CHAPTER 1

INTRODUCTION

1.1 Motivation

The computing performance is affected by the high heat dissipation in electronics equipment (research community realized this problem in the 1970s) and heat generation from the integrated circuits is continuously increasing due to compactness and high workload day by day. So, removal and controlling of heat is a challenging task in theses type of high heat flux systems, such as micro-nano electro mechanical systems (MEMS/NEMS). First, the concept of liquid-cooled microchannel cooling was introduced by Tuckerman and Pease in 1981. Since then, explosive growth in compact heat exchangers devices occurred. The liquid-cooled mini/microchannel heat sink (MCHS) has gained the interest of worldwide researchers because of better heat transfer effectiveness, compact size and lower coolant requirement than the conventional heat transfer fluid. The heat transfer performance of MCHS can be further improved by active, passive and compound augmentation techniques. External energy is required for active method; whereas, introducing flow disturbance by surface modification, swirl and enhanced fluid properties come under the passive method. The combination of both active and passive methods is known as a compound or hybrid method, which has a limitation due to its complicated design. Literature reveals that passive method has been recommended as the most effective, simple and economical technique. In view of increasing demand for energy density, coolants of better thermophysical properties can be a good candidate to dissipate higher heat generated. The use of nanofluids (fluids having enhanced thermophysical and transport properties) had been attracted one of the passive techniques within the last two decades. Single material does not hold all the favorable characteristics required for a particular purpose, so hybrid terms come here. Recently hybrid nanofluid is getting importance due to its enhanced heat transfer behavior due to hybridization, which has motivated to implement hybrid nanofluids in MCHS. This thesis presents the hydrothermal characteristics of hybrid nanofluids as a coolant in the minichannel heat sink, including experimental and numerical investigations.

1.2 Mini/microchannel heat sink (MCHS)

Mini/microchannel heat sink (MCHS) is the heat exchange device that consists of inlet and outlet port, flow channels and fins. MCHS can be produced by many techniques such as micro-machining, chemical etching, diffusion bonding, lithography, etc. MCHS is a promising choice for cooling that can provide higher heat removal rates due to its higher heat transfer surface area to volume ratio and can also be directly incorporated into the heat dissipation substrate. Because of its superior control over heat carrying capacity, microchannel heat sink appears to be the most reliable cooling technology. A channel serves two purposes (i) putting fluid into intimate contact with the walls of the channel, and (ii) bringing fresh fluid to the walls and extracting fluid from the walls as the cycle of transport is completed. The surface area to volume ratio can be increased by decreasing the diameter of the channel because it is inversely proportional to channel diameter. First channel classification was given by Mehendale et al. (2000) based on the channel dimensions. They defined microchannel in the range of 1-100 μm, mesochannel in the range of 100 μm- 1 mm, compact passage as 1-6 mm and more than 6 mm as conventional passage. This channel classification further modified by Kandlikar and Granade (2003) by considering the rarefaction effect of common gases at atmospheric pressure. These classifications are provided in Table 1.

Although the channel classification given in Table 1 is mainly for gas flow, but they are advocates for the liquid and two-phase flow also.

Table. 1.1 Channel classification based on hydraulic diameter (Kandlikar and Granade, 2003)

Conventional channels	d_h >3mm
Minichannels	3 mm≥ d_h>200µm
Microchannels	200µm≥ d_h>10µm
Transitional microchannels	10µm≥ d_h>1µm
Transitional nanochannels	1µm≥ d_h>0.1µm
Nanochannels	0.1µm≥ d_h

MCHS has many applications due to compactness, low weight, high performance and heat removal capability. MCHS has shown significant potential in many engineering, medical and environmental applications including electronic cooling, CPU, graphics card, power amplifier, radar, infrared detector, diode laser, chemical reactor, condenser, miniature gas chromatograph, micropump, miniature energy generator, microvalve, microreactor, and lab-on-a-chip devices, tissue engineering, drug delivery, organ-on-a-chip etc.

1.3 Hybrid nanofluids

The terms nanofluid is coined by Choi in 1995 at Argonne national laboratory, USA. It has been proved that the small amount of nano-sized (<100nm) particles dispersed in the base fluid, known as nanofluids, can improve the thermal performance of the heat transfer system. Nanofluid is just not a simple mixture of nanoparticles and base fluid. To prepare nanofluid, proper mixing (homogeneity) and stability is the first concern. Nanofluid is a colloidal solution of nanoparticles and base fluids (Choi, 1995). Various base fluids, nanoparticles and additives, used in nanofluid preparation are shown in Fig 1.1. Various base fluids are water, ethylene glycol, propylene glycol, water-based brine, engine oil, refrigerant, lubricant, etc. Different metals (copper, aluminum, zinc, etc.), metal oxides, alloys, allotropes of carbon (nanotubes, graphene, etc.), ceramics and metal carbides and nitrides are used as nanoparticles. But due to the limitations with the properties of a single material that makes it unsuitable for certain applications, it may either have good thermal properties or rheological properties. In certain situations, a trade-off is required between different properties. Hybrid nanofluids come into the role under such circumstances because they yield better thermal conductivity and heat transfer characteristics due to the hybridization (Sarkar et al., 2015). Hybrid nanofluids are the suspension of more than one type of nanoparticles or nanocomposites in the conventional base fluid. Hybrid nanofluid can be further classified based on types of suspension: (i) mixture of different types (two or more than two) of nanoparticles in the base fluid, (ii) hybrid (composite) nanoparticles in the base fluid. Nanocomposites represent remarkable thermophysical properties that do not show in the individual components.

Hybrid nanofluids can be prepared by either a single-step method or a two-step method. The two-step method is mostly used over the one-step method instead of having stability and agglomeration problems. The one-step method has some issues like (i) limited quantity of nanofluids can be prepared, (ii) some residual products may remain in prepared nanofluids, (iii) expensive method as compared to two-step method. Hybrid nanofluids are thus prepared to provide improved heat transfer characteristics due to an increase in thermal conductivity, translational Brownian motion, proper dispersion agglomeration, solid/liquid interface layering, the existence of an inter-particle potential, reduction in boundary layer thickness, thermophoresis, the improved

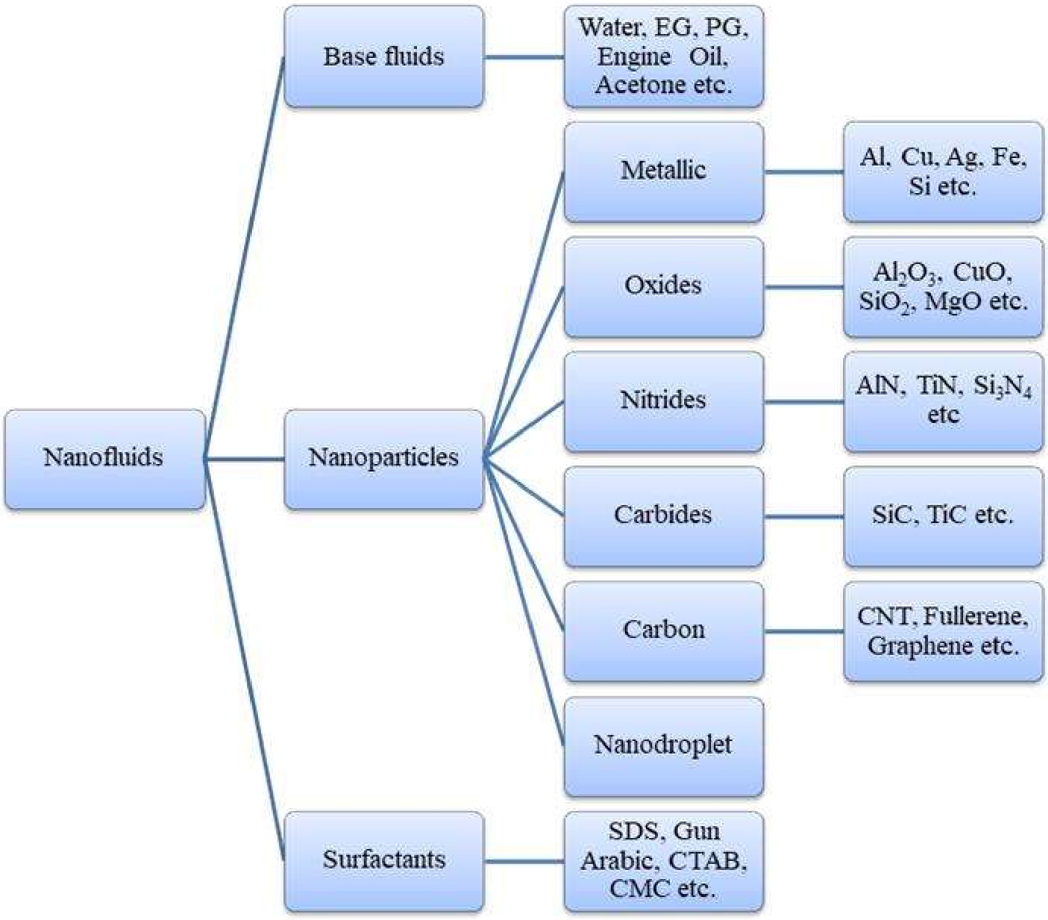

Fig. 1.1 Various base fluids, nanoparticles and additives used in nanofluid preparation

thermal network between the solid nanoparticle and fluid molecules, nanofin and nanoporous effects at the heat transfer surface. The reason behind heat transfer improvement can be summarized as (Pinto, 2016): (i) More heat transfer surface between particles and fluid due to surface area to volume increase with nanoparticles suspension, (ii) Collision between the nanoparticles, (iii) Increment in the thermal conductivity due to the interactive effect of different nanoparticles, and (iv) Proper dispersion of the nanoparticles in the base fluid, causing micro turbulences. In addition, the hybrid nanofluids provide combined thermal, physical and chemical properties of different materials, whereas a single nanoparticle does not fulfill all the requirements.

1.4 Contribution of the study

Due to the various advantages discussed above, the miniature heat exchanger device (minichannel heat sink) can be used for thermal management of Micro-Electro-Mechanical System (MEMS) devices. By incorporating unconventional fluids (mono nanofluids/hybrid nanofluid), the performance of minichannel heat sink can be further enhanced. To quantify the enhanced performance characteristics, numerical and experimental investigations have been planned to study the hydrothermal behavior of hybrid nanofluids in the minichannel heat sink.

1.5 Objectives

The objectives of the current research are summarized as:

1. ***Preparation of mixture as well as composite dispersed hybrid nanofluids.***
2. ***Characterization of nanoparticles (XRD and SEM) as well as synthesized nanofluids (stability analysis based on pH measurement and photography method, and homogeneity test).***
3. ***Measurement of thermophysical properties of different synthesized hybrid nanofluids.***
4. ***Design and fabrication of minichannel heat sink and experimental setup.***
5. ***Hydrothermal characteristics comparison of various hybrid nanofluids in minichannel heat sink.***

6. ***The effect of nanoparticle concentration, fluid inlet temperature, heat flux, particle mixing ratio and channel aspect ratio on hydrothermal characteristics of different hybrid nanofluids through minichannel heat sink.***
7. ***Numerical study on hydrothermal characteristics of minichannels with enhanced heat transfer surface using hybrid nanofluids.***

The novelty of the present work is that the effect of different nanoparticles mixture (oxide-oxide, oxide-PCM, oxide carbide, oxide-nitride, oxide-metal, oxide-allotropes of carbon) dispersed hybrid nanofluids on the hydrothermal characteristics of the minichannel heat sink is studied. Hydrothermal characteristics of different alumina-based hybrid nanofluids with different shaped nanoparticle combinations at different particle ratios and volume concentrations have been investigated. Effect of different operating variables as fluid inlet temperature, flow rates, heat fluxes, mixing ratios and aspect ratios have been studied on various output parameters. Output parameters are convective heat transfer coefficient, Nusselt number, thermal effectiveness, pressure drop, friction factor and hydrothermal performance parameter as comparison factor (heat transfer coefficient to pressure drop ratio), Figure of merit, Performance evaluation criteria, Coefficient of performance and entropy generation.

1.6 Thesis structure (methodology)

The present study is distributed in seven chapters. **In the *first chapter*, the basic background, including minichannel heat sink and hybrid nanofluids and thesis contribution are provided. In the** *second chapter*, **a literature survey on the preparation and thermophysical properties of hybrid nanofluids, experimental and numerical investigations on mini/microchannel heat sink with hybrid**

nanofluids is performed. In the *third chapter*, preparation and characterization of studied hybrid nanofluids are provided. Both nanoparticle mixture and nanocomposite dispersed hybrid nanofluids have been prepared by the two-step method. Both the nanoparticles and nanofluids have been characterized: (a) shape and size of nanoparticles and (b) stability and homogeneity of nanofluids. All the related thermophysical properties have been measured and discussed. The *fourth chapter* contains the experimentation on minichannel heat sink using different hybrid nanofluids. The effect of nanoparticle combination, nanoparticle concentration, particle mixing ratio, operating temperature, heat flux and channel aspect ratio on various hydrothermal performances are studied. In the *fifth and sixth chapters*, computational fluid dynamics (CFD) based analysis is performed to simulate the performance of the minichannel heat sink using Al_2O_3-MWCNT, Al_2O_3-TiO_2 hybrid nanofluid considering two-phase model (multiphase mixture model). The combined effect of hybrid nanofluids (Al_2O_3-MWCNT, Al_2O_3-TiO_2) and different types of ribs on the heat transfer coefficient and pressure drop are presented in chapter 6. Finally, *concluding remark and future scope* is presented in the seventh chapter.