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Heat Transfer Characteristics of Nanofluids in Helical Coiled Tube Teat Exchanger: A Review

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Abstract – The purpose of this review paper is to summarize the recently published papers on the heat transfer and flow characteristics of conventional fluids and nanofluids in helically coiled tube heat exchanger. The use of helical tubes in shell and tube heat exchanger has been investigated by various researchers in the previous 2-3 decades. The use of nanofluids in helical tubes has been investigated by some researchers in the recent years for finding new opportunities of enhancement in thermo-physical and hydrodynamic performance of shell and tube heat exchanger. This paper presents the experimental and analytical studies published on behaviour of nanofluid flowing through the helical tube in the literature.

Keywords— Nanofluid, heat transfer, helically coiled tubes, thermo-physical, hydrodynamic, enhancement.

Nomenclature		***Greek symbols***	
De	*Dean Number*	*μ*	*Dynamic viscosity*
Re	*Reynolds Number*	*Ø*	*Volume concentration*
D	*Coil diameter*	*ρ*	*Density*
R	*Tube radius*		
P	*pitch*	*subscripts*	
K	*Thermal conductivity*	*p*	*Particle*
C_p	*Specific heat*	*nf*	*Nanofluid*
		bf	*Basefluid*

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1. INTRODUCTION

The heat exchanger is thermal equipment in which energy is transferred from one fluid to another across a solid surface. Many types of heat exchangers are used in industrial processes. . Helical and spiral coils are known types of curved tubes which have been used in a wide variety of industrial applications. A centrifugal force is generated due to the curvature of the tube. Secondary flows developed by the centrifugal force are responsible for the heat transfer enhancement. Helically coiled tube heat exchangers are compact and provides large heat transfer surface area into a small volume, less fouling, operational flexibility and are easy to maintain. Hence the helical coiled tube heat exchanger is more favourable heat exchanger.

Improving the coil geometry can lead to enhance the heat transfer rate of the helical tube heat exchanger. Helically coiled tube heat exchanger uses single channel technology which means that both fluids occupy a single channel, which allows fully counter-current flow. The channels are curved and have a uniform cross section, which creates “spiralling” motion within the fluid. The fluid is fully turbulent at a much lower velocity than in straight tube heat exchangers, and fluid travels at constant velocity throughout the whole unit.

The heat transfer enhancement techniques has been classified into two main categories viz. active techniques which require external power for heat transfer augmentation, and passive techniques which need no such external power for enhancement. The use of helical tube heat exchanger is one of the passive methods. Also the use of nanofluids instead of conventional fluids as a working substance is a kind of passive technique of heat transfer enhancement. Nanofluid is a terminology for a base fluid material containing one or more than one type of nanoparticles. Usually, the nanoparticles that are used in nanofluid are made of metals (e.g. copper, tin, aluminium), Metal oxides (e.g. alumina, bismuth oxide, silica, titania, zirconia), carbides, carbon nanotubes or oxides. Nanoparticles have size less than 100nm and having thermal conductivity higher than base fluid (e.g. water, glycerine). By addition of nanoparticles, the thermo-physical properties of the working fluid are significantly improved, including thermal conductivity, viscosity, convective heat transfer coefficient. Hence nanofluid is a fluid that enhances the heat transfer rate.

Although there are a large number of papers in this field, but the reviews on this topic are very limited. Heat transfer and flow through a curved tube is comprehensively first reviewed by Naphon and Wongwises [1] and the latest review of flow and heat transfer characteristics are provided by Gabriela Huminic and Angel Huminic [2].

This review presents the recent research in heat transfer and flow characteristics of conventional fluids and nanofluids helically coiled tubes including the experimental, numerical and analytical investigations in the respective field.

2. HELICALLY COILED TUBES

Helical coiled tubes are efficient heat transfer equipments due to their geometrical shape, compact size and high heat transfer performance in comparison with straight tube heat exchangers. Several studies have been done to analyse the thermo-physical and hydrodynamic characteristics of helically coiled tube heat exchangers in laminar and turbulent flow regimes. The most important characteristic of flow in helical tube is the secondary flow developed by centrifugal force due to the curvature of tube. Consequently, heat transfer and friction are significantly larger than in straight pipes. Consequently, heat transfer and friction factor are significantly larger in helical tube heat exchangers than straight tubes.

The motion of fluid in curved tube has been studied very early by Dean [3]. The steady flow motion of incompressible fluid in curved tube has been studied theoretically and developed a correlation known as Dean number which gives significance of curvature ratio, is given as

$$De = Re\sqrt{\frac{d}{2r}} \qquad \text{.....................} \text{ (I)}$$

A. Experimental studies

There is a complicated flow pattern in helical coil in case of laminar and turbulent flow regimes which enhances the overall heat transfer coefficient. It is tedious to characterise the hydrodynamics of fluid flow in helically coiled tube due to simultaneous mixing of primary and secondary flow. Reynolds number and Dean number are unable to analyse the hydrodynamics of flow in curved tube. So, Mujawar and Rao [4] had developed the criterion for laminar flow through the helical coiled tube introducing new dimensionless number, M. It gives significance of curvature ratio of coil and Reynolds number, and is given as,

$$M = \frac{Re^{0.64}}{0.26[\frac{d}{2r}]^{0.18}} \leq 2100 \qquad \text{.................} \text{ (II)}$$

Experimental studies have been conducted on helical coil tubes under different operating conditions. S.S.Pawar [5] had experimentally investigated the steady and unsteady state convection heat transfer from helical coiled tubes mounted vertically in water for laminar flow regime. Helical coiled tubes with curvature ratios as 0.0757, 0.064, 0.055 and Prandtl number ranging from 3.81 to 4.8, Reynolds number from 3,166 to 9,658 were taken into account for this work. An innovative approach of correlating Nusselt number with ‘M’ number is proposed for the first time which is not available in the literature. Thus, dimensionless number ‘M’ was found to be significant to characterize the hydrodynamics of fluid flow and heat transfer correlations in helical coils. Comparative study of heat transfer coefficients, friction factor and Nusselt number for different geometrical conditions is done in this paper.

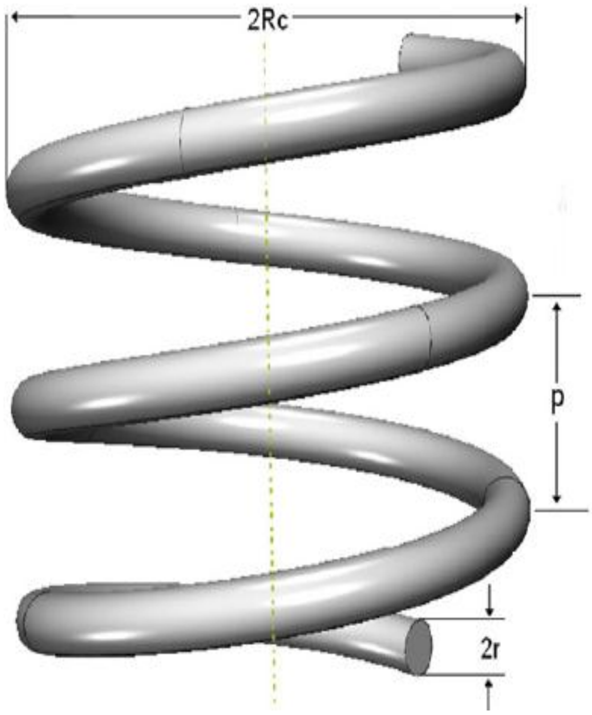

Fig.1 A geometry of helical coiled tube

In addition, experimental study [6] on isothermal steady state and non-isothermal unsteady state conditions were carried out in helical coils. Water, glycerol–water mixture as Newtonian fluids and dilute aqueous polymer solutions of sodium carboxymethyl cellulose (SCMC), sodium alginate (SA) as non-Newtonian fluids were used as different conventional fluids in this study. The overall heat transfer coefficient and Nusselt number are found to be higher for water than water-glycerol mixture and non-Newtonian fluids. From experimental results, it was also found that overall heat transfer coefficient and Nusselt numbers of both fluids decreases as helix diameter increases for the same operating conditions (same flow rates).

Experimental investigation on the shell and helically coiled tube heat exchangers was carried out by H.Shokouhmand [7].Helical coiled tubes with three different pitches and curvature ratio were tested under parallel-flow and counter-flow configurations. Overall heat transfer coefficients of the heat exchangers were calculated using Wilson plots. From the results, it was concluded that the shell-side heat transfer coefficients for larger pitches are more than that with smaller pitches.

3. NANOFLUIDS

Nanofluid is a fluid, which contains nanoparticles. These nanoparticles are generally made up metals, oxides, carbides, carbon nanotubes and are mixed with base fluids such as water, glycerin, ethylene glycol, etc. Choi [8] first suggested the first term nanoparticle. Nanofluids have higher thermal conductivity than that of conventional fluids and show good thermo-hydrodynamic nature when flowing through curved tubes. Hence, nanofluids are used as working fluid in heat exchanger applications as a passive technique of heat transfer enhancement.

After adding nanoparticles to base fluid, the thermo-physical properties of nanofluid changes. Jaafar Albadr [9] does the experimental investigation on different volume concentrations of Al_2O_3 and water nanofluid under force convective conditions. For such an investigation, the properties of nanofluid are very important to study heat transfer and hydrodynamics of nanofluid. The properties of nanofluids are calculated by using following correlations:

B. density

Pak and Cho [10] correlations given by calculated the equation for density of nanofluid,

$$\rho_{nf} = (1 - \emptyset)\rho_{bf} + \emptyset \rho_p K_{nf} \quad \text{.......... (III)}$$

C. specific heat

The correlation for specific heat was developed by Xuan and Roetzel [11] given by,

$$(\rho C_p)_{nf} = (1 - \emptyset)(\rho C_p)_{bf} + \emptyset(\rho C_p)_p \quad \text{.......................... (IV)}$$

D. thermal conductivity

The equation for calculating thermal conductivity of nanofluid was given by Yu and Choi [12],

$$\frac{K_{nf}}{K_{bf}} = \frac{K_p + 2K_{bf} - 2\emptyset(K_{bf} - K_p)}{K_p + 2K_{bf} + \emptyset(K_{bf} + K_p)} \quad \text{.......................... (V)}$$

E. dynamic viscosity

The correlation for finding the viscosity of nanofluid was deduced by Drew and Passman [13] and is given as

$$\mu_{nf} = (1 + 2.5\emptyset)\mu_{bf} \quad \text{.......................... (VI)}$$

This equation is applicable to volume concentration less than 5 percent.

The above equations are deduced for water as a base fluid and nanoparticles at room temperature.

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4. HELICALLY COILED TUBE WITH NANOFLUID

The use of nanofluid as a working substance in helically coiled tube heat exchanger is the combination of two passive techniques of heat transfer enhancement which is done by several researchers in the recent years. The experimental investigation of shell and helically coiled tube heat exchanger is done by T. Srinivas and A.Venu Vinod [14], using various concentrations (0.3, 0.6, 1, 1.5, 2 %) of CuO/water nanofluid (particle size 40nm) and varying the stirrer speed. Water is used as shell side fluid and investigation is done at different flow rates.

The figs shows the heat transfer rates for varying stirrer speeds viz. 500,1000,1500 rpm with different concentrations of CuO nanofluid. From fig.2 it is found that heat transfer increases as the Dean number increases. It is also seen that heat transfer rate increases with the increase in concentration of CuO nanoparticles. The maximum heat transfer was found to be 32.7% as compared to water at maximum concentration.

Similarly, the maximum heat transfer enhancement was 27.9% and 23.9% for stirrer speeds 1000rpm and 500rpm in fig.3 and fig.4 respectively.

From study, it was concluded that heat transfer enhancement was increasing with the increase in concentration of nanofluid and maximum at 2 % of CuO/Water nanofluid. It was also concluded that use of nanofluid is more effective than stirrer speeds for heat transfer enhancement.

An experimental analysis for pressure drop characteristics of nanofluid flow inside helical coiled tube heat exchanger has been carried out by M. Fakoor-Pakdaman [15] in the laminar flow regime.

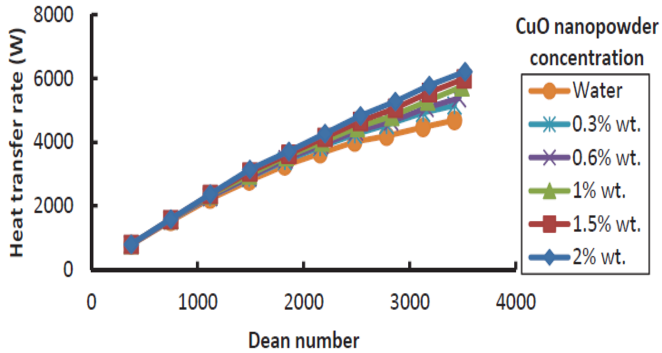

Fig. 2 Effect of CuO nanoparticle concentration on heat transfer rate (Shell side temperature=50ºC, Stirrer speed=1500 rpm)

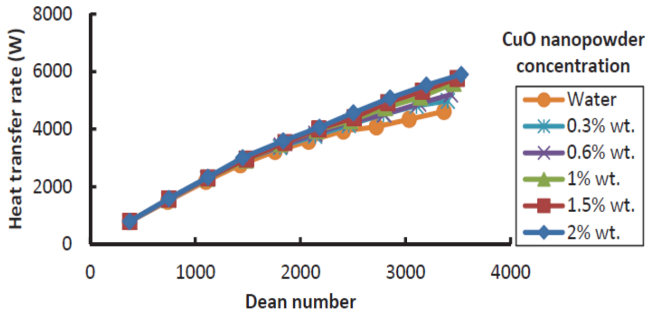

Fig. 3 Effect of CuO nanoparticle concentration on heat transfer rate (Shell side temperature=50ºC, Stirrer speed=1000 rpm)

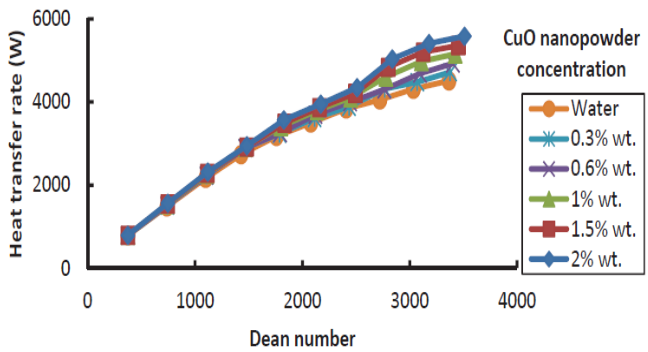

Fig. 4 Effect of CuO nanoparticle concentration on heat transfer rate (Shell side temperature=50ºC, Stirrer speed= 500 rpm)

For having isothermal boundary conditions, the temperature of tube wall kept constant at 95ºC. Comparative study has been made between straight tube and helically coiled tube and nanofluid is allowed to flow through it. The effects of different geometrical, dimensionless parameters and varying mass fraction (0.1, 0.2 and 0.4%) of nanoparticles (MWCNT) have been studied. Oil and nanofluids were used as working substance for detailed investigation of effect of fluid type on heat transfer rate.

From this investigation, it was concluded that the Nusselt number increased up to 45% by using nanofluid instead of conventional fluid. The increase in heat transfer coefficient was around 80%. In case of helical coil, the heat transfer rate increases with the coil to tube diameter ratio and decrease in coil pitch.

5. CONCLUSION

This paper is a review of recently published papers on heat transfer and hydrodynamics of helically coiled tube using conventional fluids and nanofluids as a working substance. The following conclusions are made after this review:

- Some of the researchers have investigated on the helical tube heat exchangers and studied the effect change in tube geometry on heat transfer performance of helical tube heat exchanger.

- Most of the researchers have done their work based on the calculations of empirical relations for flow over circular tubes, which neglect the effects of curvature ratio and pitch.
- Very few researchers have investigated the performance of helical tube heat exchanger using nanofluid as a working fluid.
- Use of nanofluid increases the thermo-physical parameters and pressure drop, hence increases heat transfer rate.
- Helically coiled tubes are more efficient than that of straight tubes.

FUTURE SCOPE:

Further investigation can be made by varying the geometrical parameters of helical coil tube such as curvature ratio, pitch and helix using different combinations of nanofluids, which may result in efficient and effective performance of shell and tube heat exchanger.

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