# Theoretical and Experimental Study of the Enhanced Effective Thermal Conductivity of Metal Oxide Nanoparticle Suspensions (nanofluids)

by

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## ABSTRACT

Analytical and experimental investigations were conducted to study the enhanced thermal conductivity of nanoparticle suspensions (nanofluids), to examine the relationships between the effective thermal conductivity and nanoparticle volume fraction, bulk temperature, nanoparticle size and nanoparticle materials. The experimental investigations were conducted with two different effective thermal conductivity test facilities, one is a cut-bar steady state test facility and the other one is a hot-wire transient test facility. It was experimentally discovered and confirmed that the effective thermal conductivity of nanoparticle suspension (nanofluids) increases with increases of nanoparticle volume fraction, bulk temperature and thermal conductivity of the nanoparticle material, and decreases on nanoparticle size. Based on the experimental results and an extensive and in-depth literature review, three possible mechanisms were indentified and examined, the interaction between the nanoparticle and base fluid, the interaction between nanoparticles, and the Brownian motion mixing effect of the nanoparticles. Each possible mechanism was carefully analyzed and/or experimentally verified. The interaction between nanoparticles, namely the adsorption layer, was analyzed using Gibbs energy approach. The interaction between nanoparticles, namely the aggregation of nanoparticles, was experimentally verified and valued through a method of liquid nitrogen frozen, thin film re-image TEM technique. A theoretical model of the nanoparticle Brownian motion mixing effect was developed and verified by a numerical simulation based on microscopic visual observation of the Brownian motion of 800 nm diameter nanoparticle suspensions, and comparison with the measured experimental data. A robust comparison of the experimental data was conducted, and the results were identical.

The natural convection heat transfer experiments on nanoparticle suspensions (nanofluids) were also investigated. Based on the measured thermophysical properties of the nanoparticle suspensions (nanofluids), the temperature change history was analyzed and the measured heat transfer data

were compared to the existing heat transfer coefficient and viscous pressure loss correlations available in the literature. Deterioration was found to be a result of the changes in thermophysical properties of the nanofluids. This is confirmed by a platinum film heating square cavity visualization study.

As a conclusion, first, the thermal conductivity enhancement of nanofluids over base fluids is confirmed. Second, the traditional models could give reasonable predictions on the thermal conductivity enhancements for limited types of nanoparticle materials and base fluids of the nanofluids at room temperature. However, the predictions of thermal conductivities of nanofluids at elevated temperatures from traditional models are against all the currently available experimental data. Third, the more recently proposed models on the effective thermal conductivity of nanofluids can only work for the specific experimental data they are developed on, and can not generally predict the thermal conductivities of nanofluids from other experimental study. Hence, further theoretical work on fundamental understanding of nanofluids should be conducted before a generally accepted model could be proposed. Finally, due to the thermodynamically mesostable property of nanofluids, the applications of nanofluids in the convection and two-phase heat transfer modes should be studied with the combined considering of the chemical change, chemical physics change and the nanoparticle aggregation inside the nanofluids.

The contribution of this dissertation research is, first, it discovered and verified the behavior of the effective thermal conductivity of nanoparticle suspensions. Second, it analyzed and verified the possible mechanisms behind the abnormal heat transfer properties of nanofluids and broadened the understanding of nanoparticle suspension thermophysical behavior. Finally, it enriched the experimental data of the nanoparticle suspension thermal properties and supported the potential use and optimization of future nanoparticle suspension applications.