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Numerical investigation on the single phase forced convection heat transfer characteristics of TiO_2 nanofluids in a double-tube counter flow heat exchanger☆

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ABSTRACT

In this study, forced convection flows of nanofluids consisting of water with TiO_2 and Al_2O_3 nanoparticles in a horizontal tube with constant wall temperature are investigated numerically. The horizontal test section is modeled and solved using a CFD program. Palm et al.'s correlations are used to determine the nanofluid properties. A single-phase model having two-dimensional equations is employed with either constant or temperature dependent properties to study the hydrodynamics and thermal behaviors of the nanofluid flow. The numerical investigation is performed for a constant particle size of Al_2O_3 as a case study after the validation of its model by means of the experimental data of Duangthongsuk and Wongwises with TiO_2 nanoparticles. The velocity and temperature vectors are presented in the entrance and fully developed region. The variations of the fluid temperature, local heat transfer coefficient and pressure drop along tube length are shown in the paper. Effects of nanoparticles concentration and Reynolds number on the wall shear stress, Nusselt number, heat transfer coefficient and pressure drop are presented. Numerical results show the heat transfer enhancement due to presence of the nanoparticles in the fluid in accordance with the results of the experimental study used for the validation process of the numerical model.

1. Introduction

Water, oil, and ethylene glycol mixture is one of the low thermal conductivity of widely used conventional heat transfer fluids that limits the enhancement of the performance and compactness of these devices belong to the electronic, automotive and aerospace industries. Improvements on the thermal conductivity by suspending small solid particles in the fluid are one of the solutions to prevent this disadvantage. Thermal conductivity is an important parameter in enhancing the heat transfer performance of a heat transfer fluid. Since the thermal conductivity of solid metals is higher than that of fluids, the suspended particles are expected to be able to increase the thermal conductivity and heat transfer performance. Many researchers have reported experimental studies on the thermal conductivity of nanofluids. Metallic, non-metallic and polymeric particles are used to form slurries by adding into fluids. Some of problems such as abrasion and clogging can be seen due to the suspended particles' sizes that are of millimeter dimensions. For that reason, these kinds of large particles are not suitable for heat transfer enhancement. Recently, advances in manufacturing technologies have made the production of particles in the nanometer scale possible (i.e., 10 nm<particle diameter<100 nm). The uniform and stable suspensions are obtained by means of these smaller sized particles. Thus, the nanofluids provide higher heat transfer enhancement than existing techniques. The use of particles of nanometer dimension was first continuously studied by a research group at the Argonne National Laboratory around a decade ago. Choi [1] was probably the first one who called the fluids with particles of nanometer dimensions 'nano-fluids'. The term 'nanofluid' refers to a two-phase mixture usually composed of a continuous liquid phase and dispersed nanoparticles in suspension.

In spite of the two phase mixture specialty of nanofluids, they are easily fluidized and can be nearly considered to behave as a fluid [2] due to the tiny size of solid particles. For that reason, it is possible for nanofluids to be treated as single phase flow. It is assumed that the fluid phase and particles are in thermal equilibrium and moving with the same velocity in certain conditions [3] considering the ultrafine and low volume fraction of the solid particles. The advantage of single phase flow is about its simplicity and required less computational time. It should be noted that experimental, numerical and theoretical solutions are strongly affected by physical properties of nanofluids. In addition, there is some inconsistency on this subject in the literature.

The most well-known nanoparticles are Al_2O_3, CuO, TiO_2 and they are used by many researchers in their experimental works together with the base fluids of water and ethylene glycol. In spite of the different size of the particles and type of base fluids, the enhancement

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