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Research Paper

# Computational fluid dynamics (CFD) technique to study the effects of helical wire inserts on heat transfer and pressure drop in a double pipe heat exchanger

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## HIGHLIGHTS

- The influence of coiled wire inserts on various parameters of a double pipe heat-exchanger is studied.
- The latter parameters are the Nusselt number, friction coefficient and overall efficiency.
- The CFD simulations have been performed using two commercial softwares.
- Taking the advantage of proper wire coils could improve the Nusselt values to 1.77 times.
- Proper friction coefficient and Nusselt number correlations are proposed.

## ARTICLE INFO

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## ABSTRACT

In this communication, the computational fluid dynamics (CFD) technique has been employed to study the influence of coiled wire inserts on the Nusselt number, friction coefficient and overall efficiency in double pipe heat-exchangers. For this purpose, some wire coil inserts fitted inside heat-exchangers were meshed and simulated at various Reynolds numbers by using the CFD softwares of Gambit and Fluent. To fulfill reliable and validated results, a big effort was made to generate structural hexahedral meshes over all of the heat-exchanger geometries. The validated models, then, made clear the object and the conditions which could exactly facilitate heat transfer throughout double pipe heat-exchangers. The outcome of this work indicates that taking the advantage of proper wire coils could improve the Nusselt values to 1.77 times. Following the numerical simulation, proper friction coefficient and Nusselt number correlations for various coiled wire inserts with different geometry arrangements under the laminar flow were proposed. Unlike the preceding relations, the correlations of this work are based on the occupied spaces where helical wires take up inside tubes; therefore, the two modified correlations can both be used for non-uniform helical wire insert geometries.

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## 1. Introduction

Thermal equipment designers have always attempted to enhance heat transfer to reduce thermal equipment sizes as well as costs. In industrial processes, heat exchangers have widely been exploited so as for energy losing to be avoided [1]. To develop a proper heat exchanger, many investigators are making a big attempt to introduce a type of exchanger to be not only compact but also to have a high overall heat transfer coefficient [2]. For a long time, different methods have been used to increase convective heat transfer coefficients [3]. These methods are generally divided into two groups: passive methods and active methods. Passive methods are much more efficient than active ones due to their simpler performance and ease of utilization in modern thermal equipment [4]. Active methods, such as generating a vibrational flow in mobile fluids, require some external power input to enhance heat transfer. In contrast, passive methods such as coiled wire inserts

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**Nomenclature**

| | | | |
|---|---|---|---|
| $C_p$ | heat capacity (kJ/kg K) | $NS$ | wire normalize surface area |
| $d$ | diameter of wire (mm) | $P$ | pitch length (mm) |
| $D$ | inside diameter of tube (mm) | $p$ | pressure (Pa) |
| $D_h$ | hydraulic diameter (mm) | $Pr$ | Panhandle number |
| $f$ | friction coefficient | $Re$ | Reynolds number |
| $\vec{f}$ | volumetric force | $T$ | temperature (K) |
| $GCI$ | grid convergence index | $udf$ | user defined function |
| $G_s$ | a constant number (1.25) | $z$ | order of convergence rate |
| $g_i$ | grid converged results (For example Nu) | $\vec{\upsilon}$ | velocity (m/s) |
| $h$ | heat transfer coefficient (W/m$^2$ K) | $t$ | time (s) |
| $k$ | thermal conductivity (W/m K) | $\rho$ | mass density (kg/m$^3$) |
| $L$ | heat exchanger length (mm) | $\mu$ | bulk viscosity (Pa s) |
| $\dot{m}$ | mass flow rate (kg/m$^3$) | $\mu_w$ | water viscosity (Pa s) |
| $Nu$ | Nusselt number | $\eta$ | overall enhancement efficiency |

[5] and micro fin tubes [6] rely on no external power input. These methods are used to enhance the heat transfer rate by increasing either the flow path or generating an angular acceleration to the fluid flow. The importance of swirl flows in industrial applications was discussed by Saqr et al. numerically [7]. At the end of their numerical study, they derived a relation to bold the effect of swirl flows on the entropy augmentation in heat-exchangers. Among the passive methods, coiled wire inserts and twisted tape inserts are more common. The twisted tape inserts inside heat-exchangers result in vortex flow along the heat-exchangers, without having a proper thermal contact with the heat-exchanger walls. In contrast, the coiled wire inserts reduce the heat-exchanger hydraulic diameters and can be used as fin extended surfaces to enhance the heat transfer rates. They result in less pressure drop than the twisted tape inserts although the coiled wire inserts increase the heat-exchanger friction coefficients [8]. When selecting either of the two methods, two factors shall be considered: efficiency and cost. Garcia et al. [9] stated that of all devices used to increase heat transfer rate, the wire coils exhibit striking results since they can be added to equipment easily, and also they culminate in lower pressure drop while their costs are relatively low too.

In the systems containing oil fluids, an increase in the coefficient is more considered due to their low convective heat transfer coefficient. Chiou [10] investigated the effect of coiled wire inserts on chilling horizontal heat-exchangers filled with an oil fluid. He observed an increase in the convective heat transfer coefficient due to the cutting of the thin laminar sub-layer in the fluid film and turbulency augmentation. Later, Garcia et al. [9] examined heat transfer enhancement through coiled wire inserts in a heat-exchanger under laminar, transition and turbulent regimes for the Reynolds numbers ranging from 80 to 90,000 and the Prandtl numbers ranging from 2.5 to 150. They used a water system as well as a water-propylene mixture, and finally reported an increase in heat transfer by using the coiled wire inserts. Uttarwar et al. [11] investigated seven different types of coiled wire inserts inside horizontal tubes. They used oil as a fluid with the Reynolds numbers ranging from 30 to 700 and the Prandtl numbers ranging from 300 to 675, and then they reported the effect of the type and geometric characteristics of the wire inserts on heat transfer rates. Zimparov and Penchev compared thermal and hydraulic performance of coiled wire inserts and twisted tape inserts inside a heat-exchanger in turbulent flow regions [3]. The results showed that the coiled wire inserts were more efficient and useful than the twisted tape inserts. Eiamsa-Ard et al. [12] examined the effect of combining heterogeneous coiled wire inserts (with varying pitch lengthes) and twisted tape inserts on the thermal performance, dimensionless Nusselt number and friction coefficient, and then they compared the results with a plain heat-exchanger. The results showed an improvement in terms of the thermal properties, Nusselt number, and friction coefficient. A comprehensive review of the passive methods employed to increase heat transfer rate within horizontal heat-exchangers has been presented by Dewan et al. [4]. This study included the examination and comparison of the effect of twisted tape inserts, coiled wire inserts, fin extended surface etc. inside the heat-exchangers under laminar and turbulent flows. Following these works, Vahidifar and Kahrom [13] tried to scrutinize the role of inserted wire coils and rings in a double pipe heat exchanger performance. They placed the objects inside the inner tube through which air with $Pr = 0.7$ was flowing and becoming warm. So as to have findings with high accuracy, they repeated their tests with three different d/D ratios and three various pitch ratios while the velocity of air was changed from 1 to 6 m/s. In their experiments, it was the wire coil that rotated the flow and created a centrifugal force whereby the flowing fluids with a high density (low temperature) gave way to the fluids with a low density (high temperature), and then increased heat transfer rate of the heat exchanger. Eventually, it was asserted that the overall enhancement efficiency of the inserted wire coil with d/D = 0.11 and P/D = 1 at a high Reynolds number can be mounted about 128%. To reveal the role of coiled wire inserts on fluid flow performance inside a round pipe, Muñoz-Esparza and Sanmiguel-Rojas [14] employed OpenFOAM package which is based on the finite volume method beside some of their experimental tests. Their experiment was conducted on four wire coil inserts with four dimensionless pitch values of 1.5, 2.5, 3.37 and 4.50 inside a pipe. The authors' results show that there are four different regions in the $Re$-$f$ diagrams when using helical wire inserts. In region I, when $Re < 500$, the flow regime is steady and laminar. In region II, when $500 < Re < 600$, the flow regime is not steady, but it is still laminar. When the flow is in region III, $600 < Re < 850$, a high degree of instability is defined for the flow. In the end, in region IV, $850 < Re$, there is a turbulency in the flow, and it is impossible to simulate the flow by using the laminar model. A constant friction coefficient value appeared within the Reynolds number range of 600 –850, region III, in their experimental results at each of the pitch values. They declared that the friction factor intensity relates strongly on pitch size since for the flow with higher value of dimensionless pitch, the growth of the relative friction coefficient is somewhat smaller than that for the flow with lower pitch size. Solano et al. [15] presented a work in which fluid dynamics and heat transfer in small oscillatory baffled reactors with helical coil inserts were tested. Time-dependent flow on the basis of the periodic and laminar flow was used in the simulation. They employed SIMPLE and first-order upwind algorithm to discretize

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