Effective Thermal Conductivity of Dispersions with a Liquid Continuous Phase

Francisco E. B. Bioucas, Michael H. Rausch, Thomas M. Koller, Andreas P. Fröba
Institute of Advanced Optical Technologies – Thermophysical Properties (AOT-TP), Friedrich-Alexander-University Erlangen-Nürnberg (FAU), Erlangen, Germany

Dispersions of solid, liquid, or gaseous particles on the nano- or micrometer scale with a liquid continuous phase are of interest for many applications of process and energy technology. Here, the miniaturization of electronic devices by efficient cooling, the development of high-performance materials for thermal insulation, or the design of new working fluids for energy storage can be mentioned. A key property characterizing dispersed systems is their effective thermal conductivity. First experimental observations in the 1990s claimed that adding a small amount of solid nanoparticles to liquids can enhance the effective thermal conductivity of nanofluids by up to 300% relative to the base fluid. This report has triggered a plethora of experimental and theoretical studies, most of which give similar conclusions. However, other studies do not observe any significant enhancement. Until now, debate has continued with respect to the relevant mechanisms affecting thermal conduction in nanofluids, where the Brownian motion of the dispersed particles is also considered as a main factor for an enhanced energy transport.

In the present contribution, the research activities performed at AOT-TP in connection with the effective thermal conductivity of dispersions with a liquid continuous phase are summarized. Our theoretical model for the effective thermal conductivity of nanofluids accounts for the heat transfer mechanisms caused by thermal conduction of the base fluid and the particles as well as microconvection due to the particle Brownian motion. The consideration of the latter effect was found to limit the enhancement of the effective thermal conductivity. To probe this hypothesis, a steady-state parallel-plate method was used successfully for the measurement of the effective thermal conductivity of nanofluids with particle volume fractions up to 0.3. For the same systems, dynamic light scattering (DLS) could be applied to analyze translational and rotational diffusion of the dispersed particles. From this, it is possible to get information on particle size and shape which are essential parameters for the effective thermal conductivity. Measurement results for dispersions of solid particles in water show only a moderate change of the effective thermal conductivity. This change is positive or negative for particles with larger or smaller thermal conductivities than the base fluid and follows the trend predicted by our model.