A THERMAL CONDUCTIVITY MODEL FOR NANOFLUIDS INCLUDING EFFECT OF THE TEMPERATURE–DEPENDENT INTERFACIAL LAYER

INTRODUCTION

In the development of efficient heat transfer equipment, the thermal conductivity of the heat transfer fluid plays a vital role. Traditional heat transfer fluids such as water, oil and ethylene glycol mixture, are inherently poor heat transfer fluids. So, researchers mix metallic nanoparticles into traditional fluids in order to increase the heat transfer efficiency. These mixtures are called nanofluids. The heat transfer efficiency of nanofluids is increased because the thermal conductivity of the metallic nanoparticles is higher than that of the traditional fluids.

Previously, the enhancement in the thermal conductivity of the nanofluids was assumed to depend mainly on the volume fraction of nanoparticle (Masuda *et al.*, 1993; Eastman *et al.*, 1997; Pak and Cho, 1998; Lee *et al.*, 1999; Eastman *et al.*, 2001; Xie *et al.*, 2002; Kwak and Kim, 2005). A thermal conductivity model that was based on the above assumption was called a stationary model (e.g. Maxwell's model (1873) and Hamilton and Crosser's model (1962)). However, later works showed that the increase in temperature also enhanced the thermal conductivity of nanofluids (Das *et al.*, 2003; Chon *et al.*, 2005; Li and Peterson, 2006). A dynamic model was therefore developed based on the stationary model with the inclusion of the thermal dispersion effect due to the Brownian motion of nanoparticles (Khannafer *et al.*, 2003; Koo and Kleinstreuer, 2004; Chon *et al*, 2005). Although the temperature-dependent effect could be predicted by the dynamic model, the volume-fraction-dependent effect was not satisfactorily predicted.

Recently, the thermal conductivity of the interfacial layer of the nanoparticles has been shown to have an effect on the thermal conductivity of nanofluids (Patal *et al.*, 2003; Wang *et al.*, 2003; Yu and Choi, 2003; Yu and Choi, 2004; Xue *et al.*, 2004; Leong *et al.*, 2006). Leong *et al.* (2006) has proposed a stationary model that includes the interfacial layer effect. Their model has been shown to have higher accuracy in predicting the volume-fraction-dependent effect than the other stationary models. Nevertheless, the Leong et al.'s model has not been able to predict the temperature-dependent effect.

The present work therefore firstly modifies the Leong et al.'s stationary model by combining it with the thermal dispersion effect (Amiri and Vafai, 1994; Khannafer *et al*., 2003; Koo and Kleinstreuer, 2004) and tests the modified model against the available data. It is found that the modified dynamic model based on the Leong et al.'s stationary model gives good prediction for the non-flowing fluid which has only Brownian motion of nanoparticles but gives poor prediction for the flowing fluid (Sections 2.2 and 5). This is because the Brownian motion of nanoparticles for the flowing fluid is negligibly small compared to the velocity of the main flow. The velocity of the main flow is therefore used in the model and this causes the over prediction of thermal conductivity by all dynamic models. This accords with the Keblinski *et al*. (2002) and Buongiorno (2006) who have suggested that the role of the Brownian motion is not important for the flowing fluid. The enhancement in the thermal conductivity due to the increase in temperature of the flowing nanofluid hence does not come from the dispersion effect of the Brownian motion. It is possible that the enhancement in heat transfer of the flowing nanofluids comes from the temperature-dependent interfacial layer effect.

It can be seen from the literature that there is still no thermal conductivity model for nanofluids that includes the effect of the temperature-dependent interfacial layer. The present work therefore aims to modify the stationary model of Leong *et al*. (2006) to include the effect of the temperature variation on the thermal conductivity of the interfacial layer and also evaluate the model constants for Al_2O_3 and CuO nanoparticles. The performance of the present model is assessed by comparing with the thermal conductivity models of Maxwell (1873), Chon *et al*. (2005) and Leong *et al*. (2006) for the non-flowing fluid using the experimental data of Masuda *et al*. (1993), Eastman *et al*. (1997), Pak and Cho (1998), Lee *et al*. (1999), Das *et al*. (2003), Chon *et al*. (2005) and Li and Peterson (2006) for Al_2O_3 and CuO nanoparticles. Then, the present model is evaluated for the flowing fluid using the turbulent convective heat transfer problem in nanofluids along a uniformly heated tube using the experimental data of Pak and Cho (1998) and the simulation by Maïga *et al*. (2004).

OBJECTIVES

1. To review and analyze the experiments and models of thermal conductivity of nanofluids.

2. To modify the thermal conductivity model to include effects of the temperature dependent interfacial layer and also evaluate the constants for different types of nanoparticles.

3. To test the modified thermal conductivity model for the convective transport of nanofluids.

4. To study if nanoparticle movement enhances the thermal conductivity and convective heat transfer.

5. Comparisons between homogenous approach and species approach are done in order to find a suitable model to describe the convective transport of nanofluids.

SCOPES

1. Study nanofluids behavior in a uniform heated tube including the thermal conductivity and convective transport.

2. Simulate the convective transport by FLUENT software using the homogeneous (single fluid) model and species model.

3. User defined function (UDF) is used to defined the dependent function on the properties of nanofluids.