CFD Examination on Heat Transfer Upgrade in Turbulent Stream inside a Roundabout or Circular Channel with Fe$_3$O$_4$ Nanofluid

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ABSTRACT
Assessing the warmth or exchange improvement because of the utilization of nanofluids has as of late turned into the focal point of enthusiasm for some analysts. This recently presented class of cooling liquids containing ultrafine nano particles (1–100 nm) has shown intriguing conduct amid tests including expanded warm conductivity and increased warmth exchange coefficient contrasted with an immaculate liquid. This article audits and condenses the numerical studies performed around there. A hypothetical investigation of single stage through a channel will be done. The CFD reenactment of warmth exchange attributes of a nanofluid in a roundabout tube under consistent warmth flux will be considered utilizing CFX solver (rendition 13.0) in the turbulent stream. Fe3O4 nanoparticles in water with groupings of 0.02%, 0.1%, 0.3%, and 0.6% will utilized as a part of this reenactment. The majority of the thermo-physical properties of nanofluids are thought to be temperature autonomous. The normal molecule sizes of 36 nm will be utilized as a part of this exploration. The objective is to discover the adjustment in warmth exchange coefficient with changing the Reynolds number and the centralization of nanoparticles. The maximum convective warmth exchange coefficient will be seen with the adjustment in grouping of nano-particles in water. The computational liquid progress (CFD) model mathematical statements will be understood to foresee the hydrodynamic and warm conduct of the funnel. The geometry of the issue and cross section of it will be done in ANSYS Workbench. The models will get illuminated by ANSYS CFX 13.0 solver. Keywords: ANSYS, HYPOTHETICAL, nanofluid, renditi on, utilization.

INTRODUCTON
Conventional heat transfer fluids such as water or ethyleneglycol, used in cooling or heating applications are characterized by poor thermal properties. In the past years, many different techniques were utilized to improve the heat transfer rate in order to reach a satisfactory level of thermal efficiency. The heat transfer rate can passively be enhanced by changing flow geometry, boundary conditions or by improving thermo physical properties for example, increasing fluid thermal conductivity. The heat transfer properties of thermo fluid play an important role in the development of energy-efficient heat transfer equipment. Passive enhancement methods are commonly utilized in the electronics and transportation devices. But the working fluids such as ethylene glycol, water and engine oil have poor heat transfer properties. In that regard, the development of advanced heat transfer fluids with higher heat transfer properties is in a strong demand. One way to enhance fluid thermal conductivity is to add small solid particles in the fluid. Addition of milli or micro sized solid particles is one of the very old techniques of heat transfer enhancement. Industrially, this technique is not attractive because of the inherent problems such as sedimentation, increased pressure drop, fouling and erosion of the flow channel. These problems can be overcome with nanofluids, which is a dispersion of nano-sized particles in a base fluid. The nano-sized particles increase the thermal conductivity of the base fluid which inturn increases the heat transfer rate. This property has attracted the attention of researchers in the past decade, thought the mechanism is not fully understood yet. Nanofluid is a fluid containing nanoparticle-sized particles, called nano particles. These fluids are engineered colloidal suspensions of nanoparticles in a base fluid have been explained by Buongiorno. The nano particles used in nanofluids are typically made of metals, oxides, carbides or carbon nanotube and the common basefluids include water and ethylene glycol. Nanofluids have novel properties that make them potentially useful in many applications in heat transfer, including microelectronics, fuel cells, pharmaceutical processes and hybrid-powered engines that have been explained by Das et al. Nanofluids exhibit enhanced thermal conductivity and the convective heat transfer coefficient compared to the base fluid by Kakaç and Pramuanjaroenskij. Thermal conductivity of Fe3O4 nanofluids is explained by many researchers. Most of the experimental work is undertaken for the estimation of heat transfer coefficient of Al2O3 and Cu nanofluids in plain tube and some researchers have concentrated for the estimation of heat transfer of coefficient of Al2O3 nanofluid in plain tube with twisted and wire coiled inserts. Thermal conductivity of magnetic Fe3O4 nanofluids literature is available, experimental turbulent convective heat transfer and friction factor of Fe3O4 magnetic nanofluid for tube flow and with twisted tape inserts data is not available. The advantage with this fluid
is separation of magnetic nanoparticles (Fe3O4) from the basefluid is possible, which is not possible with non magnetic (Al2O3,Cu and TiO2) type nanoparticles. The present investigation is carried out to estimate turbulent forced convective heat transfer and friction factor at different volume concentrations of Fe3O4nanofluid in a plain tube under turbulent flow conditions. Based on the experimental data generalized regression equations are developed for Nusselt number and friction factor.

**COMPUTATIONAL FLUID DYNAMICS**

In this study a single phase models are used for solving the respective category problems. This model will calculate one transport equation for the momentum and one for continuity for each phase, and then energy equations are solved to study the thermal behavior of the system. The theory for this model is taken from the ANSYS CFX 13.0.

1. **Properties of numerical solution method**

   The solution method should have certain properties. In most cases, it is not possible to analyze the complete solution method. One analyzes the components of the method; if the components do not possess the desired properties, neither will the complete method but the reverse is not necessarily true. The most important properties are summarized below.

   1. **CONSISTENCY**: The discretization should become exact as the grid spacing tends to zero.
   2. **STABILITY**: A numerical solution method is to be stable if it does not magnify the errors that appear in the course of numerical solution process.
   3. **CONVERGENCE**: A numerical method is said to be convergent if the solution of the discretized equation tends to the exact solution of the differential equation as the grid spacing tends to zero.
   4. **BOUNDEDNESS**: Numerical solution should lie within proper bounds.
   5. **REALIZABILITY**: Models of phenomena which are too complex to treat directly (for example, turbulence, combustion, or multiphase flow) should be designed to guarantee physically realistic solution.
   6. **ACCURACY**: Numerical solution of fluid flow and heat transfer problems are only approximate solutions.

   A. **modeling errors**, which are defined as the difference between the actual flow and the exact solution of the mathematical model
   B. **discretization errors**, defined as the difference between the exact solution of the conservation equation and the exact solution of the algebraic system of equation obtained by discretizing these equation, and
   C. **iteration errors**, defined as the difference between the iterative and exact solution of the algebraic equation system.

2. **Simulation of single phase fluid flow**

   It is well known that nanoparticles have very high thermal conductivity compared to commonly used coolant. Thus, the thermal conductivity and other fluid properties are changed by mixing the particle in fluid. The changed properties of the nanofluids determine the heat transfer performance of the straight pipe with nanofluids. This point is illustrated in this chapter by doing the computational fluid dynamics (CFD) analysis of the hydrodynamics and thermal behaviour of the single phase flow through a circular Pipe (Lee and Mudawar, 2007).

3. **Specification of problem**

   Consider a steady state fluid flowing through a circular pipe of constant cross section as shown in Fig. 3. The diameter and length of circular channel are 0.014 m and 1.7 m respectively. The inlet velocity is \( u \) (m/s), which is constant over the inlet cross-section. The fluid exhausts into the ambient atmosphere which is at a pressure of 1 atm.

![Fig 1: Circular pipe geometry](image)

As fluid flows through in a pipe at both hydraulic and thermally fully developed condition, the Nusselt number is constant for laminar flow and it follows the Dittius-Boelter equation for turbulent flow.

4. **Meshing of geometry**

   Structured meshing method done in ANSYS Workbench was used for meshing the geometry. Nodes were created. The 2D geometry of circular channel with structured mesh is shown in Fig. 2.

![Fig 2: Meshed model of pipe with zoomed view](image)
5. Physical models
Based on the Reynolds number,

\[ \text{Re} = \frac{D u \rho}{\mu} \]

either viscous laminar model or standard k-\( \varepsilon \) model is used for laminar and turbulent flow respectively. The choice of the model is shown in Table 4.1. D is the diameter of the channel, \( \rho \) and \( \mu \) are the density and viscosity of the fluid.

<table>
<thead>
<tr>
<th>Reynolds no. (Re)</th>
<th>Flow (Model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2000</td>
<td>Laminar</td>
</tr>
<tr>
<td>&gt; 2000</td>
<td>( k-\varepsilon ) Model</td>
</tr>
</tbody>
</table>

Table 1: Properties of fluid

6. Material properties
Pure water is used as base working fluid and magnetic Fe3O4 nanofluid is taken as nanoparticles. The density, heat capacity, and thermal conductivity of Fe3O4 are 5180 kg/m³, 670000 J/kg K, and 80.4 W/m K respectively. The properties of nanofluids (nf) are given in Table 4.2 at 30°C temperature and 100 kPa pressure.

<table>
<thead>
<tr>
<th>Volume-fraction (%)</th>
<th>Density (kg/m³)</th>
<th>Specific heat (J/kg K)</th>
<th>Thermal conductivity (W/m K)</th>
<th>Viscosity (kg/m sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02</td>
<td>996.53</td>
<td>4312.16</td>
<td>0.609357</td>
<td>0.0008038</td>
</tr>
<tr>
<td>0.1</td>
<td>999.88</td>
<td>4844.82</td>
<td>0.610788</td>
<td>0.0008292</td>
</tr>
<tr>
<td>0.3</td>
<td>1008.25</td>
<td>6176.46</td>
<td>0.614374</td>
<td>0.0008949</td>
</tr>
<tr>
<td>0.6</td>
<td>1020.806</td>
<td>8173.92</td>
<td>0.61978</td>
<td>0.0009064</td>
</tr>
</tbody>
</table>

Table 2: Water base fluid properties with different concentration of Fe3O4 nanoparticles

7. Method of solutions
There are two ways to solve the problem stated above: (i) analytical method and (ii) CFD method. Lee and Mudwar, 2007 have used analytical method. The results given by Lee and Mudwar, 2007 are having errors in wall temperature and mean temperature calculation at the given inlet mass flow rate. Hence, in the present study, the analytical values of heat transfer coefficients are calculated. The heat transfer coefficients are also obtained using CFD methods and then both the values are compared.

The CFD method follows the use of commercial software ANSYS CFX 13.0 to solve the problem. The specified solver uses a pressure correction based iterative SIMPLE algorithm with 1st order upwind scheme for discretizing the convective transport terms. The convergence criteria for all the dependent variables are specified as 0.001. The default values of under-relaxation factor as shown in Table 4.3 are used in the simulation work.
The above contour plot shows, with the change in volume concentration of nanofluids, the Reynolds number gets increased progressively. The increase in volume concentration also increases the Nusselt number. The focal point of investigation was to evaluate the effect of particle volume concentration on convective heat transfer characteristics in the developed region of the tube flow containing water-Fe₃O₄ nanofluid. It was observed that 0.6% of nanofluids showed the highest heat transfer characteristics than that of the base fluid (water). The average heat transfer coefficient and Nusselt number increased by increasing the particle concentration and flow rate. The average temperature of nanofluid decreased by increasing the particle size.
Fig: 14 Pure water
Fig: 15 0.02% nanofluid

Fig: 16 0.1% nanofluid
Fig: 17 0.6% nanofluid

Fig: 18 Nusselt Number

Fig: 19 0.02% nanofluid

Fig: 20 0.1% nanofluid

Fig: 21 0.3% nanofluid
In the figure 23, it is seen that the local Nusselt number is larger for nanofluids throughout the tube. This is mainly due to the thermal dispersion in the flow. Thermal dispersion results in a higher effective thermal conductivity at the center of the tube which Nusselt number becomes higher when compared to the flow of pure water. Figure above also shows that increasing particle volume fraction increases Nusselt number. This is due to the fact that the effect of thermal dispersion becomes more pronounced with increasing particle volume fraction.

It should be noted that the fully developed nanofluid Nusselt number values are also higher than pure water case. Associated values for different particle volume factions of the Fe3O4/water nanofluid are presented in above figures. It is seen that increasing particle volume fraction increases the fully developed Nusselt number.

CONCLUSION

In this project, the heat transfer coefficient in the developed region of pipe flow containing Fe3O4-water nanofluid during the constant heat flux was simulated using CFD. The focal point of investigation was to evaluate the effect of particle volume concentration on convective heat transfer characteristic in the developed region of the tube flow containing water-Fe3O4 nanofluid. It was observed that 0.6% of nanofluids showed highest heat transfer characteristics than that of the base fluid (water).

The average heat transfer coefficient and Nusselt number increased by increasing the particle concentration and flow rate. The average temperature of nanofluid decreased by increasing the particles size.

In this work the hydrodynamics and thermal behavior of circular pipe were studied. Pure water and its nanofluids (Fe3O4) were considered in pipe channel. A steady state computational fluid dynamics (CFD) models was simulated by ANSYS Fluent 13.0 here. The effect of Reynolds number and Nusselt number on the flow behavior of the pipe was studied.

A numerical study of single phase fluid flow in a pipe was discussed. Water is used as a base fluid and its nanofluids are used as fluid medium. Key conclusion of this chapter can be summarized as follows.

- The computational results successfully validated the analytical data for circular pipe channel.
- Heat transfer coefficient is constant throughout the circular channel due to its fully developed conditions.
- As the concentration of nanoparticle increases heat transfer coefficient also increases, with the increase in Nusselt number.
- Wall temperature increase within the flow direction of circular channel at very low Re simulation of Single Phase Fluid Flow in a Circular channel.
- Wall temperature has negligible variation for higher Reynolds number.

REFERENCES


