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Effect of nanoparticle shape on the heat transfer and thermodynamic performance of a shell and tube heat exchanger ☆

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ABSTRACT

Nanofluid is a heat transfer fluid that can improve the performance of heat exchanger systems. Different parameters such as particle size, shape, and volume concentration affect the performance of these systems. The objective of this paper is to study the effect of different nanoparticle shapes (such as cylindrical, bricks, blades, platelets, and spherical) on the performance of a shell and tube heat exchanger operating with nanofluid analytically. Boehmite alumina (γ-AlOOH) nanoparticles of different shapes were dispersed in a mixture of water/ethylene glycol as the nanofluid. The thermodynamic performance of the shell and tube heat exchanger that is used in a waste heat recovery system was analysed in terms of heat transfer rate and entropy generation. Established correlations were used to measure the thermal conductivity, heat transfer coefficient and rate and entropy generation of nanofluid. The results show an increase in both the heat transfer and thermodynamic performance of the system. However, among the five nanoparticle shapes, cylindrical shape exhibited better heat transfer characteristics and heat transfer rate. On the other hand, entropy generation for nanofluids containing cylindrical shaped nanoparticles was higher in comparison with the other nanoparticle shapes. However, the increased percentage of entropy was below 1%. Therefore, this greater entropy generation could be deemed negligible and cylindrical shaped nanoparticles are recommended to be utilized in heat exchanger systems working with nanofluids.

1. Introduction

Due to the technological advancement and growth of industrial processes as well as the environmental and energy concerns, heat exchanger systems must be improved to transfer heat more efficiently. Changing the boundary conditions and flow geometry [1–4], as well as enhancing the thermal conductivity of conventional base fluid are mooted as passive ways to improve the convective heat transfer of these devices [5]. The researchers preferred the latter option to improve the performance of heat exchanger systems through using nanofluids [6–10]. The term nanofluid is applied to a suspension of solid nanoparticles, that can be either metallic or non-metallic material, into conventional fluids [11]. The most important physical property of nanofluids in many applications including heat exchanger is thermal conductivity [12]. The thermal conductivity enhancement of nanofluids can be attributed to several factors such as volume fraction, temperature, material type, size and shape. Numerous studies have been conducted to determine the effect of these parameters on the enhancement of thermal conductivity of nanofluids [13,14]. It has been seen that the thermal conductivity of nanofluid increases linearly with respect to the nanoparticle volume fraction [15,16]. Therefore, the effective thermal conductivity of nanofluids is expected to enhance the heat transfer performance compared with the conventional heat transfer liquid [17]. The Maxwell model [18] was the earliest model that was used to determine the thermal conductivity of micro/mini particles suspended at low volume concentration of suspensions. To overcome the limitation of this model, another model was developed by Bruggeman [19] where results obtained for particles at low volume concentration were similar to the results obtained using the Maxwell model. Unlike the Maxwell model, for particles at high volume concentration, results obtained using the Bruggeman model were in agreement with the results obtained from experimental investigations [20]. Nevertheless, the Maxwell model is frequently used for comparison purposes with experimental findings due to its simplicity to determine the thermal conductivity of nanofluids [21].

The Maxwell model does not take the shape of particles into consideration. An extended version of the Maxwell model was proposed

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