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## **NANOFLUID HEAT TRANSFER AND APPLICATIONS**

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### **KEYNOTE**

In many industrial applications, the conventional heat transfer fluids are refrigerants, water, engine oil, ethylene glycol etc. Even though an improvement in energy efficiency is possible from the topological and configuration points of view, much more is needed from the perspective of the heat transfer fluid. Despite considerable research and developmental efforts on enhanced heat transfer surfaces, major improvements in cooling capabilities have been constrained because of the poor thermal conductivities of traditional heat transfer fluids used in today's thermal management systems. In the development of any energy-efficient heat transfer fluids, the thermal conductivity enhancement in heat transfer plays a vital role. One such latest advancement in heat transfer fluids, is the use of nano-sized (1 - 100 nm) solid particles as an additive suspended in the base fluid which is a technique for heat transfer enhancement. Improving the thermal conductivity is the key idea in enhancing the heat transfer characteristics of conventional fluids and in turn the heat transfer coefficient. Hwang et al [1] reported that the nanofluids are claimed to be a non-agglomerated mono-dispersed particles in the base fluids, which proved to be enhancing the heat transfer more than 50% in real-time applications even when the volume ratio of the nano-particle to base fluid is less than 0.3%. It has been reported by Das et al [2] that nanofluids with less than 2% volume fraction are extremely stable and remain suspended in the liquid indefinitely. In many thermal industrial appliances, heat exchangers are used to exchange the heat between the hot

and cold fluids; for example, solar water heater. A survey of the published literature indicates that only very limited work has been done till date in finding the heat transfer coefficient of a nanofluid with metal nanoparticles in variety of heat exchangers, while undergoing the cooling process. Cooling heat transfer experiments with nanofluids would find application in solar air conditioning, solar water heaters, building heating, industrial process heaters, and milk pasteurization etc. Therefore, it is important to study the heat transfer characteristics, such as, thermal conductivity, viscosity, heat transfer coefficient and pressure drop of any new working fluid before it is used in a system for any specific application.

Focusing on the enhancement of thermal conductivity, viscosity and the forced convective heat transfer experimentally, several existing published articles which involve the use of nanofluids are briefly discussed. Heat transfer enhancement through modification of fluid thermo-physical properties by adding dispersed particles to a base fluid has been a topic of interest since the early works by Ahuja [3]. The experimental studies of Masuda et al [4], Choi et al [5] and Eastman et al [6] have reported significant enhancement of nanofluid thermal conductivity, beyond the predictions of models such as Maxwell [7] and Hamilton and Crosser [8]. This finding generated great interest in nanofluids and their potential for heat transfer enhancement. Pak and Cho [9] explored alumina-water and titania-water nanofluids in turbulent convective heat transfer in tubes and found enhancement in the Nusselt number. Xuan and

Li [10] investigated turbulent convective heat transfer of copper/water nanofluid and observed more than 39% enhancement with 1.5% volume concentration. Xuan and Roetzel [11] developed a heat transfer correlation for nanofluids to capture the effect of energy transport by particle “dispersion”. Yang et al [12] measured laminar convective heat transfer performance of graphite nanofluids in horizontal circular tube. Wen and Ding [13] studied nanofluid laminar flow convective heat transfer and reported 41% enhancement in the entry region. Ding et al [14] observed significant convective heat transfer enhancement of multi-walled carbon nanotube dispersion in water and the enhancement depended on the flow conditions (Reynolds number), and volume concentration. Duangthongsuk et al [15] reported 11% enhancement in the convective heat transfer coefficient with 0.2 % volume concentration of TiO<sub>2</sub> nanoparticles flowing in a horizontal double-tube counter flow heat exchanger under turbulent flow conditions. Convective heat transfer of alumina nanofluid in micro-channels was investigated by Lee et al [16]. Nanofluid application in microelectronics cooling was recently explored by Chein and Chuang [17].

All the nanofluid studies reported in the literature have concluded that nanofluids provide higher heat transfer enhancement with respect to the base fluids; and the nanofluids have higher heat transfer coefficients than those of the base-fluids at the same Reynolds number. In the recent past, most of the convective heat transfer studies have been performed in nanofluids with only oxide nanoparticles. Moreover, Maiga et al [18] reported that, with regard to the nanofluid thermal properties, the actual amount of experimental data available in the literature remains surprisingly small. However, only very few work has been reported on the hydrodynamic and heat transfer behavior of nanofluids in the laminar, transition and the turbulent regimes with pure metal nanoparticles such as silver, copper, gold and graphene with different volume concentrations probably less than one volume percentage (< 1 %). Hence, more investigations on the convective heat transfer coefficient and pressure drop characteristics of a nanofluid suspended with metallic nanoparticles with low volume concentration is essential for developing the new advanced heat transfer fluid. The use of nanofluids in a wide variety of applications appears promising. But the development of the field is hindered by (i) the lack of agreement of the results obtained by different researchers; (ii) poor characterization of suspensions; and (iii) lack of theoretical understanding of the mechanisms responsible for changes in properties.

This article, therefore, concludes by outlining several important issues that should receive greater attention in the near future. Further experimental studies in the convective heat transfer of nanofluids are needed in the following areas. 1. Future convective studies must be performed with metallic nanoparticles with different geometries and concentrations to

consider heat transfer enhancement in laminar, transition and turbulence regions. 2. The use of nanofluids in micro heat pipes and looped heat pipes for satellite cooling application could enhance the performance with considerable reduction in thermal resistance. However, recent studies indicate particle aggregation and deposition in micro-channel heat sinks. Further study is required in these areas to identify the reasons for and the effects of particle deposition. 3. There appears to be hardly very few research papers in the use of nanofluids as refrigerants. Nanoparticles-refrigerant dispersions in two-phase heat transfer applications can be studied, to explore the possibility of improving the heat transfer characteristics of evaporators and condensers used in refrigeration and air-conditioning appliances. Applied research in nanofluids which will define their future in the field of heat transfer is expected to grow at a faster pace in the near future.

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