physical-chemical methods which deal with studying materials and processes under conditions of programmed changing of the surrounding temperature using heat source is to be studied and it is simulated using Computer technology, Computational Fluid Dynamics (CFD) Fluent software.[6] Thus in induction cooker (heating) with helical coil process electrical energy requirement is reduced as compared to conventional process to develop energy efficient Helical Coil Induction Heater.

II. LITERATURE REVIEW

The scholars in the technical field have carried out work on improvement aspect of induction heating process. Their work has been reported through the various published articles. A systematic study of these articles is carried out. In the past studies more stress is being given to design aspects of helical coil for performance improvement in heat transfer and different coil configurations used in induction heating process conferring to application. Thus, literature review has enunciated induction cooker techniques available as heat source. At first stage considering basic terminology with definitions and then turn to modern techniques available under this category. The literature reviewed has been presented accordingly. Design aspects of helical coil specifically related to heat exchanger and induction heating process especially induction cooker intended for deviations of water temperature caused by induction cooker as heat sources, is focused here.

1) CFD Analysis Techniques for Heat Transfer in Helical Coil

As per the literature sighted there are various techniques available of CFD analysis for design and development of helical coil utilized in heat transfer analysis are investigated and discussed. Modern techniques available under this category, the literature reviewed under this category has been presented here:

During the investigation on computational fluid dynamics (CFD) study of isothermal laminar single-phase flow of water in a hollow helical pipe model, the abstract is given here. Single phase flow of water through helical pipe at various Reynolds number especially laminar flows is analysed using CFD software. This work signposts that centrifugal forces created inside the helical pipe due to curvature effect which causes high velocity region at the outer side of hollow helical pipe as compared to straight tube where high velocity region created at the center of pipe and causes acceleration forces acting on the fluids produces pressure region at the outside of coil. The study indicates that the simulated results obtained with CFD software for single phase water flow through hollow helical coil found to agree with experimental data. [22]

Work done on the numerical analysis of a of helical coil heat exchanger using CFD to determine heat transfer rate and comparison with the straight tube under similar geometrical and operating conditions, the abstract is given here. This work present close agreement with correlation obtained is validated with CFD simulation result carried out using CFD software and this indicate that heat transfer rate, Nusselt number and heat transfer coefficient are found to be higher in helical coil as compared with the straight tube. The heat transfer rate increases with the increase in mass flow rate in both cases of simulation but is higher in case of helical coil shows improvement in heat transfer rate. Also, the pressure drops found in helical coil more for identical boundary conditions of straight tube. finally, this paper concludes for higher mass flow rates pressure drop varies exponentially which indicates requirement of higher pumping for helical coil. [23]

A strategy for the comparative performance study of different helically coiled heat exchanger with two and three helical coils through computational fluid dynamics (CFD) simulations for heat transfer characteristics is described. The motivation for performing such a simulation is discussed, with reference to the literature and a description of the modeling approach is given. Simulation performed using steady state analysis with variable hot fluid inlet temperature shows heat exchanger with three turns was more efficient as compared with heat exchanger with two turns, this indicates as length of coil and inlet temperature of fluid is increases the heat transfer rate of helical coil with the appropriate boundary conditions. The graphical representation shows efficiency of helical coil with two turn and three turn rise with inlet temperature of fluid increases. This research is necessary for future work to study the number of coils turns with best optimization of the process of heat transfer in heat exchanger. [6]

This work present heat transfer analysis of helically coil heat exchangers using CFD software. The abstract is given here. It shows detailed characteristics and physics of fluid flow also heat transfer to single-phase water flowing through helical pipes with CFD simulations are carried out by varying coil parameters such as pitch circle diameter, tube pitch, pipe diameter and their influence on heat transfer for different boundary conditions are analyzed. In this present work analysis is carried out with both constant wall temperature and constant wall heat flux boundary conditions to determine the influence of that on heat transfer coefficient of helical coil used as heat exchanger. It also establish relation between coil pitch circle diameter, coil pitch and pipe diameter of helical coil; as the coil pitch increases change in Nusselt number values is almost negligible. The main influence on heat transfer through helical coil is helical coil tube diameter which shows that low tube diameter, the secondary flows are weaker and hence mixing is lesser. This produces nearly the same heat transfer at top and bottom section of helical coil. Regression analysis was carried out and the result verifies a linear relationship between Nusselt number and pipe diameter.[25]

A study of experimental and CFD estimation of heat transfer in helically coiled heat exchanger was carried out to investigate fluid to fluid heat transfer characteristics inside the helical coil through varying the different boundary conditions. An experimental study was conducted for different flow rates through coil and also different value temperature at the inlet of helical pipe. In this study, Overall heat transfer coefficient obtained from experiments and calculations is compared with CFD simulation result analysis found to be close agreement. Heat transfers characteristics of the heat exchanger with helical coil are also studied using the CFD code FLUENT version 6.2 which was analysed for three boundary conditions. The boundary conditions selected were Constant wall temperature, Constant heat flux and Constant convective heat transfer coefficient which indicate marginal changes in Nusselt number. It was found the specification of a constant wall temperature or constant heat flux boundary condition for an actual heat exchanger does not yield proper modelling. Hence, the heat exchanger is analysed considering conjugate heat transfer and temperature dependent properties of heat transport media. This works established correlation depends on the results obtained experimentally and CFD modelling to calculate the inner heat transfer coefficient of the helical coil and the correlation is useful in further studies. [26]

Numerical modelling of water flow in a helicoidally pipe for laminar and turbulent flow using CFD analysis, the conclusion is given here. Computational fluid dynamics (CFD) study of isothermal laminar single-phase flow of water in a hollow helical pipe model an annular helically coiled tube has been modelled for different fluid flow regimes. It was found that centrifugal forces create a high velocity region at the outer side of the annular helicoidal pipe walls. The simulated result obtained with CFD software found friction factor decreases as the tendency for turbulence increases. The best consistency between correlation in literature and CFD model results observed for turbulent region closer to experimental data.[27]

III. CFD SIMULATION

It is important to control input values of variables so as to get targeted responses; which is only possible by adopting the approach maintained in this case for determination of values of water outlet temperature generated in different helical coil. For this purpose, this chapter is focused on details of analysis using computational fluid dynamics software for water outlet temperature from helical coil raises due to constant heat supplied from induction cooker, for the development of energy efficient helical coil induction heater. The invention of high-speed digital computers, combined with the development of accurate numerical methods for solving physical problems, has revolutionized the way of study and practice fluid dynamics. This approach is called Computational Fluid Dynamics (CFD) and it has made possible to analyze complex flow geometries with the same ease as that faced while solving idealized problems using conventional methods. CFD may thus be regarded as a zone of study combining fluid dynamics and numerical analysis.

CFD substitutes test and experimentation as well as reduces the total time of testing and designing. Computational fluid dynamics study of the system starts with the construction of desired geometry and mesh for modelling the dominion. 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 the describing of the boundary and initial conditions for the dominion and leads to modelling of the entire system.

CFD may be used to determine the performance of a component at the design stage or it can be used to analyse difficulties with an existing component and lead to its improved design for example, CFD methodology for the temperature variation through a component as follows:

- The first step is to identify the region of interest. The geometry of the region of interest is then defined. If the geometry already exists in CAD, it can be imported directly. The other elements of the simulation are then defined, including the boundary conditions and fluid properties.
- The flow solver is then run to produce a file of results, which contain the variation of velocity, temperature and any other variables throughout the region of interest.
- The results can be visualized and provide the engineer with a full understanding of the behavior of the temperature of the fluid throughout the region of interest.

This can lead to design modifications, which can be tested by changing the geometry of the CFD model and sighted the effect.

ANSYS FLUENT consists of software modules, which are linked by the flow of information required to perform a CFD analysis as shown in figure 1 gives the overview of the CFD modelling process.

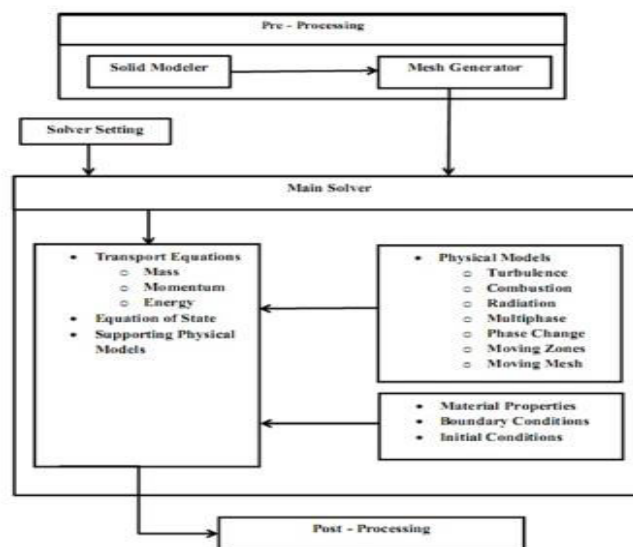


Figure:1 Overview of modelling process

CFD Modelling of Helical Coil:

The geometry model of helical coil is made in CAD Package CATIA. For CFD Modelling internal volume of geometry is required. Internal volume is got from CATIA. Iges/Step format of it is imported to ANSYS ICEM CFD Meshing Software. Geometry is repaired in ANSYS ICEM CFD.

Problem Definition:

The Helical coils data for same flow rates between 16 to 94 lph at ten levels and the constant heat supply condition is given for analysing its performance using CFD. The different Helical Coil with N=3.25, N=4, N=5 are developed. The major objective of analysing such systems is to determine the temperature rise of water flows through helical coil geometry using CFD.

Construction of the Model:

The 3D model for helical coil is created using CAD Package CATIA V5 R19. It is imported in Ansys fluent workbench with igs/step file saved in Catia. The extra length added at inlet and outlet of helical turns of coil which helps in reducing the non-uniformity of flow. The geometrical specifications of the helical coil have chosen somewhat arbitrarily same in experimentation. Diameter of helical coil is 0.1095m centre to centre, pitch of helical coil is 0.0095 m, helical tube diameter is 0.0095m and thickness 0.5 mm with variable number of turns is selected as N=3.25, N=4 and N=5. The model of helical coil is shown in figure 2.

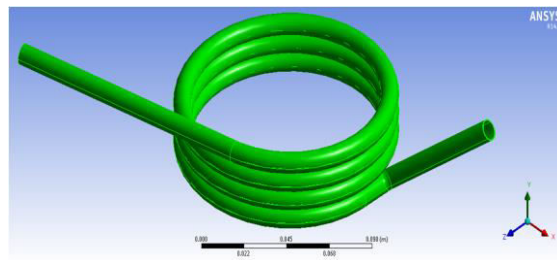


Figure: 2 Model of Helical Coil N=3.25

Then all the parts are defined i.e. inlet is defined as Inflow, outlets as Outflow and wall.

Grid Generation for the Helical Coil with Solid-Fluid Interface:

The ANSYS ICEM-CFD is used for discretization of domain. Initially a relatively coarser mesh is generated. This mesh contains tetrahedral cells having triangular faces at the boundaries. Care is taken to use tetrahedral cells as much as possible. It is meant to reduce numerical diffusion as much as possible by structuring the mesh in a well manner, particularly near the wall region. Later on, a fine mesh is generated for this fine mesh, the edges and regions of high temperature and pressure gradients are finely meshed which is solid fluid interface. Details of mesh are given below in table 1.

Table 1: Mesh details

Parameter	Details
1.Global Mesh Size	10 mm
2. Surface Mesh Size	10 mm
3. Curve Mesh Size	10 mm
4.Mesh Type	tetrahedral
5.No. of Elements	430767
6.Mesh Quality	0.4

Mesh is checked first for duplicate elements, unconnected vertices and then mesh is smoothened by smoothing tool. Then file is exported to FLUENT file, which is imported in ANSYS-FLUENT. The Mesh domain of helical coil N=3.25 are as shown in figure 3

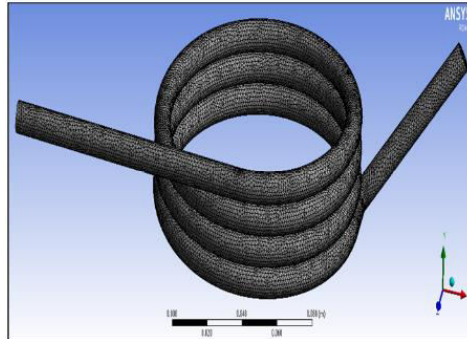


Figure: 3 Meshing domain of Helical Coil $N=3.25$

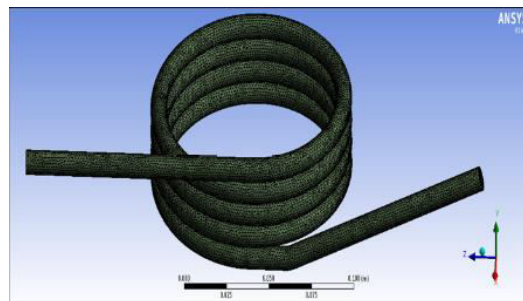


Figure: 4 Meshing domain of Helical Coil $N=4$

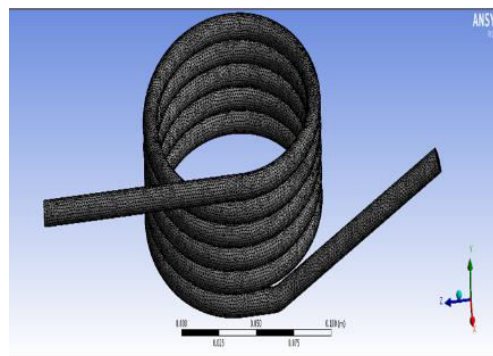


Figure: 5 Meshing domain of Helical Coil $N=5$

Boundary Conditions:

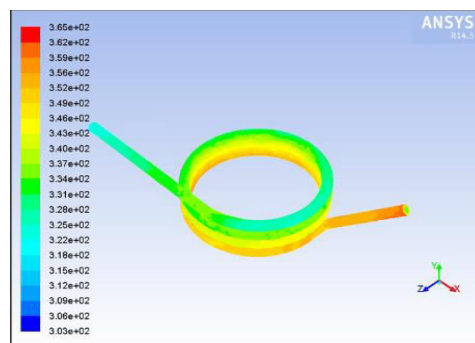
Boundary conditions are used according to the need of the model. Boundary conditions used at inlets are velocity of water and at outlets static pressure is applied. Domain surface is used as a wall with ‘No Slip Condition’ and heat flux data.



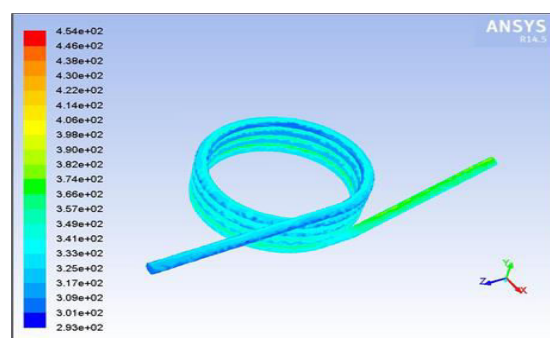
Figure: 6 FLUENT simulation model of Helical Coil N=3.25

IV. RESULTS AND DISCUSSIONS

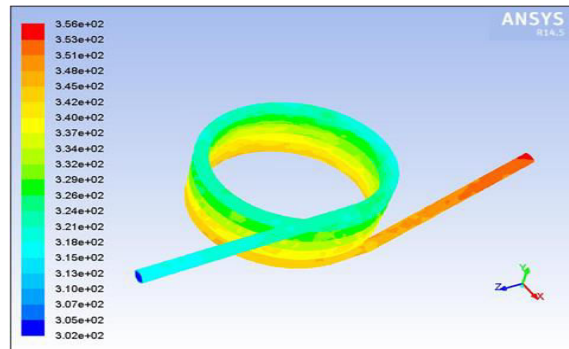
The CFD simulation results for temperature profile for different helical coil along the length from inlet to outlet have been plotted using Ansys Fluent software in following manner



Graph 7: The temperature contour for Helical Coil N=3.25 at constant flow rate 36 lph

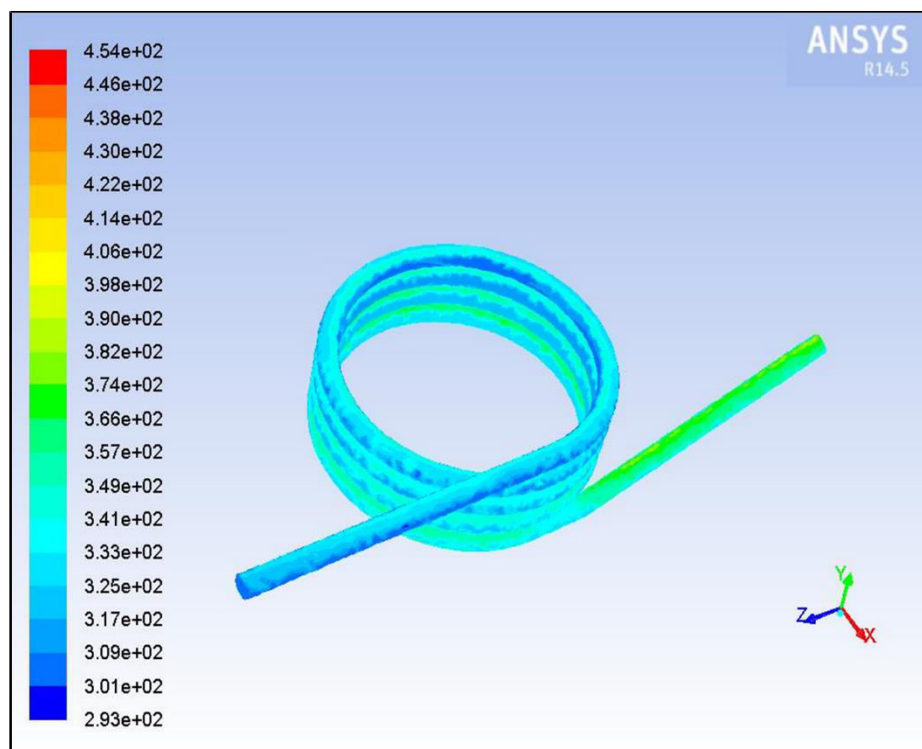


Graph 8: The temperature contour for Helical Coil N=4 at constant flow rate 36 lph



Graph 9: The temperature contour for Helical Coil N=5 at constant flow rate 36 lph

It is observed from the graph: 7 to 9, temperature field for Helical Coil N = 3.25, N=4, N=5 at constant flow rate 36 lph that Helical Coil N=3.25 to N=5 static temperatures of helical coil increase due to wall heat flux applied in boundary condition causes rise in fluid temperature flows through the coil.



V. CONCLUSION

As per the studies, related to thermal analysis of helical coil induction heater, the following conclusions be drawn from the present simulations and would be presented as follows.

1. It is observed that the water outlet temperature from helical coil is increases with decrease in water flow rate with constant heat supply from induction cooker.
2. It is also concluded from the results that as number of turns of helical coil increases which convey increase in water outlet temperature at same flow rates condition for all helical coils fabricated. The water outlet temperature is highest in helical coil N=5.
3. It has been observed that length of coil is increases as increase in number of turns of helical coil, results in higher water outlet temperature from helical coil.

4. It seems from the results that higher the number of turns of helical coil will have better heat transfer rate.
5. As predicted proposed systems results in reduction in energy consumption as compared with conventional water heater used for water heating where hot water required.
6. The values obtained using CFD analysis for water outlet temperature from helical coil gives data for development of energy efficient water heater using induction heating process.

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