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Effect of twisted tape inserts on heat transfer, friction factor of Fe_3O_4 nanofluids flow in a double pipe U-bend heat exchanger

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ABSTRACT

The convective heat transfer, friction factor, effectiveness and number of transfer units (NTU) of Fe_3O_4/water nanofluids flow in a double pipe U-bend heat exchanger and with twisted tape inserts were estimated experimentally. The experiments were conducted in the Reynolds number range from 16,000 to 32,000, particle volume concentrations range from 0.005% to 0.06% and twisted tape inserts of H/D = 10, 15 and 20 were used. The Nusselt number of nanofluids increases with increase of particle volume concentrations and Reynolds number and it further increases with decrease of twist ratio of twisted tape inserts. The Nusselt number is enhanced to 14.76% (no insert) and it is further increased to 38.75% (with twisted tape inserts of H/D = 10) at 0.06% volume concentration and at Reynolds number of 30,000 compare to water data. Similarly, the friction factor penalty of 1.092-times (no insert) and further friction penalty of 1.251-times (with twisted tape inserts of H/D = 10) at Reynolds number of 30,000 compared to water data. New Nusselt number and friction factor correlations have been proposed based on the experimental data. Finally the effectiveness and NTU of heat exchanger is enhanced for nanofluids flow in a double pipe heat exchanger with twisted tape inserts.

1. Introduction

The double pipe heat exchangers are commonly used heat transfer equipments in industrial applications because of small size, compactness and easy manufacturing. The most commonly used fluids are water, ethylene glycol, propylene glycol and engine oil. The heat transfer of these fluids is limited because of their low thermal conductivity values. Choi [1] and his team developed nanofluids, which is prepared by dispersing nanometer size solid particles in water, ethylene glycol, propylene glycol and they observed increased thermal conductivity values compared to base fluids. These enhanced thermal conductivity values make the use of nanofluids in heat exchange devices highly desirable. Sarafraz et al. [2] observed thermal performance enhancement of 44% for 0.3% mass concentration of CNT/water nanofluids in a double pipe heat exchanger in the Reynolds number range from 900 to 10,500. Sarafraz and Hormozi [3] observed heat transfer enhancement of 67% for 1.0% volume concentration of 50:50% ethylene glycol/water based silver nanofluids flow in a double pipe heat exchanger. Sonawane et al. [4] observed heat transfer enhancement of 16% for 3% volume concentration of Al_2O_3 nanofluid flow in a double pipe heat exchanger at a Reynolds number of 3992. Reddy et al. [5] reported heat transfer enhancement of 10.73% with a friction penalty of 8.73% for 0.02% volume concentration of TiO_2 water based nanofluids. Zamzamian et al. [6] considered Al_2O_3/ethylene glycol and CuO/ethylene glycol nanofluids in a double pipe and plate heat exchangers and observed heat transfer enhancement of 1.0% weight concentration of Al_2O_3 nanofluid is 26% and 37% for double pipe heat exchanger, heat transfer enhancement of 1.0% weight concentration of CuO nanofluid is 38% and 49% for plate heat exchanger, respectively. Khedkar et al. [7] observed heat transfer enhancement of 16% at 3.0% volume concentration of Al_2O_3/water nanofluids flow in a concentric tube heat exchanger. Hemmat Esfe and Saedodin [8] conducted heat transfer experiments for MgO/water nanofluid flow in a double pipe heat exchanger in the particle concentrations range from 0.005 to 0.02% wt. and observed higher heat transfer rates. Aghayari et al. [9] observed heat transfer enhancement of 19% and Nusselt number enhancement of 24% for 0.3% volume concentration of Al_2O_3/water nanofluid flow in a double pipe heat exchanger. Sudarmadji et al. [10]

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prepared Al_2O_3/water nanofluids with particle volume concentrations of 0.15, 0.25 and 0.5; they conducted heat transfer experiments for these nanofluids flowing in a tube and they observed Nusselt number increment of 40.5% compared to pure water under 0.5% volume concentration. Duangthongsuk and Wongwises [11] observed heat transfer enhancement of 11% at 0.2% volume of TiO_2/water nanofluid flow in a horizontal double tube counter flow heat exchanger under turbulent flow conditions.

For further convective heat transfer enhancements, turbulent promoters (twisted tape, longitudinal strip, helical tape, screw tape, etc.) are generally used inside the fluid flow. The twisted tapes are one of turbulent promoters, which are used for further heat transfer enhancements. The concept of twisted tape inserts was used by Manglik and Bergles [12,13], Smithberg and Landis [14], Lopina and Bergles [15], Thorsen and Landis [16] for single phase fluids flow in a tube and they developed Nusselt number and friction factor correlations. After that, nanofluids flow in a tube with twisted tape inserts were analyzed by Sundar and Sharma [17]. They considered Al_2O_3 nanofluids flow in a tube with twisted tape inserts and developed Nusselt number and friction factor correlations. Wongcharee and Eiamsa-ard [18] conducted heat transfer, friction and thermal performance characteristics of CuO/water nanofluid flow in a tube with twisted tape with alternate axis and obtained that, the Nusselt numbers increase up to 12.8 and 7.2-times of the plain tube and further increases to 13.8 with twisted tape inserts at 0.7% volume concentration and at Reynolds number of 1990.

The present paper explains about the heat transfer, friction factor, and effectiveness-NTU of Fe_3O_4 nanofluids flow in a double pipe heat exchanger with twisted tape inserts. The experiments were conducted in the particle volume concentrations of 0.005%, 0.01%, 0.03% and 0.06% in the Reynolds number range from 16,000 to 30,000. Further experiments were conducted for nanofluids flow in a heat exchanger with H/D = 10, 15 and 20. The results are compared with the literature values and developed new Nusselt number and friction factor correlations.

2. Nanofluids preparation

The nanofluids of 0.005%, 0.01%, 0.03% and 0.06% volume concentrations were prepared by dispersing Fe_3O_4 nanoparticles in distilled water. The bulk quantity of 15 L nanofluids was prepared. The Fe_3O_4 nanoparticles were purchased from Sigma-Aldrich Chemicals, USA. The surfactant of cetyl trimethylammonium bromide (CTAB) (nearly equal to 1/10th of weight of nanoparticles) was used to obtain the stable nanofluids. The quantity of nanoparticles required for various concentrations was estimated using Eq. (1).

$$\text{Volume concentration, } \phi \times 100 = \left[\frac{\left(\frac{W_{Fe3O4}}{\rho_{Fe3O4}}\right)}{\left(\frac{W_{Fe3O4}}{\rho_{Fe3O4}}\right) + \left(\frac{W_{water}}{\rho_{water}}\right)}\right] \tag{1}$$

where ϕ is the % of volume concentration, $\rho_{Fe_3}O_4 = 5810\ kg/m^3$, $\rho_{water} = 998.5\ kg/m^3$, $W_{water} = 15{,}000$ g and $W_{Fe_3}O_4$ is the weight of the nanoparticles.

The amount of nanoparticles and surfactant required for the preparation of 0.005%, 0.01%, 0.03% and 0.06% volume concentrations were shown in Table 1. For the preparation of 0.005% volume concentration of water based (15 L) nanofluids, the quantity of 4.364 g of Fe_3O_4 and 0.4364 g of CTAB was used. The surfactant (0.4364 g) was first dispersed in 15 L of water and stirred vigorously, after that 4.364 g of nanoparticles were added and sonicated for 2 h. This process had to be split in three batches of 5 L, because of small capacity of the ultrasonicator. Upon completion of this operation, the nanofluid is stirred with a high speed stirrer for 24 h. The procedure was repeated for the preparation of 0.01%, 0.03% and 0.06% volume concentrations of nanofluids. The thermophysical properties of Fe_3O_4 nanofluids were shown in Table 2 [19].

Table 1
Quantity of nanoparticles and surfactant used for the preparation of 15 L of nanofluid.

ϕ (%)	Nanoparticles used for 15 L, (g)	Surfactant used for 15 L, (g)
0.005%	4.364	0.436426
0.01%	8.728	0.872897
0.03%	26.19	2.619213
0.06%	52.39	5.239999

3. Experimental setup and procedure

The schematic diagram of an experimental setup was shown in Fig. 1a and the test section details were shown in Fig. 1b. The experimental setup consists of two concentric tube heat exchangers, data logger along with personal computer, cooling water tank and heating water tank, set of thermocouples, flow meters (both hot and cold), and U-tube manometer. The test section is a concentric double pipe, the inner tube ID is 0.019 m and OD is 0.025 m, which is made up of stainless steel, the annulus tube ID is 0.05 m and OD is 0.056 m, which is made up of cast iron. The test section has a two-pass for the inner tube (Fig. 1b), the bend is placed at a distance of 2.2 m with a radius of 0.160 m. The total length of the inner tube is 5 m and the effective length of each heat region is 2.2 m. In order to minimize the heat loss from the test section, the annulus tube of test section was wrapped with asbestos rope material. Four thermocouples (resistance temperature detectors (RTD) type) were used to measure the inlet and outlet temperatures of the hot fluid (water or nanofluid) and cold fluid. The thermocouple needles were connected to the data acquisition system and the readings were recorded in the computer for further processing. Before using the thermocouples in the test section, they are calibrated and their resolution is ± 0.1 °C resolution. In the test section the flow is assumed to be hydrodynamically fully developed considering the aspect ratio (*l/d*; *l*: length; *d*: diameter) is equal to 354. Two flow meters (MAS Technologies Ltd., India) were used to measure the flow rates of cold fluid and hot fluid (water or nanofluids). The water/nanofluids was heated with electric heater in a receiving tank, after reaching the required temperature (60 °C) the hot fluid (water/nanofluid) was supplied through the inner tube, while the cold fluid, which is the cooling medium, flows through the annulus tube. In the test section, the inner tube and annulus flows have a counter-flow arrangement. The temperature of the cold water (annulus side) was maintained around 29 °C and kept constant flow rate of 8 LPM (0.133 kg/s). The hot Fe_3O_4 nanofluid (tube side) with constant inlet temperature of 60 °C from the hot fluid tank was supplied through the inner tube at different mass flow rates of 8, 10, 12 and 14 LPM (0.133 kg/s to 0.233 kg/s). The experiments were conducted sequentially at different particle concentrations of 0.005%, 0.01%, 0.03% and 0.06%. Each nanofluid of 15 L was prepared freshly and used in the experiments. The temperatures of cold and hot nanofluids were recorded at steady state. The test section was calibrated with water as the working fluid, before using the Fe_3O_4 nanofluid. For each and every nanofluids experiments the test section is cleaned with pure water. The thermo-physical properties of the nanofluids were calculated at mean temperature. The formulas used for Nusselt number calculations are presented in Section 3.

The pressure drop across the inner tube of the test section was measured by placing a U-tube manometer between both ends of the tube. To achieve this purpose, 4-mm holes were drilled at both ends of the inner tube and are connected using flexible tubing to the U-tube manometer; mercury (*Hg*) is the manometric fluid and the equivalent height is recorded as a function of the mass flow rate. The mercury column height is converted into water column height for further friction factor calculations. The system reaches steady state after approximately