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Research Paper

Experimental investigation on intensified convective heat transfer coefficient of water based PANI nanofluid in vertical helical coiled heat exchanger

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HIGHLIGHTS

- Heat transfer coefficient increases with an increase in vol% of PANI nanofibers.
- The effect of Reynolds number of nanofluid on heat transfer coefficient was examined.
- Around 70% enhancement in Heat transfer coefficient for 0.5 vol% PANI nanofluids.
- Increase in heat transfer coefficient was found with an increase in the Reynolds number.

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ABSTRACT

In the present study, heat transfer enhancement with the use of water based PANI (polyaniline) nanofluid was investigated in vertical helically coiled tube heat exchanger. Initially, PANI nanofibers were prepared with the use of ultrasound assisted emulsion polymerization method. Then the prepared PANI nanofibers were dispersed in base fluid in varying concentration (0.1–0.5 vol%) in order to get uniformly dispersed PANI nanofluid in the presence of sonication. The effect of PANI nanofibers concentration in nanofluid and Reynolds number on heat transfer coefficient have been investigated in helical coiled heat exchanger. It was found that the average heat transfer coefficient increases with an increase in the volume% of PANI nanofibers in nanofluid and Reynolds number. The heat transfer coefficient of base fluid i.e. distilled water was found to be 304 W/m^2 °C (at $x_i/D = 692.3$) whereas it was found to be increased to 515.8 W/m^2 °C (at $x_i/D = 692.3$) for 0.5 vol% PANI concentration in nanofluid. The percentage enhancement in the heat transfer coefficient was found to be 10.52% at 0.1 vol% of PANI nanofibers in nanofluid and was found to be increased to 69.62% for 0.5 vol% of PANI nanofibers.

1. Introduction

In recent years cooling of mechanical, electrical and electronic components has become a problem in today's fast-growing technologies and also similar problem was observed in the thermal management in the area of optical devices. Therefore the devices for the effective removal of heat are being required for these applications. Further it is essential to develop compact devices with use of efficient cooling fluids which will provide more effective cooling systems with superior cooling capacities and decreased sizes is a need of the hour. It have been observed that the use of different shaped heat exchange devices (helical, spiral) offers heat transfer enhancement. Therefore use of helical coils for heat exchange (cooling devices) will enhance the heat transfer capability of the fluid itself i.e. with nanofluids without ant sedimentation in the tube [1–4].

The geometry of the heat exchanger also plays a critical role in determining heat transfer characteristics. Due to their compact structure and high heat transfer coefficient, curved tubes have been introduced as one of the significant heat transfer enhancement techniques. Helical tubes are well known types of curved tubes which have been used in a variety of applications, such as heat recovery processes and steam power plants, membrane separation, air conditioning, refrigeration and cryogenics processes, chemical reactors, food and dairy processes, electronics, environmental engineering, manufacturing industry and solar energy concentrators systems [5,6]. Secondary flow in coiled tubes as a result

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Nomenclature

A	inner surface area of the copper helical coil	r	radius of tube (m)
C_p	heat capacity of nanoparticles	$T_b(x)$	fluid bulk temperature being measured at a distance 'x' from the inlet
C_{bf}	heat capacity of base fluid	$T_s(x)$	wall temperature at a distance 'x' from the inlet
$C_{P_{nf}}$	heat capacity of nanofluid	T_{bi}	bulk fluid inlet temperature of the copper helical coil
D	diameter of inside tube of helical coil	T_{bo}	bulk fluid outlet temperature of the copper helical coil
D_c	diameter of helix	T_i	inlet fluid temperature (°C)
$hi(coil)$	heat transfer coefficient in helical coil	T_O	outlet fluid temperature (°C)
$hi(straight)$	heat transfer coefficient in straight tube	T_S	wall temperature (°C)
$\bar{h}$	average heat transfer coefficient	ρ_{nf}	density of nanofluid
k_{bf}	thermal conductivity of base fluid	ρ_p	density of nanoparticles
k_{nf}	thermal conductivity of nanofluid	ρ_{bf}	density of base fluid
k_p	thermal conductivity of nanoparticles	ϕ	volume fraction of nanoparticles in nanofluid
L	length of tube (m)	μ_{nf}	viscosity of nanofluid
$\dot{m}$	mass flow rate of fluid (kg/s)	μ_f	viscosity of fluid
q_s	heat flux applied to the fluid		

of centrifugal forces is a well-known phenomenon. The centrifugal forces caused by the curvature of the tube produce a secondary flow field (superimposed on the main axial flow), with a circulatory motion pushing the fluid particles toward the core region of the tube. This flow increases the heat and mass transfer as compared with the values obtained for straight tubes [5,7–9]. Hashemi and Akhavan-Behabadi [7] have carried out an experimental investigation in order to investigate the heat transfer and pressure drop characteristics of CuO nanofluid flow inside horizontal helical tube under constant heat flux. In their report the effect of various parameters like flow Reynolds number, fluid temperature and nanofluid particle concentration on heat transfer coefficient and pressure drop of the flow was investigated. It has been reported that applying helical tube instead of the straight tube is a more effective method to improve the convective heat transfer coefficient. Hashemi and Akhavan-Behabadi [7] have reported 78.4% enhancement in heat transfer coefficient at 82.2 Reynolds number in helical coil compared with straight tube. Further it have been concluded that the nanofluid has improved performance in helical coil compared with straight tube. Kumar et al. [8] have used Al_2O_3/water nanofluid in shell and tube helically coiled heat exchanger under turbulent flow condition with varying nanoparticles concentration. It has been reported that there is significant enhancement in the Nusselt number (56% higher than pure water for 0.8 vol% Al_2O_3 nanoparticles). Kahani et al. [9] investigated TiO_2/water nanofluids under laminar flow conditions through helical coiled tubes. The study showed that there is significant increase in heat transfer rate due to TiO_2 nanoparticles. Further Xu et al. [10] have also concluded same possibilities for the enhancement in the heat transfer coefficient in helical coil compared to straight tube.

Further Polyaniline (PANI) nanofibers are being used for the preparation of nanofluid [11,12]. PANI is also widely studied conducting polymer because of its better conducting properties, ease of doping process, environmental stability and potential applications in electrochemical devices [13,14]. The addition of PANI in the base fluids leads to enhancement in the thermal conductivity of the formed nanofluids [12]. Further the agglomeration and stability problems of PANI nanofluids can be overcome by preparing the colloidal suspension of PANI. Further conventional polymerization method produces non-uniform structures of PANI and hence it will affect the properties of nanofluids. Therefore the use of ultrasound assisted emulsion polymerization for the preparation of colloidal suspension of polymer is promising technique [15–18]. Bhanvase et al. [19] have investigated the heat transfer enhancement using PANI and PANI-CuO nanocomposite based nanofluids in straight tube under constant heat flux condition. It has been reported that the 0.5 vol% PANI and PANI-CuO nanofluids show enhancement in heat transfer coefficient by more than 12% and around 38%, respectively. However, there is no article in the literature that reports the use of PANI nanofluid for heat transfer enhancement in helical coiled tube heat exchanger.

Significant enhancement in the heat transfer properties have been observed when helical coil was used instead of straight tube in heat exchangers [7,10]. It is attributed to the geometry of the helical coil which significantly enhances the heat transfer coefficient and other properties. Further as fluid flows through the helical coil, centrifugal force is generated in the coil and due to which secondary flow is generated. This secondary flow is significantly responsible for the change in temperature and velocity distribution along tube cross-section. Secondary flow is also responsible for significant enhancement in the heat transfer rate due to above mentioned reasons and velocity gradient across tube section. Therefore, in the present study, heat transfer coefficient of PANI/water nanofluid inside a helical coiled tube heat exchanger was investigated experimentally. All experiments were carried out in a wide range of Reynolds number (812 –1896) and PANI nanofibers loading (0.1–0.5 vol%).

2. Experimental

2.1. Materials

The chemicals used for the preparation of PANI nanofibers by ultrasound assisted emulsion polymerization were of analytical grade and used as received. Ammonium persulphate (APS), hydrochloric acid, and aniline were purchased from Merck India. Sodium lauryl sulphate (SLS) used as surfactant was purchased from S.D. Fine Chem. Ltd, Mumbai. Distilled water was used throughout the experiment.

2.2. Preparation of PANI nanofibers by ultrasound assisted method

The preparation of PANI nanofibers were carried out by an ultrasound assisted emulsion polymerization method. Initially 1 M HCl solution was prepared and then 10 g aniline was added to 200 mL 1 M HCl solution. Ammonium persulphate (APS) and sodium lauryl sulphate (SLS) solutions were prepared by adding 5 g APS in 50 ml distilled water and 3 g SLS in 20 ml distilled water, respectively. Aniline solution and SLS solutions were transferred to sonochemical reactor (Dakshin India, Frequency 22 Hz, Power = 240 W). The resultant solution was cooled in ice bath to