



# Experimental Study of Fluid Flow and Heat Transfer of $Al_2O_3$ -Water Nanofluid in Helically Coiled Micro-Finned Tubes

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**ABSTRACT:** In this study, inactive methods of enhancing heat transfer in the shell and tube heat exchangers, such as using smooth and micro-fins helically coiled tubes, and employing nanofluids as the working fluid, are investigated experimentally. A number of experiments are carried out for the flow of the  $Al_2O_3$ -water nanofluid in a shell and tube heat exchangers with helically coiled smooth as well as micro-finned tubes, and the pressure drop and the heat transfer coefficient are measured. The experiments are conducted for the Dean number ranging from 500 to 4000, for the fin helix angle between 18 and 25°, and for the nanofluid volume fractions of 0, 0.5 and 1%. The average heat transfer coefficients of the tube side of heat exchangers in each case is calculated using the Wilson plot method. Empirical correlations are proposed for the heat transfer coefficient of the nanofluid following through the tube-side of the heat exchanger in terms of the Dean number, the fin helix angle, the fin height and the volume fraction of the nanofluid. Based on the experimental results, using micro-finned coiled tubes together with increasing the micro-fin helix angle and employing nanofluid enhance the heat transfer while increasing the pressure drop through the heat exchanger.

**Review History:**

Received:  
Revised:  
Accepted:  
Available Online:

**Keywords:**

Micro-finned tube  
Nanofluid  
Helically coiled tube  
Wilson plot method  
Heat transfer

## 1. INTRODUCTION

Different methods are available to enhance the heat transfer performance of shell and tube heat exchangers. Adding nanoparticles to the working fluid, i.e., employing nanofluid as the working fluid, using tubes with internal micro-fins, employing helically coiled tubes, as well as various combination of these techniques are among the passive method of improving the heat transfer performance of the heat exchangers.

There are a number of recent experimental studies devoted to the single-phase fluid flow through the micro-finned tubes [1-8]. A comprehensive literature survey on the thermal-hydraulic characteristic of the fluid flow and heat transfer inside pipes have been conducted by Ji et al. [9]. They observed that, among the considered enhanced tubes, the tube with internal micro-fins yielded the best thermal-hydraulic performance.

The helically coiled tubes are frequently employed in the shell and tube heat exchangers to make them compact and to enhance their performance. There are some experimental and numerical studies concerning the fluid flow and heat transfer of the shell and tube heat exchanger with the smooth and helical coiled tubes [10-12]. However, a comprehensive literature review, reveals that there is very little if any study devoted to investigating the pressure drop and the heat transfer coefficients of this class of heat exchangers with the coiled tubes having internal micro-fins. Therefore, the present experimental investigation is concerned with studying the developing fluid flow and heat transfer of  $Al_2O_3$ -water

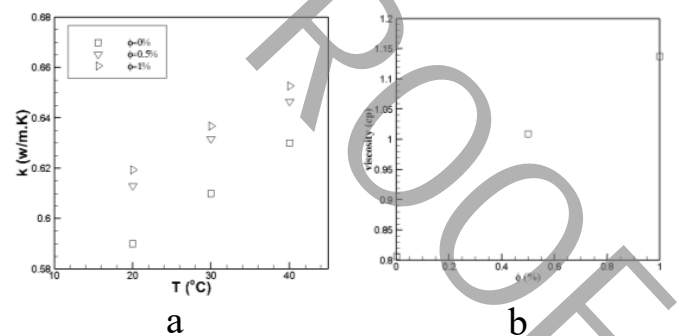
nanofluid inside the coiled tubes of the shell and tube heat exchangers with internal micro-fins.

## 2. THE NANOFLUID THERMOPHYSICAL PROPERTIES

In this study, the  $Al_2O_3$  water nanofluid is employed as the working fluid. The results of the measurements of the thermal conductivity and the viscosity of the nanofluid are presented in Figs. 1(a) and 1(b), respectively.

## 3. EXPERIMENTAL EQUIPMENT

The test section of the experimental apparatuses employed in this study is a shell and coiled tube, a counter flow heat



**Fig. 1: Thermal conductivity and the viscosity of the  $Al_2O_3$ -water nanofluid for the different volume fraction of the nanofluid at different temperatures. (a) thermal conductivity (b) viscosity**

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**Table 1: Characteristics of the coiled tubes employed in the experiments**

Coiled tube number	Number of coils	Coil pitch (mm)	Coil diameter (mm)	Helix angle	Tube length (m)
1	12	15	104	smooth	4.25
2	12	15	108	18	4.35
3	12	15	105	25	4.30
4	21.5	15	61	smooth	4.30
5	21.5	15	63	18	4.35
6	21.5	15	65	25	4.35

exchanger. The heated working fluid (nanofluid) flow inside the coiled tubes while losing heat to the cool distilled water which flows inside the shell. The shell is made of Plexiglas. Three types of coiled tube namely one smooth and two helically micro-fined tubes are employed in this study.

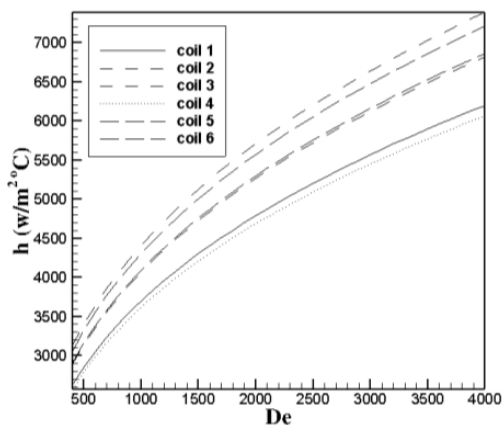
#### 4. EXPERIMENTAL PROCEDURE

Six different coiled tubes are employed in the experiments whose characteristics are given in Table 1. Subsequent to starting the experimental apparatus and reaching the steady state condition, the temperature and the pressure difference at the inlet and the outlet of the tube are measured and recorded every five minutes. For each coiled tube and for a fixed volume fraction of the nanoparticles, experiments are carried out for 10 to 15 different mass flow rates of the nanofluid between 0.1 to 2.5 lit/min. Moreover, three different volume fractions of the nanoparticles, namely 0, 0.5 and 1%, are employed in the experiments. The experiments are conducted for Reynolds number of the fluid flow inside the tube between 300 to 6500 and the Dean number ranging from 500 to 4000.

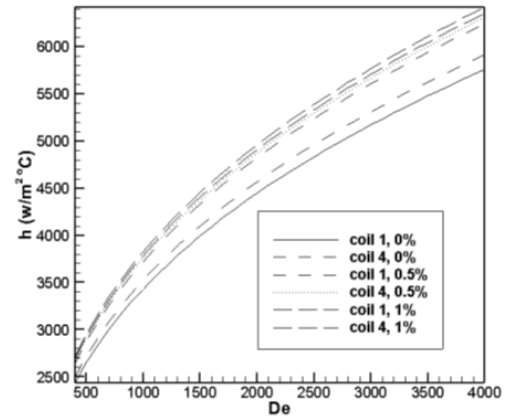
The Wilson plot method, which is based on utilizing the temperature difference between the inlet and the outlet temperature of the fluid inside the tube, is employed to calculate the heat transfer coefficient [13].

#### 5. RESULTS AND DISCUSSION

The heat transfer coefficient of the coiled tube side with respect to the Dean number for the six different coiled tubes of Table 1 is presented in Fig. 2. As it is observed from this



**Fig. 2: Variation of the heat transfer coefficient with respect to De for the six considered coiled tube**



**Fig. 3: Variation of the heat transfer coefficient with respect to De for the coiled tube No.1 and No.4. for the different volume fraction of the nanoparticles**

figure, the heat transfer coefficient increases with increasing the Dean number (De). Moreover, for a constant De, it increases with increasing the micro-fin helix angle. Variation of the heat transfer coefficient with respect to De for the coiled tube No.1 and No.4 and for the volume fraction of the nanoparticles equal to 0, 0.5 and 1% are shown in Fig. 3. The results show that, for a constant De, the heat transfer coefficient increases with increasing the nanofluid volume fraction for the considered cases.

#### 6. CONCLUSIONS

The fluid flow and heat transfer of the  $\text{Al}_2\text{O}_3$ -water nanofluid inside various smooth and micro-fined coiled tubes of a shell and tube heat exchanger are studied experimentally. The results show that using micro-fined tubes and increasing micro-fin helix angle result in the heat transfer enhancement through the heat exchanger.

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