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Experimental study of friction factor during convective heat transfer in miniature double tube Hair-pin heat exchanger

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Abstract

In this research paper, we have experimentally investigated the single phase fluid flow characteristics in the inner tube of miniature size concentric double tube Hair-pin heat exchanger with constant heat flux. This work was carried out for distilled water and water-ethylene glycol mixtures (0%, 10%, 20% and 25% ethylene glycol by volume) as heat transfer cold fluid flowing inside the inner tube to carry away heat from the annulus hot fluid. The obtained Friction factor and pressure drop are compared with the existing conventional correlations. Experimentally obtained pressure drop shows good agreement with theoretical values in laminar flow.

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Keywords: Macrotubes; Laminar flow; Turbulent flow; Pressure drop.

1. Introduction

In the last few decades, a number of experiments have been addressed to the study of frictional characteristics of fluid flow in miniature tubes. Velocity distribution and pressure drop are the key components to understanding the flow characteristics in the design of miniature tube heat exchangers. Cooling is one of the most important technical challenges in numerous industries such as automobiles, electronics and manufacturing units. Present scenario of the miniature heat exchangers is a serious concern to many small devices where required heat transfer area is low. Application of the miniature size double tube hairpin heat exchangers is in radiators of electric transformers, air conditioners, cars' radiators, and refrigerators etc. Development of faster cooling technologies for increasing thermal loads is the foremost requirement in today's era. The conventional methods of increasing the cooling rate (fins and micro-channels) are already stretched to their limits. Hence, there is an urgent need for new and innovative coolants to achieve this high-performance cooling. Traditional heat transfer fluids such as water, propylene glycol, engine oil, and ethylene glycol are inherently poor heat transfer fluids. Glycols are used as

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additive in water to decrease the freezing point and elevate the boiling point of water. Especially ethylene glycol-water mixture is used as a medium for convective heat transfer. Water is the easily available cheapest fluid but the poor source of heat transfer. The industries have a strong need to develop advanced heat transfer fluids with significantly higher thermal conductivity than water. The thermal conductivity of heating or cooling fluid is an important property in the development of energy efficient heat transfer systems. At the same time, in all processes involving heat transfer, the thermal conductivity, viscosity and specific heat of the fluid are the basic properties taken account in designing and controlling the process. Whereas, roughness of the surface of the wall, type of fluid (single or two phases), flow rate, physical properties of the fluid, surface-fluid interaction, etc. has been the major parameters which affect the fluid flow in tubes.

Chen et al., (2003) investigated the influence of the ratio of curvature radius (2R/D) in the range 3.91- 8.15 and spacer length (L/D), i.e., the length between two consecutive 180^0 return bends, in the range 1.93-7 on the frictional performance of U-tube heat exchanger in single phase flow for 3.3 and 5.07 mm diameter tube and concluded that the bend friction factor increases with the decrease in curvature ratio and spacer length. Also a correlation for equivalent friction factor was proposed for $200 < Re < 18000$. Their results showed fair agreements with the existing correlations of **Ito (1959) and Popieil and Wojtkowiak (2000)** for the single-phase data. Another correlation was proposed by **Piotr et al. (2007)** for pressure drop in 180^0C return bends based on a total of 241 experimental data points for diameters (D) from 3.3 mm to 11.6 mm, bend radius (R) from 6.4 mm to 37.3 mm, and curvature ratios from 2.3 to 8.2. The correlation predicted all data with an RMS deviation of 25%, and 75% of the data fall within ±25% error bands. **Prasad and Gupta, (2012)** experimentally investigated the forced convective heat transfer enhancement and variation of friction factor in a typical test section made up of a u-tube double pipe heat exchanger involving a circular tube filled with a full-length insertion of twisted tape for varying Reynolds Number from 3,000 to 31,000 and compared the results with the straight tube data. They observed that significant increase in heat transfer coefficient and friction factor.

The heat transfer coefficient and the friction factor significantly depend on the working fluid. The thermal conductivity of any heat transfer (water or ethylene glycol) can exceptionally be increased by dispersing metallic or non-metallic nanometer sized particles (**Sundar and Singh, 2013**). This concept, as first proposed by **Choi (1995),** has diverted the interests of researchers in exploring the effectiveness of nanofluids as heat transfer fluid. **Duangthongsuk and Wongwise (2010)** studied the friction factor and heat transfer coefficient of 21 nm TiO_2 particles dispersed in Water (0.2-2.0 vol%) in a horizontal double tube counter-flow heat exchanger for Reynolds number varying from 3000 – 18000. It was found that heat transfer coefficient for nanofluids of 1.0 vol.% was approximately 26% greater than that of water, while for volume concentration of 2.0 vol.% was approximately 14% lower than that of base fluid water. The pressure drop of nanofluids was slightly greater than the base fluid and increases with increasing the concentrations. **Xie et al., (2010)** reported the convective heat transfer enhancement of nanofluids as coolants in laminar flows inside a circular copper tube with constant wall temperature. They compared the performance of different nanofluids consisting of Al_2O_3, TiO_2, ZnO, and MgO nanoparticles with a mixture of 55 vol.% distilled water and 45 vol.% ethylene glycol as a base fluid and observed that MgO, Al_2O_3, and ZnOnanofluids exhibited superior enhancements of heat transfer coefficient, with the highest enhancement being up to 252% for MgO nanofluid at a Reynolds number of 1000. **Peyghambarzadeh et al., (2011)** performed a comparative study of heat transfer with using pure water, pure ethylene glycol and their binary mixtures in car radiators. Furthermore, they used different concentrations of Al_2O_3 nanofluids of these base fluids and observed its effects on the heat transfer performance of the car radiator. The result was in agreement to earlier works, the heat transfer enhancement being highest with nanofluids and lowest for pure water. **Prasad et al., (2015)** experimentally studied the turbulent forced convection heat transfer and friction factor of Al_2O_3–water nanofluid flowing through a concentric tube U-bend heat exchanger with and without helical tape inserts in the inner tube. Their experiments were conducted in the Reynolds number range from 3000 to 30,000, volume concentrations of 0.01% and 0.03% and helical tape inserts with aspect ratios 5, 10, 15 and 20. The friction factor for the entire inner tube for 0.03% concentration of nanofluid with helical tape inserts of aspect ratio 5 was increased by 1.38-times, as compared to water; in general and consistent with theory, the pressure drop in the inner tube increases with an increase in nanoparticle volume concentration and aspect ratio of the inserts. Many other researchers such as **Heris et al., (2007)**, **Nguyen et al., (2007)**, **Sharma et al., (2009)**,**Fotukian and Nasr Esfahny (2010)** and **Ho et al., (2010)** have also studied the convective heat transfer performance and pressure drop of various size and concentration of nanoparticles flowing in varying dimension of double tube heat exchangers. **Kumar et al., (2015)** investigated the convective heat transfer characteristic in the miniature concentric double tube Hair-pin heat exchanger with constant