CHAPTER 1: INTRODUCTION

1.1 THERMAL MANAGEMENT
Thermal management is one of the thrust areas of research with applications in automobile cooling, industrial cooling, renewable energy utilization, etc. Thermal management deals with control of system temperature using thermodynamics and heat transfer.

Thermal management influences the performance and shelf life of various temperature sensitive instruments and processes in industries. The removal of heat dissipated and maintenance of the temperature of the systems at their ideal working temperature are essential to ensure the efficacy and proper functioning of high speed engines, microprocessors, etc. Heat dissipation rates and the temperature of the systems have increased enormously due to the usage of higher end technologies, high speed microprocessors, high speed engines, etc. making efficient cooling a challenging task.

1.2 NEED FOR EFFICIENT HEAT TRANSFER FLUIDS
Different stratagems adopted to improve the efficiency of heat transfer systems include (i) active modes and (ii) passive modes. Active modes of improving heat transfer involve increasing coolant velocity and improving thermal conductivity of the coolants whereas the passive modes involve the use of fins, channels with expansions & constrictions, and higher heat transfer area. Passive modes of improving heat transfer involves alteration in the design of the heat exchanger which may lead to increase in the fixed cost of the heat transfer system. Though higher heat transfer rates can be achieved through supplying coolant at higher velocities, it is accompanied by higher pumping power, which in turn
affects the overall energy savings. Hence, improving the thermal conductivity of the coolants appears to be an appropriate choice for heat transfer applications.

1.3 GENESIS OF NANOFLUIDS

Thermal conductivity of liquids lies in the range of 0.1 – 10 W/mK, which is one (or) two orders-of-magnitude less than that of solid materials. The genesis of nanofluids can be traced back to Maxwell’s prediction [1] of enhancing thermal conductivity of liquids by addition of metallic particles to liquids. However, it could not be practically applied then due to the utilization of milli- or micro-meter sized particles for preparing the solid-liquid dispersions. Dispersions of milli- or micro-meter sized particles possess major limitations such as rapid settling of particles due to gravity, increased demand of pumping power and clogging of channels.

In 1995, Choi from Argonne National Laboratory, USA envisioned the concept of using nanotechnology in thermal engineering to develop efficient heat transfer fluids [2]. High colloidal stability, low pumping power penalty and negligible wear & tear make dispersions of nanoparticles in liquid coolants suitable for practical applications. Such nanoparticle dispersions, which are new class of heat transfer fluids was termed as ‘nanofluids’ by Choi.

1.4 NANOFLUdIDS – AN INTRODUCTION

Nanofluids are stable colloidal dispersions of solid nanoparticles in a base liquid. The primary particle dimension should be less than 100 nm. Extensive research has been carried out on nanofluids, the new class of heat transfer fluids, over the past two decades since 1995.
1.4.1 Materials for nanofluid formulation

The choice of the nanomaterials for nanofluid formulation is determined by the application of the nanofluid. The factors to be considered in the choice of nanomaterial are (i) thermal properties (ii) chemical stability (iii) toxicity (iv) compatibility with base fluid (v) cost and (vi) availability.

The dispersed (or) solid phase used for nanofluid formulation includes different kinds of materials like

(i) Metals like Au [3,4], Ag [5–7], Cu [8,9], Fe [10–12], etc

(ii) Metal oxides like Al₂O₃ [13–15], Fe₃O₄ [16–18], TiO₂ [19–23], SiO₂ [24,25], ferrites [26,27], etc

(iii) Carbon materials like CNTs [8,28–30], Graphene [31,32], Graphene oxide [33,34], carbon nanohorns [35,36], Graphite [37,38], diamond [39–41], etc.

(iv) Carbides like SiC [42–45]

(v) Nitrides like AlN [46,47], BN [48,49] etc.

The commonly used continuous phase (or) base fluids for nanofluid formulation are

(i) water [50–52],

(ii) glycol [53–55],

(iii) glycol-water mixtures [56–58],

(iv) oils [28,59–61], etc.
1.4.2 Formulation strategies

Two methods are normally utilized for formulation of nanofluids. They are (i) one step method (ii) two step method.

(i) One step method - Nanoparticles are simultaneously synthesized and dispersed in the liquid. Examples include inert gas condensation, chemical reduction, pulsed wire evaporation, arc-submerged nanoparticle synthesis system (ASNSS: melting of electrode (metal) submerged in a dielectric liquid) etc.

(ii) Two step method – Nanoparticles are synthesized in the first step and then dispersed separately in the base fluid as the second step.

Two step method for nanofluid formulation is simple and scalable and has been widely adopted by the researchers for nanofluid formulation.

The greatest challenge in nanofluid technology is the achievement of colloidal stability. Nanomaterials tend to agglomerate when dispersed in liquids due to the attractive van der Waals forces. Several techniques such as ultrasonication, mechanical/magnetic stirring, shear homogenization have been used to disperse the nanomaterials in liquids. Different strategies such as electrostatic stabilization, steric/electrosteric stabilization have been followed in order to achieve colloidal stability. In electrostatic stabilization, the surface charge of the nanomaterials are altered by changing the dispersion pH such that repulsive forces due to the particles’ surface charge overcome the attractive intermolecular forces, resulting in stable dispersion. In steric stabilization, surfactant molecules added to the dispersion adsorb on to the particles’ surface leading to repulsive steric forces that helps in the maintaining colloidal stability. In electrosteric stabilization, the surfactants added
to the dispersions get ionized into ions and adsorb on the particles’ surface and provide higher surface charge to the particles.

1.4.3 Other Applications

With their tunable thermophysical properties, nanofluids find applications in different arenas like mass transfer, lubrication, biomedical applications. Nanofluids have been well established as heat transfer fluids due to their superior thermal properties. In biomedical applications such as magnetic hypothermia, iron oxide nanoparticles are preferred due to their magnetic properties and biocompatible nature [62]. Magnetic nanofluids [62], functionalized CNT nanofluids [63,64], graphene oxide nanofluids [65] have been used for targeted drug delivery applications. Biocompatibility of the nanomaterials is of major concern in biomedical applications.

Nanofluids enhance gas-liquid mass transfer through grazing effect. Increase in transport rate of gas molecules through the liquid film surrounding the gas bubble by nanoparticles is called grazing effect. Nanoparticles adsorb onto the liquid film and adsorb the gas molecules and desorb them into the liquid. Hence, the nanoparticles used for gas-liquid mass transfer should have adsorption capability and should have affinity towards the gas molecules of interest [66,67]. The addition of solid nanoparticles to lubricants reduces friction and improves the anti-wear property [68].

1.5 REFERENCES


