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A Brief Review on Thermal Behaviour of PANI as Additive in Heat Transfer Fluid

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Abstract: Since a decade ago, investigation on nanofluids has grown significantly owing to its enhanced thermal properties compared to conventional heat transfer fluids. This engineered nanofluid has been widely used in the thermal engineering system to improve their energy consumption by improving the thermal efficiency of the system. The addition of nano-size particles as additives dispersed in the base fluids proved to significantly either improve or diminish the behaviour of the base fluids. The behaviour of the base fluid highly depends on the properties of the additives material, such as morphology, size, and volume fraction. Among the variety of nanoparticles studied, the conducting polymers have been subject of high interest due to its high environmental stability, good electrical conductivity, antimicrobial, anti-corrosion property and significantly cheap compared to other nanoparticles. As such, the main objective of the present review is to provide an overview of the work performed on thermal properties performance of conducting polymers based nanofluids.

Keywords: Nanofluids, nanoparticles, conducting polymers

1. Introduction

At present, nanofluids have been widely used in various thermal engineering fields with the aim to improve the thermal efficiency of the system which minimizes the usage of energy and provide more sustainable approach. These nanofluids showed to have a great prospect to meet the requirement of industrial needs and the innovative technology in the thermal and cooling performance systems [1].

A number of studies related to the enhancement of heat transfer capability through the use of small particles which dispersed in based fluids have attracted the nanotechnology scientist to explore and generate more ideas to further improve the thermal and cooling system [2]. The conventional type nanoparticle additives have been proved to improve the heat transfer properties of the base fluid. However, the conducting polymers nano additives have been shown to have additionally good rheology properties which include active and functional interactions with nanoparticles,

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providing huge potential for numerous applications that yet to be developed and optimized. The major goal of this brief review is to provide a brief review of the recent development of nanofluids focusing on conducting polymers as its additives.

1.1 History and Development of Nanofluid

Choi [3], the pioneer in nanofluid research, from Argonne National Laboratory (ANL) from his work, has proved a significant thermal properties improvement when nanoparticles dispersed in conventional heat transfer fluid. ANL was the first research centre to report the scientific achievements of the nanofluids studies. He reported a detailed work which includes the nanofluids development method, characterization mechanisms and theoretical understanding related to the heat transfer of nanofluids with dynamic mechanism between nano additives and fluid interface layers. The work on nanofluids has grown substantially after the publication of their work. Figure 1 demonstrates the exponential development in nanofluid research publications and statistic of nanofluids in various branches of subject areas.

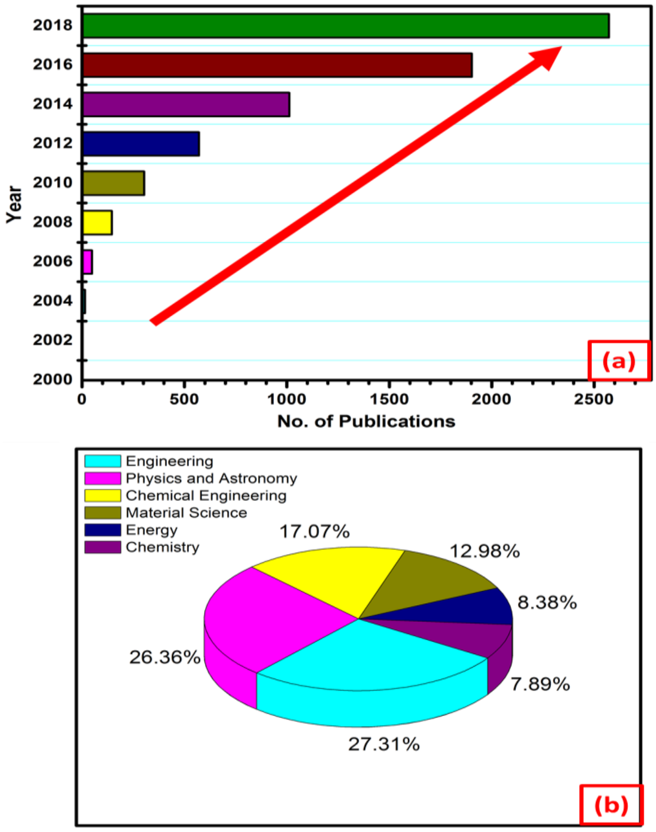

Fig. 1 - (a) Statistics of nanofluids research paper by year (Source: Web of Science); (b) Statistic of nanofluids publication by subject areas (Source: Scopus)

1.2 Overview of Nanofluid Application

Nanofluids have several phenomenal properties which makes them astonishing for different applications. Physicists and biologist have used nanofluids to identify biological nanomaterials with similar morphology as DNA in aqueous solutions. Meanwhile, in the development of smart electronics system, there is great potential for efficient thermal system and cooling of the electronics systems. Also, the use of nanofluids in numerous field such as energy production and utilization, manufacturing and transportation, thermal management has also yielded enormous advantages. Table 1 lists several examples of nanofluids application reported by previous researchers.

Table 1 - Example of nanofluid application

Additives	Basefluids	Application`	Ref
CNT	Water	Solar Collector	[4]
CuO, AlO, SiO	EG and water	Heating System	[5]
Silver	Water	Drug Delivery System	[6]
Al2O3	Water	Cooling of Microchips	[7]
FePt	Water	Cancer Therapeutics.	[8]
Alumina	Water	Nuclear Reactor	[9]
Magnetic np	Water	Hyperthermia	[10]
MWCNT	Water	Water Chiller System	[11]
CuO, Al2O3	Transmission oil	Vehicle Engine Cooling System	[12]

2. The Nano Additives

Usually, the nano-additives use for the development of nanofluid is usually in the range of less than 100nm. These are because the particles size less than 100nm has considerably extraordinary behaviour than their bulk counterpart. Similarly, the developed nanofluids would also have a behaviour considerably extraordinary from their original fluids, in term of properties such as density, viscosity and thermal conductivity.

The liquid-solid interface developed inside the nanofluids system believed to be the factors that influence the nanofluids properties. The liquid atoms and the nano-additives surface forms an interface layer. Theoretically, these atoms in interphase layers are believed to have more ordered arrangement compare to the bulk fluid. Since solid nano additives are established to have a highly ordered arrangement with good heat transfer ability than liquids, such an interface layer is expected to create better thermal transfer properties. Figure 2 demonstrates single nano-additive with an interfacial layer in a fluid medium as proposed by Leong et al. [13].

Nano-additives can be in the form of noble metals (e.g., Pd, Pt, Ag, Au), magnetic nanoparticles (e.g., Fe, Ni, Co), semiconductors (e.g., Si, CdS. ZnS), metal oxides oxides (e.g., Al, Cu, Ti), and conducting polymers nanoparticles (e.g., PANI, Ppy) suspended in any conventional heat transfer fluid to form an engineered nanofluid system [14]. They can be classified into two main categories: single element material nanofluids and hybrid elements nanofluids.

From the performed literature survey, the finding indicates that most of the work for the nanofluid studies have been carried out using metallic, oxides, carbon nanotubes and carbon nanofiber. Very low amount of work has been reported using conducting polymers to develop the nanofluids and their properties. As such, the next section will report the recent development of using conducting polymers as additives in nanofluids

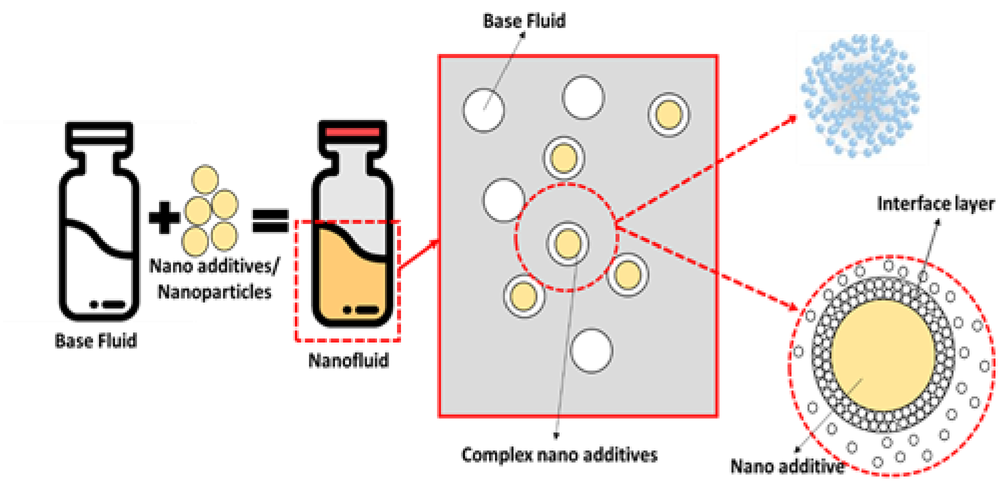

Fig. 2 - System of nanofluids and the nano additives particle with interfacial layer in a fluid medium.

3. Conducting Polymers Nano Additives

Conducting polymers is an organic polymer that has conductivity behaviour as such metallic or semiconductors materials [15]. These polymers usually synthesised via oxidative polymerisation with the help of particular initiator to initiate the polymerisation as similar to the conventional polymers polymerisation method [16]. The synthesized polymer usually posses semiconductivity or their conductivity may be comparable to the metals. Unlike traditional polymers, conducting polymers are non-thermoplastic in nature but belongs to the class of organic materials. Due to the easy synthesizing procedures, distinctive properties, cost-effective, high chemical and irradiation stability and most importantly environment-friendly, the conducting polymers nano-additives gained immense interest from the researchers to be exploited for advanced applications [15, 17]. As to date, more than 25 different kinds of conducting polymers have been successfully synthesized [17, 18]. Table 2 lists some of conducting polymers that have have been successfully synthesized and their conductivity properties relative to common metals and plastics

Table 2 - Conducting Polymers and their conductivity properties relative to common metals and plastic

Material	Conductivity
Noble metals	10^5-10^6 S/cm
Polyacetylene	10-10^4 S/cm
Polyaniline	10^{-1}-10^3 S/cm
Polypyrrole	10^{-1}-10^2 S/cm
Polystyrene	10^{-11}-10^{-10} S/cm
Nylon	10^{-12} S/cm

3.1 PANI Conducting Polymer as Nano Additives

Fig. 3 shows the thermal conductivity enhancement of some conducting polymers based nanofluids as reported by previous researchers. Among the available conducting polymers, PANI has been material of interest as it has not been widely explored. Polyaniline (PANI) has developed as nano additives for nanofluid system and has attracted great attention among researchers due to its unique behavior such as good in conductivity, cost effectiveness and non-toxic[19-23]. PANI nanofibers are usually synthesized via oxidative polymerization approach and exhibit fiber like morphology that provides higher surface area[24, 25].

In nanofluid research area, PANI, has been used to improve the thermal physical properties of traditional heat transfer fluids. The experimental observation of thermal conductivity enhancement using 0.24 vol% PANI dispersed in 140 vol% DI water-based nanofluids at 80 °C temperature was recorded by Wan et al., [21]. Due to the higher crystallinity and morphological uniformity of reinforced PANI nanofibers, the thermal properties of PANI/water nanofluid were found to be improved. Heat transfer enhancement using PANI/water nanofluids was studied in a vertical helically coiled tube heat exchanger by Bhanvase et al., [22]. The increase in the heat transfer coefficient was found to be 69.62% for 0.5 vol% of PANI nanofibers volume concentration. Meanwhile, Gurav et al. [18] conducted an experiment to investigate the heat transfer characteristics of PANI-based nanofluids at various PANI nanoparticle concentrations (0–1.2 wt percent) in water. In a copper tube, the heat transfer efficiency of PANI nanofluid was also investigated under constant heat flux conditions. The heat transfer coefficient increases as the colloidal PANI concentration rises, according to the findings. The heat transfer coefficient increased by 33% when PANI nanofluids were added at 0.2 wt%, and by 63 percent when PANI nanoparticles were added at 1.2 wt%. In another research work, Sofiah et al.,[26] dispersed PANI nanofibers in the RBD palm olein oil at a volume concentration of 0.01-0.5 vol% to study its thermal physical properties of formulated nanofluid system. The experimental results show an enhancement of around 25% in the thermal conductivity when 0.5 vol% PANI nanofibers were added to the RBD palm olein base fluids. The dispersion of PANI nanofibers also remain the flow behavior of RBD palm olein as all the formulated nanofluid system exhibited Newtonion behaviour

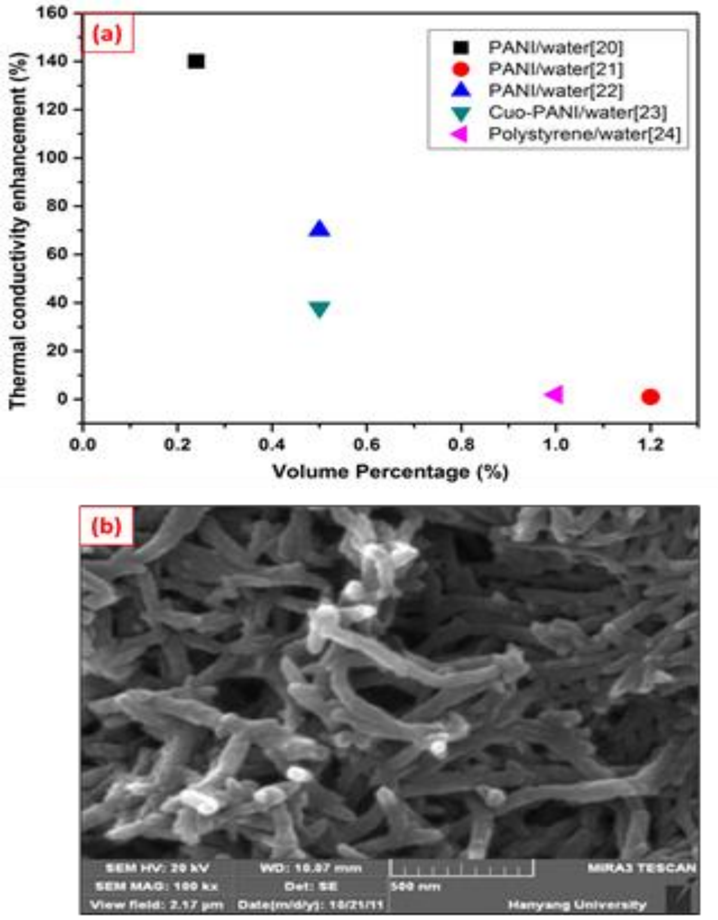

Fig. 3 - (a) Experimental data on thermal conductivity of conducting polymers nanofluids [19-23]; (b) SEM image of Polyaniline [24]

4. Conclusions

This review article provides a brief overview of the recent development in nanofluids focusing PANI as its additives. Since the thermal conductivity of solid materials is much higher than that of liquids, the suspended nano-additives are expected to be able to increase the heat transfer performance of the newly engineered liquid. As to date, limited studies have been carried out using conducting polymer as an additive to develop the nanofluid, specially PANI. Although PANI has shown and has substantial properties, it is yet to be widely explored. Thus, more investigation are required to be performed using conducting polymers, especially PANI as additives in nanofluids for greater prospect and humanity.

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