CAD modeling of fluid domain with twisted tape inserts using Creo Design software

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Abstract - *This study aimed to analyze the effect of outer and inner tube flow rates on heat transfer coefficients in a tube-in-tube helical coil heat exchanger using computational fluid dynamics (CFD) analysis. The CFD simulation employed a fluid mixture of Al2O3/water with a 1% volume fraction, and different fluid inlet velocities ranging from 0.01m/s to 0.05m/s were examined. Several parameters, including temperature distribution, pressure drop, heat transfer coefficient, and Nusselt number, were compared. The Nusselt number comparison curve indicated that CuO/water nanofluids with a 1% volume fraction exhibited the lowest Nusselt number, while a slightly higher Nusselt number was observed for CuO/water nanofluids with a 2% volume fraction. Notably, the highest heat transfer characteristics were observed for Al2O3/water with a 1% volume fraction due to the enhanced thermal conduction in the 1% Al2O3 vapor component of the fluid.*

Key Words: Heat Transfer, Pressure Drop, Reynolds Number, Nusselt number, CFD Model

1. INTRODUCTION

Heat exchangers demonstrate satisfactory thermal efficiency for efficient commercial operation of industrial machinery. To enhance the thermal efficiency of heat exchanger pipes through convection heat transfer, various strategies can be employed, both active and passive. These strategies encompass modifications to the fluid passage, incorporation of spin generators, and utilization of Nano fluids. The primary objectives of these methods are to reduce plant irreversibility, improve heat transfer efficiency, optimize volume, and enhance fluid flow characteristics.

Researchers worldwide have been investigating ways to enhance convective heat transfer efficiency in tubes by exploring different types of additives as liquid phase transformers. These additives contribute to changes in addition geometry, normal velocity gradients, and act as inducers of mixing, disorder swirl generators, and dwell time enhancers. The transfer of thermal energy occurs when the liquid passes from one fluid to another within the heat exchanger. Heat transmission can occur through the fluid surface or between solid-fluid particles. Thermal gradients or temperature variations are crucial for heat transmission among liquids or from the liquid to the surroundings.

Heat exchangers find widespread use in the heating and cooling of fluids, as well as in processes such as evaporation and condensation. They are also employed in applications such as sterilization and pasteurization. In heat exchangers, fluids are segregated by walls to prevent intermixing, and such heat exchangers are referred to as retrievers.

The application of nanofluids in heat exchangers is a promising approach to address the issue of low thermal conduction and reduced efficiency in complex fluid systems. When the thermal properties of the fluid are enhanced, it becomes possible to improve heat transmission within heat exchangers, which in turn allows for more compact designs. One effective method is to increase the heat-carrying capacity by introducing finely dispersed particles into the fluid.

Different types of powders, such as metallic, non-metallic, and polymeric particles, can be incorporated to form slurries in liquid mediums. These fully suspended fluids exhibit higher heat capacities compared to plain fluids, resulting in improved heat transfer efficiency within the heat exchanger. A mechanical application test was conducted to observe the impact of slurry mass, droplet size, scale, and flow rate on heat exchange behavior.

While suspended particles typically have dimensions ranging from micrometers to millimeters, their large size can lead to issues such as scratching and blockage. To overcome these challenges, fluids with nanoparticles are utilized to achieve limited practical issues in heat exchange enhancement. Nanoparticles offer a promising approach for improving fluid heat exchange characteristics. Particles smaller than 100 nm exhibit unique properties distinct from those of ordinary solids. Nano-sized powders demonstrate enhanced interactions compared to micron-sized particles. Researchers have explored the suspension of nanoparticles in fluids to create highly effective heat exchange fluids.

By incorporating nanophase elements into heating and cooling fluids, the heat exchange performance of the liquid can be significantly enhanced.

Flow over cylindrical systems finds extensive applications in various fields, including heat exchangers, cooling systems, and thermal equipment. In the context of a heat exchanger, two crucial phenomena occur: fluid flow within the channels and the heat transfer between the fluids and the channel walls. Enhancements to heat exchangers can be achieved by improving these processes.

Firstly, the rate of thermal exchange depends on the surface area-to-volume ratio, implying that smaller channels result in higher coefficients of thermal exchange. Additionally, optimizing the properties of thermal exchange fluids, such as nanofluids, within a heat exchanger can significantly increase the thermal transfer coefficient.

2. PROBLEM IDENTIFICATION:

Investigating the impact of nanofluids on enhancing heat transfer characteristics in helical insert tubing requires an examination of their use in a heat exchanger, as nanofluids have the potential to significantly improve heat transfer rates compared to conventional base fluids.

3.2 RESEARCH GAP reframed: Existing research has focused on enhancing heat transfer using twisted tapes and nanofluids, as well as optimizing parameters for improved heat transfer. However, there is a need to explore the application of Al2O3/water and CuO/water nanofluids to enhance heat transmission and reduce friction coefficients.

2.2 OBJECTIVES:

The objectives of this study are as follows:

1. Create a fluid domain model with twisted tape inserts using Creo design software.
2. Perform CFD analysis using water as the base fluid to determine temperature, velocity, pressure, and heat transfer coefficient. Conduct the analysis at different Reynolds numbers.
3. Repeat the CFD analysis after replacing the base fluid with Al2O3/water nanofluids.
4. Repeat the CFD analysis after replacing the base fluid with CuO/water nanofluids.
5. Based on temperature analysis and other relevant factors, evaluate the effectiveness of the different fluids and identify the most suitable nanofluid for heat transfer enhancement in helical insert tubing.

3. METHODOLOGY

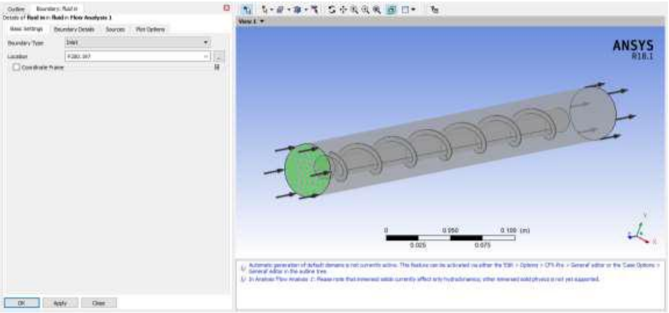


Figure 3.1: Fluid Inlet definition

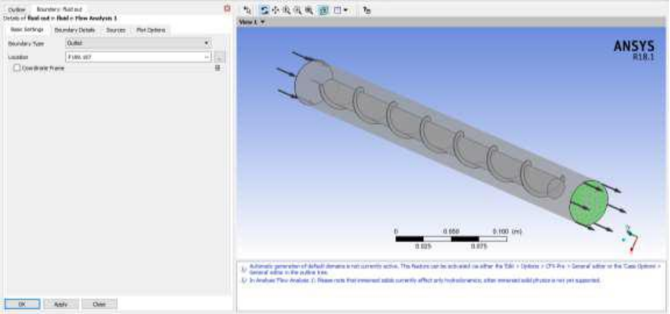
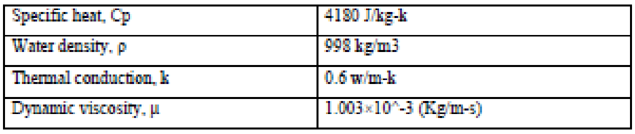


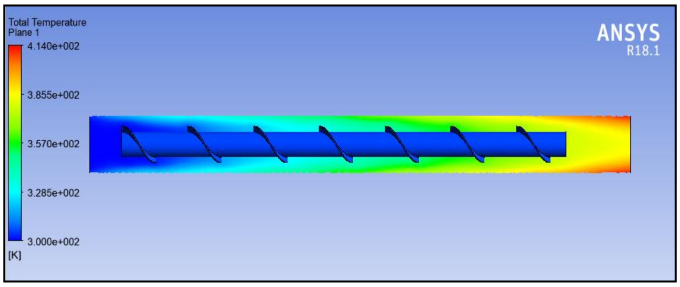
Figure 3.2: Fluid outlet definition

The fluid inlet conditions are defined by a velocity of 0.01m/s and a temperature of 300K. In different cases studied, the inlet velocity is varied to 0.02m/s, 0.03m/s, 0.04m/s, and 0.05m/s. additionally, a heat flux of 100,000W/m2 is applied to the outer wall of the cylindrical domain.

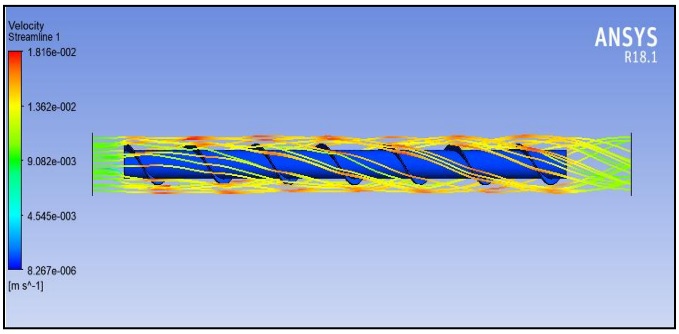
The first computational fluid dynamics (CFD) simulation involves utilizing water as the base fluid. The analysis is carried out at various fluid inlet velocities, namely 0.01m/s, 0.02m/s, 0.03m/s, 0.04m/s, and 0.05m/s. The properties of the water employed in the examination are specified in table 5.1.



Specific heat, Cp	4180 J/kg-k
Water density, ρ	998 kg/m3
Thermal conduction, k	0.6 w/m-k
Dynamic viscosity, μ	1.003×10^-3 (Kg/m-s)



The given diagram, labeled as Figure 3.2, displays the temperature distribution of water functioning as a fluid with a kinematic viscosity of 0.01. This temperature distribution was obtained through the implementation of a helical screw tape insert in a pipe. The contour plot vividly portrays an escalation in temperature from the inlet wall to the outlet wall of the fluid. Towards the inlet, the temperature is almost 300K, indicated by a shade of dark blue. Moving towards the outlet, there is a significant rise in temperature with a mid-region temperature change from 300K to 357K, depicted by a green shade, and 414K near the outlet edge, shown by a red color, with a yellow shade at the central area.



According to the information provided, Figure 3.3 (upper) portrays a velocity streamline plot of CuO/water functioning as the fluid. The plot elucidates the flow characteristics of the fluid throughout the system. The fluid exhibits an inlet velocity of 0.009 m/s upon entering the domain. As the fluid traverses through the helix, the streamline plot reflects variations in the flow behavior, converting from a streamlined flow to a turbulent flow in this section. At the helix region, the fluid velocity is illustrated as 0.018 m/s, depicted by the vibrant red lines, indicating an escalation in velocity compared to the inlet velocity. The turbulent flow depicts increased mixing as well as fluctuations in velocity and pressure experienced by the fluid. The streamline plot demonstrates an equivalent fluid velocity of 0.009 m/s at the outlet, which is similar to the inlet velocity. Thus signifying that there is no notable change in velocity between the inlet and outlet regions of the domain.

The fifth Computational Fluid Dynamics (CFD) analysis is carried out utilizing Al2O3/water (2% volume fraction) as fluid. The analysis is conducted for different fluid inlet velocities, comprising of 0.01m/s, 0.02m/s, 0.03m/s, 0.04m/s, and 0.05m/s.

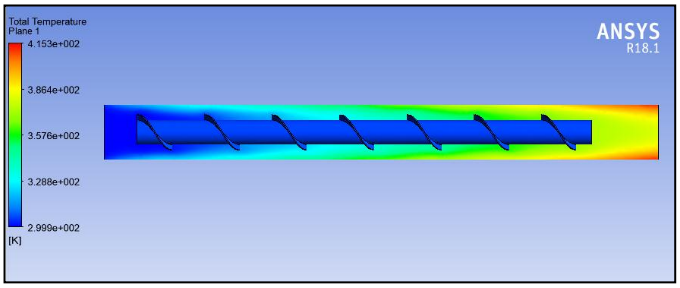


Figure 3.4 showcases a temperature plot of Al2O3/water, where the fluid has an inlet velocity of u = 0.01. The plot specifically depicts the temperature distribution within a pipe equipped with a helical screw tape insert.

The contour plot visually represents the gradual elevation of temperature as one progresses from the fluid inlet towards the fluid outlet wall. Initially, at the fluid inlet, the temperature is depicted by a deep blue shade, symbolizing a value of approximately 300K. However, as one moves closer to the exit, the temperature steadily rises.

Within the mid-region, the contour plot demonstrates a transition from 300K to 357K, observable through the presence of a green hue. Moreover, near the exit, the temperature intensifies further, reaching a value of 415K. This intensified temperature is illustrated by a red color along the edge and a yellow shade at the center of the contour plot.

Figure 3..5 and Figure 3.6 showcase the RN vs NN curve for both 1% and 2% volume fractions of Al2O3/water. As observed, an increase in RN corresponds to a concurrent increase in NN. Remarkably, the minimum observed value of NN is 1591, while the maximum RN value recorded is 7928.

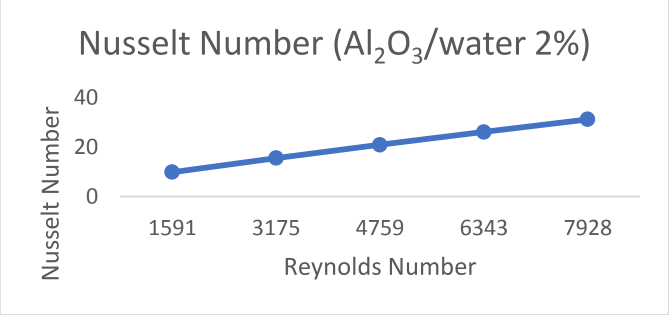


Figure 3.4: Nusselt number vs Reynolds number for Al_2O_3/water (2% volume fraction) as fluid

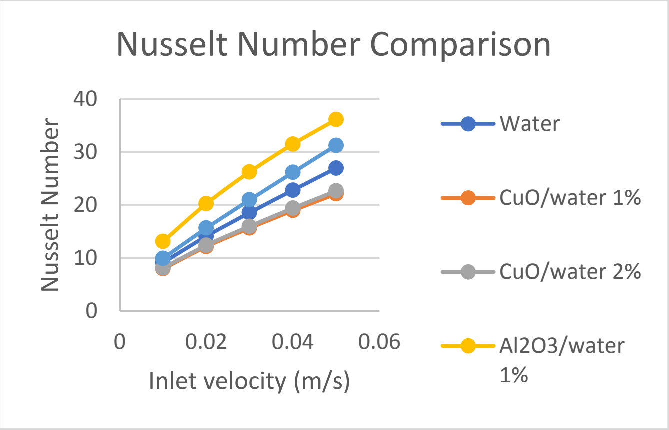


Figure 3.5: Nusselt number comparison for different fluid type and volume percentage

4. CONCLUSION:

The present study utilized numerical simulation to investigate the impact of nanofluids on heat transfer characteristics within a spiral screw tape inserted tube. Using computer simulation software allowed for an efficient and cost-effective means of evaluating fluid flow and heat transfer characteristics as compared to experimental methods. Key findings from the study include:

1. An increase in Reynolds number (RN) corresponded to an increase in Nusselt number (NN) across all fluid types, indicating an enhanced frequency of heat transfer at higher fluid velocities and turbulent flow conditions.

2. The use of Al2O3/water nanofluids significantly improved heat transfer characteristics in water.

3. In contrast, the use of CuO/water nanofluids led to lower heat transfer efficiency despite water's higher friction factor.

4. Specifically, the use of Al2O3/water nanofluids led to a 43.7% increase in heat transfer compared to water at a fluid velocity of 0.01 m/s.

5. Moreover, compared to water at a fluid velocity of 0.03 m/s, the use of Al2O3/water nanofluids resulted in a 41.5% improvement in heat transfer.

Overall, the results of this study demonstrate the effectiveness of nanofluids in enhancing heat transfer characteristics in pipes, with Al2O3/water nanofluids showing particular promise.

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