RESULTS AND DISCUSSIONS

The performance of the present thermal conductivity model for the non-flowing fluid is assessed by comparing it with the stationary models of Maxwell (1873) and Leong et al. (2006), the dynamic model of Chon et al. (2005) and our modified dynamic model (Eq. 28) of thermal conductivity for non-flowing fluid. All models are also evaluated by using the available experimental data of thermal conductivity for nanofluids (Masuda et al., 1993; Eastman et al., 1997; Pak and Cho, 1998; Lee et al., 1999; Das et al., 2003; Chon et al., 2005; Li and Peterson, 2006).

The dependence of the thermal conductivity on volume fraction for various sizes of Al_2O_3 nanoparticles (particle diameters = 13 nm, 33 nm and 38.4 nm) in water at room temperature is shown in Figures 5-7. Figure 8 shows this dependence for 35 nm CuO nanoparticles in water at room temperature. The thermal conductivity dependence on temperature is shown in Figures 9-13 at a range of 290 to 350 K, for different sizes of Al_2O_3 naoparticles (particle diameters = 11 nm, 38.4 nm, 47 nm and 150 nm) in water at volume fractions of 1% and 4%. Figures 14-15 show this dependence for 29 nm CuO nanoparticles in water at volume fractions of 4% and 6%.

The predictions of the Maxwell's model (1873) for the dependence of the thermal conductivity on volume fraction are lower than values produced by the experimental data of 13 nm and 33 nm Al_2O_3 nanoparticles and 35 nm CuO nanoparticles in water based fluid as shown in Figures 5, 6 and 8. Also, Figure 7 shows that the Maxwell's model over-predicts the thermal conductivity of 38.4 nm Al_2O_3 nanoparticles. The Maxwell's model cannot predict the dependence of the thermal conductivity on temperature for all nanoparticle sizes and types and this is shown in Figures 9-15.

The Leong et al's model (2006) predicts the volume fraction dependent thermal conductivity of nanofluids accurately for all different sizes of nanoparticles when assessed by using the experimental data of 13 nm, 33 nm and 38.4 nm Al_2O_3 nanoparticles and 35 nm CuO nanoparticles in water based fluid. This is shown in

Figures 5-8. However, Leong et al’s model cannot predict the dependence of the thermal conductivity on temperature for all nanoparticle sizes and types as shown in Figures 9-15.

The accuracy of Chon et al.’s model (2005) in predicting the dependence of thermal conductivity on volume fraction is low when assessed by using the experimental data of 13 nm, 33 nm and 38.4nm Al_2O_3 nanoparticles and 35 nm CuO nanoparticles in water based fluid. This is shown in Figures 5-8. The Chon et al.’s model gives reasonable prediction for the dependence of thermal conductivity on temperature for all nanoparticle sizes and types which is shown in Figure 9-15.

The accuracy of our early modified dynamic model in predicting the dependence of thermal conductivity on volume fraction gives good prediction for all different sizes of nanoparticles when assessed by using the experimental data of 13 nm, 33 nm and 38.4 nm Al_2O_3 nanoparticles and 35 nm CuO nanoparticles in water based fluid. This is shown in Figures 5-8. The modified dynamic model is simplified to Leong et al.’s model in this case. Moreover, the modified dynamic model also gives good prediction for the dependence of thermal conductivity on temperature for all nanoparticle sizes and types which is shown in Figures 9-15.

The capability of the present model in predicting the volume fraction dependent thermal conductivity of nanofluids for different sizes of nanoparticles is shown to be satisfactory when assessed against the experimental data of 13 nm, 33 nm and 38.4 nm Al_2O_3 nanoparticles (Figures 5-7) and 35 nm CuO nanoparticles (Figure 8) in water based fluid. The present model also gives good prediction for the dependence of thermal conductivity on temperature for all nanoparticle sizes and types which is shown in Figures 9-15.

The interfacial layer thickness in the present model ranges between 0.5 to 3 nm for various nanoparticle sizes and temperatures which accords with Xue et al.’s model (2004) and Leong et al.’s model (2006) that assume 3 nm and 1 nm for the interfacial layer thickness, respectively.

The present model gives reasonable account of thermal conductivity of nanofluid in the case of the flowing fluid along a uniformly heated tube. Although the modified dynamic model give better prediction in the case of the non-flowing fluid, it over-predicted the thermal conductivity of nanofluids in the case of the flowing fluid as shown in Table 21 for the averaged thermal conductivity of nanofluid for the turbulent convective heat transfer in nanofluid along a uniformly heated tube of Pak and Cho (1998).

The present model also gives good prediction for the ratio of averaged heat transfer coefficients (h_{nf}/h_f) in the case of the flowing fluid when assessed against the experimental data of Pak and Cho (1998) (Figure 16). While, Maxwell's model, Leong et al's model and the simulation by Maïga et al. (2004) give the under-estimated prediction as shown in Figure 16.

Furthermore, solving the species transport equation of nanoparticles for the convective transport in nanofluids, gives values close to the homogenous approach as can be seen in Table 22 and U-tube in Table 23. Hence, it can be concluded that the convective heat transfer of nanofluids can be given by the homogenous approach because the convective heat transfer of nanofluids mostly dependents on the properties of the nanofluid. However, the thermal conductivity of nanofluids strongly depends on the volume fraction and temperature. Therefore, it is very important that the thermal conductivity models have to include both volume fraction and temperature dependences. The present model including effect of the temperature-dependent interfacial layer covers both dependences of these effects

Table 21 Averaged thermal conductivity of nanofluid for the turbulent convective heat transfer in nanofluid of Pak and Cho (1998)

Averaged thermal conductivity of nanofluid (water/Al_2O_3 nanoparticle) with particle diameter = 13 nm and volume fraction = 1%					
Dynamic model		Stationary models			
Non-flowing fluid	Flowing fluid	Non-flowing fluid		Flowing fluid	
Modified	Modified	Present	Leong et al's	Present	Leong et al's
0.659	87.510	0.654	0.659	0.672	0.659

Table 22 Ratio of averaged heat transfer coefficients using the homogeneous approach and species transport approach for the turbulent convective heat transfer in nanofluid along a uniformly heated tube

Ratio of averaged heat transfer coefficients (h_{nf}/h_f)					
Approaches	Volume fraction (%)				
	1	2.5	5	7.5	10
Homogeneous	1.1089	1.2554	1.5187	1.8045	2.1130
Species transport	1.1092	1.2557	1.5191	1.8050	2.1135

Table 23 Averaged heat transfer coefficients using the homogeneous approach and species transport approach for the turbulent convective heat transfer in nanofluid along U-tube at 5% particle volume fraction

Approaches	U-tube	
	Thermal conductivity	Averaged wall function heat transfer coefficient
Homogenous	0.8805765	32657.73
Species transport	0.8822377	32720.97