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NANOFLUIDS: SYNTHESIS, PHYSICO-CHEMICAL PROPERTIES AND APPLICATIONS

Chemistry

KEYWORDS: nanofluids, hybrid nanofluids, physico-chemical properties.

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ABSTRACT

The use of nanofluids as heat transfer fluids have greatly enhanced the cooling efficiency of equipments. Nanofluids have attracted great interest for their enhanced properties over conventional base fluids and fluids having micro or milli sized particles. Hybrid nanofluids are on an ongoing research nowadays. Researchers have developed hybrid nanofluids for enhancing the thermo-physical properties of conventional nanofluids. It has been found that hybrid nanofluids shows enhancement in thermal conductivity and viscosity over nanofluids and in some cases nearer to the particle which is present in large volume fraction than the other and is also dependent on temperature and volume concentration of the nanoparticles. Research on theoritical models for both nanofluids and hybrid nanofluids are yet still to be proposed for explaining their behaviour and mechanism in heat transfer.

INTRODUCTION

Heat generated from high power equipments, vehicles, electrical appliances, food industry and air-conditioning systems requires a high amount of cooling, where fluids are mainly used. But these fluids have poor thermal properties for application as heat carriers. With the advancement in nanotechnology, the suspension of nanoparticles to conventional base fluids have greatly enhanced the physico-chemical properties and therefore high cooling possibilities due to the presence of nanoparticles having large surface area, high dispersion behaviour, with less clogging and abrasion compared to the micro or bulk particles. This leads to reduction of size of heat transfer equipments with higher efficiency, cost reduction for their fabrication and wide application in variable biological and non-biological fields. These fluids are called nanofluids, the term defined by Choi (1995)[1] as "fluids engineered by dispersing nanoparticles less than 100 nm in base fluids". Nanoparticles like metals, oxides, ceramics, nitrides and carbon nanotubes have been used for making nanofluids, but the use of hybrid nanoparticles to give hybrid nanofluids is still at a small extent.

Nanofluids can be prepared by single step[2,3](Fig.1) or two step[4,5] methods(Fig.2), where details, advantages and disadvantages have been discussed elsewhere[6,7]. Preparation of nanofluids with high stability should be given more attention before implementing it into various industrial and commercial applications. Various methods have been taken up to increase the stability of nanofluids during preparation by adding surfactant, surface modification , controlling pH and ultrasonication, which can be evaluated by using zeta potential, sedimentation, centrifugation, spectral analysis, 3ω, electron microscopy and light scattering methods[8,9].

Nanofluids have promising applications in various biological and non-biological fields, are summarised in Fig.3.

LITERATURE REVIEW

Various studies on physico-chemical properties of nanofluids and hybrid nanofluids [Fig.4] have been reported by different group of researches as summarised in Table 1& 2.

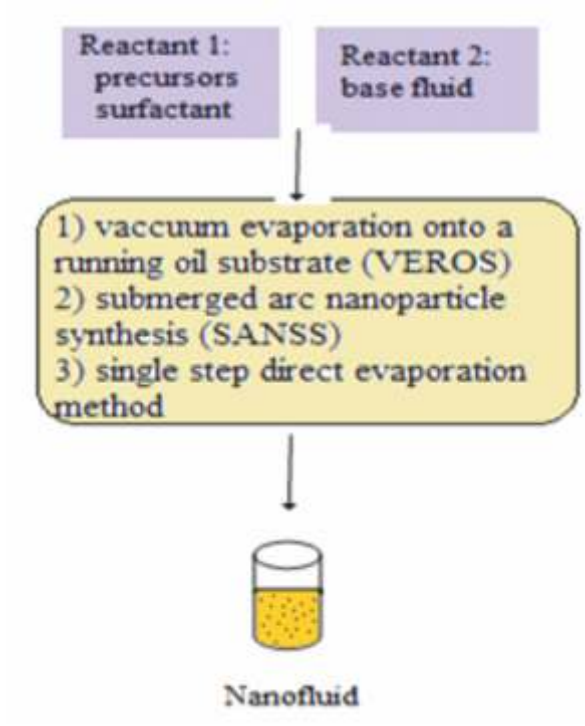


Fig. 1: Schematic representation of nanofluid preparation using single–step method

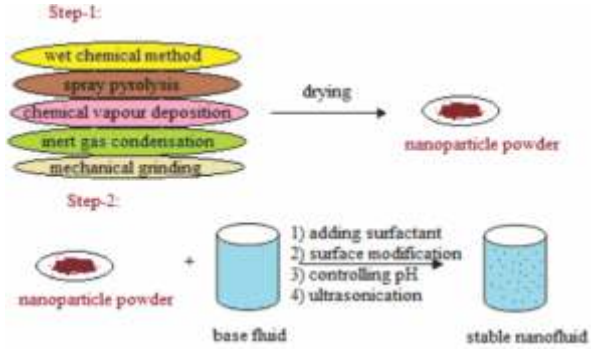


Fig.2: Schematic representation of stable nanofluids preparation using two-step method

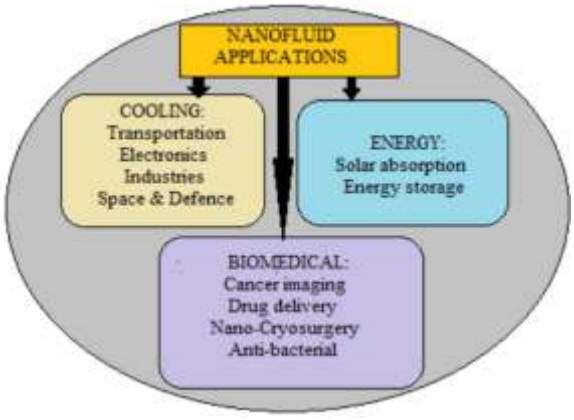


Fig.3: Various areas of Application of Nanofluids

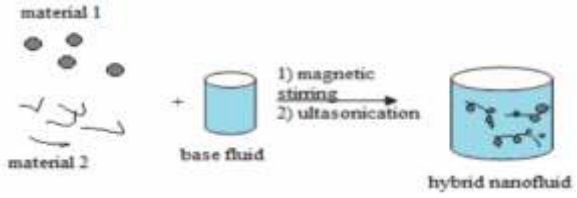


Fig.4: Schematic presentation on the preparation of Hybrid Nanofluids

Table1: Summary of the physico-chemical properties of nanofluid:

Materials	Base fluids	Diameter(nm) Length(μm)	Volume Fraction (vol%)	Model applied	Methodology	Properties studied	References
Al_2O_3, CuO, Cu	water and oil	-	5	none	-	Thermal conductivity	[10]
CuO, Al_2O_3	deionised water and ethylene glycol	29,36	1-10	Hamilton-Crosser, Maxwell	Two-step: mixing in polyethylene container, gas condensation	Thermal conductivity	[11] [12]
Fe	ethylene glycol	10±1	0.1-0.55	none	Two-step: Chemical vapour condensation	Thermal conductivity	[13]
Al_2O_3	ethylene glycol/ water/ propanol/ distilled water	8, 20, 43 10±5 12	1.5-8.6, 0.005-0.065, 0.005-0.03, 0.1-0.5 &1, 1-4	Maxwell, Kriegher-Dougherty Hamilton-Crosser & Maxwell-Garnett, Bruggemann	Two-step: ultrasonic vibration	Thermal conductivity, viscosity, specific heat, density, electrical conductivity	[14] [15] [16] [17]
SiO_2, Al_2O_3	deionised water/ ethylene glycol, transformer oil, water distilled water	12,30 10 10,11	0.45-5,0.5 &1.5, 0.0-0.1 0.5-5	Hamilton-Crosser, Einstein, Brinkman, Batchelor	Two-step: mixing, ultrasonic disruptor, sonication	Thermal conductivity and viscosity Specific heat	[18] [19] [20]
CNT	distilled water, ethylene glycol, decene (oleylamine)/ water (gum Arabic)	15(diameter), 30(length) 25(diameter), 35(length)	0.1-1.0 0.01-0.1	Hamilton-Crosser, Davis Maxwell, new model	Two-step	Thermal conductivity	[21] [22]
Graphene	distilled water	5-1500, <2μm(diameter) 2nm(thickness)	0.01-0.2 0.025-1.0	Maxwell Nan	Single step: Oxidation-reduction process, ultrasonication	Thermal and electrical conductivity viscosity	[23] [24]
CuO (decorated graphene)	deionised water, ethylene glycol	-	0.05	none	Two-step: ultrasonication	Thermal conductivity, Electrical conductivity	[25]
ZnO	ethylene glycol, glycerol (ammonium citrate) propylene glycol	67.17 20,40,60	0-4 1-7	Koo & Kleintreuer, Maxwell, Jeffrey, Bruggemann, Einstein, Ohshima	Two-step: mixing	Thermal conductivity, viscosity, surface tension electrical conductivity	[26] [27]
Cu	kerosene, toluene, decahydro-naphthalene	40-60	0-0.01	none	Two-step: surface modification	Thermal conductivity, viscosity	[28]
Au, Al_2O_3, TiO_2, CuO, CNT (SDS)	toluene, water	1.65, 20, 40, 33, 150(diameter) & 10(length)	0.003, 0-15, 0-3, 0-10,0-1	Hamilton-Crosser, Yamada and Ota	Two-step: Chemical reaction, sonication	Thermal conductivity, thermal diffusivity	[29]
MgO, TiO_2, ZnO, Al_2O_3, SiO_2	ethylene glycol	20	0.5-5	Einstein, Brinkman, Batchelor	Two-step: mixing	Thermal conductivity, viscosity	[30]

Table2: Summary of the physico-chemical properties of hybrid nanofluids:

Materials	Base fluids	Diameter(nm) Length(μm)	Volume Fraction (vol%)	Model applied	Methodology	Properties studied	References
SiO_2+ MWCNT	distilled water (sodium dodecyl bezene sulfate)	10, <10(diameter) & 10(length)	0-1	none	Two-step: Wet chemical method	Viscosity & density, thermal conductivity	[31] [32]
Al_2O_3/Fe_2O_3 +CNT	poly-alpha-olefin oil (span-80)	70, 10(diameter) & 2(length)	0-1	none	Two-step: Spray pyrolysis	Thermal conductivity	[33]
Al_2O_3+Cu	deionised water (sodium lauryl sulphate)	-	0.1-2	Weber, Einstein, Brinkman, Batchelor	Two-step: Ultrasonic vibration	Thermal conductivity, viscosity	[34]
Ag+SiO_2	transformer oil	5.5±2.4	-	Maxwell	One-step: mixing	Thermal conductivity, dielectric strength	[35]

METHODOLOGY & CHARACTERIZATION

Various chemical reductions such as alcohol[36], hydrogen[37], sodium borohydride[38] electrochemical[39], photochemical[40] and sonochemical[41] methods have been used to synthesise metal nanoparticles. The prepared nanoparticles can be dispersed in different base fluids/polymers and characterised by techniques viz; Transmission Electron Microscopy, Ultraviolet-visible Spectroscopy, Fourier Transformed Infrared Spectroscopy, Dynamic Light Scattering, Environmental Scanning Electron Microscope and Small angle X-ray Scattering to analyse size, shape, crystalline nature, elemental composition, colour, surface plasmon absorption, functionality, hydrodynamic radius, zeta potential/molecular weight, homogeneity/uniformity and interactions between various components present in nanofluids.

DISCUSSION

For the last decade, the synthesis of metallic nanoparticles has been widely investigated, for obtaining controlled morphology, distribution and nanoparticle's size in aqueous and non-aqueous solutions. Chemical reduction of metal cation precursors is mostly used for metal nanoparticle synthesis using H_2, CO, borohydrides and hydrazine as reducing reagents. The electrochemical reactions involved are:

Reduction of the metal cation: $M^{n+} + ne^- \rightarrow M^o$

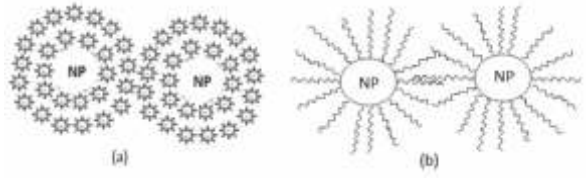
The E^0 potential with reference to H2 gas: $2H^+ + 2e^- \rightarrow H_2$, E^0=0.00V at standard conditions.

Electrochemicals reaction for borohydride anion may be written as:

$B(OH)_3 + 7H^+ + 8e^- \rightarrow BH_4^- + 3H_2O$, E^0=-0.48V.

Similarly, for hydrazine, it can be written as:

$N_2 + 5H^+ + 4e^- \rightarrow N_2H_5^+$, E^0=-0.23V. Proper adjustment of pH and with E^0>-0.48V, the complete reduction of metals can be achieved using these reducing agents[42], further, reactions are summarised in Fig. 5. Metallic nanoparticles for nanofluids can be reduced in presence of stabilizers from their precursors using ultrasonic wave, photoenergy, microwave, electrolysis and X-ray[43].



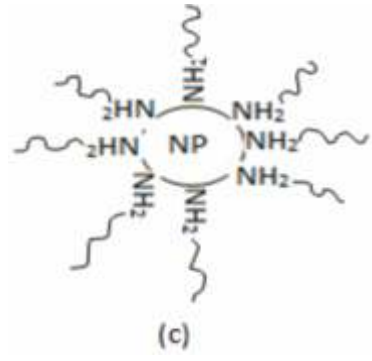


Fig. 6: Illustration of electrostatic (a), steric (b) and chemical (c) stabilizations for increasing stability of nanofluids.

CONCLUSION

The enhancement of physico-chemical properties of nanofluids and hybrid nanofluids depends mainly on stability, preparation method being the main factor. Size, shape, state of nanoparticles, pH of solution, solvents, particle volume concentration, surfactants and clustering effects also attribute. No doubt, nanofluids have exhibited promising features in variety of heat transfer applications, still the contradictions are observed in the findings of various research outputs and their related mechanisms involved. This has produced a great challenge in front of scientists to study the detailed mechanistic behaviours involve in the structural illucidations in nanofluids.

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