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Preparation and evaluation of stable nanofluids for heat transfer application: A review

Babita [a], S.K. Sharma [a,*], Shipra Mital Gupta [b]

[a] USCT, Guru Gobind Singh Indraprastha University, Dwarka, India
[b] USBAS, Guru Gobind Singh Indraprastha University, Dwarka, India

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ABSTRACT

High heat load is becoming a barrier in industrial development. This high heat load can be overcome by increasing the rate of heat transfer. Heat transfer rate can be increased by increasing temperature gradient, area of heat transfer or by improving thermo physical properties of heat transfer fluids. Emergence of modern technology provides a great opportunity to process and produce particles in the size range of 1–100 nm called nanoparticles having high specific surface area. Colloidal suspension of nanoparticles into the conventional fluid called nanofluid has higher thermal conductivity compared to conventional fluids. Long term stability of nanofluid is one of the basic requirements for its better utilization in heat transfer applications. Preparation of a long term stable nanofluid is one of the main technical challenge. The main focus of this study is to review the work carried out by various researchers in the last two decades and to summarize the preparation and analytical techniques used for preparation of stable nanofluids. The paper also discusses some new challenging issues that need to be solved for better industrial application of nanofluids.

1. Introduction

Transfer of heat from one place to another is an important requirement in industries. High heat load is becoming a barrier in the development of various industries such as production, transportation, manufacturing, microelectronics, etc. [1]. If there is an enhancement in the rate of heat transfer in industrial processes then there will be saving in energy, reduction in processing time and increase in the life of equipments [2]. So, the development of high performance heat transfer system has become the urgent priority for the industries.

There are various ways to increase heat transfer rate. Improvement in heat transfer rate can be achieved by increasing the temperature gradient of the system under consideration, but sometimes it is difficult to do so because it is often limited by the process or material constraints [2]. Heat transfer can also be increased by increasing the heat transfer area of heat exchangers. However, this technique involves an undesirable increase in the size of thermal systems. Another factor effecting heat transfer rate is heat transfer coefficient. Heat transfer coefficient is affected by the geometrical parameters of heat exchangers such as tube arrangement, pitch, tube diameter, etc. It is reported that different heat exchangers such as shell and tube, helically coiled, straight tube, elliptical tube, plate, frame, etc. have different heat transfer characteristics under same conditions [3–6]. It was reported that heat transfer coefficient was higher for the helical coils in comparison to straight tubes. In case of curved geometries, centrifugal force is created due to the presence of secondary flow, which ultimately affects the heat transfer characteristics significantly [7]. Heat transfer also depends on the surface condition of the equipments such as artificial cavities, structured surfaces, etc. Generally, heat transfer is more in the case of rough surface as compared to smooth surface [8,9]. However, such complex shaped geometrical heat exchangers have their own limitations like high fixed cost of installation and difficulty in maintenance. Heat transfer coefficient can also be increased either by increasing fluid velocity up to a certain extent or by improving thermo physical properties of the fluid such as viscosity, density, thermal conductivity, etc.

Conventional heat transfer fluids viz. water, pumping oil, ethylene glycol, etc. do not have sufficient capability of heat transfer due to very low thermal conductivity. Emergence of modern technology provides a great opportunity to process and produce particles in the size range of 1–100 nm called nanoparticles having high specific surface area. It has been reported that adding nanoparticles into the conventional fluids enhance the thermal conductivity of fluids [10–14].

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* Corresponding author.
E-mail address: skschem1964@gmail.com (S.K. Sharma).

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Numerous experimental and theoretical studies had been reported in literature to evaluate enhancement in thermal conductivity of nanofluids prepared by mixing nanoparticles like metals, metal oxides, ceramics, carbides, metal alloys, carbon nanotubes with basefluids such as water, ethylene glycol, oil, etc. Literature shows that thermal conductivity of nanofluids depends on various factors such as concentration, size, shape, aspect ratio and material of nanoparticles, temperature, basefluid, pH, surfactants, etc. [15–24]. Thermal conductivity of Cu/Water nanofluid increased as pH increased from 8.5 to 9.5 [17]. Thermal conductivity of Al_2O_3/Water nanofluid increased from 8% to 11% as temperature was raised from 22 °C to 52 °C [25].

The thermal conductivity of TiO_2/Water nanofluid increased with increase in volumetric concentration from 0.2 to 2 vol% and decreased with increase in temperature [13]. According to Keblinski et al. [26] enhancement in thermal conductivity was found to be 40% only by dispersing 1 vol% Cu nanoparticles in ethylene glycol. Thermal conductivity enhancement of MWCNTs/Water nanofluids was found to be 11.3% at 1.00 vol% [10]. Zhu et al. [11] reported 18%, 28% and 31% enhancement in thermal conductivity at 1, 3 and 5 vol% respectively for CuO/Water nanofluid.

Despite of the numerous studies on thermal conductivity of nanofluids, there is no model available in the literature which can give the enhancement in thermal conductivity for all kinds of nanofluids over a wide range of concentration of nanoparticles. Also, there are some discrepancies regarding effect of particle size, volumetric concentration, temperature, etc. on thermal conductivity. Some reports had shown an enhancement in thermal conductivity with a decrease in particle size [22,27,28] while others had shown a decrease in thermal conductivity with a decrease in particle size [29–31]. Few authors had reported that thermal conductivity increased linearly with an increase in volumetric concentration [32,33] where as others had reported a non linear pattern [34–36]. In some reported data, thermal conductivity was shown to decrease with an increase in temperature [13] while it is shown to increase with an increase in temperature in some others reports [29,36–38].

With the addition of nanoparticles to the basefluid, viscosity of the overall fluid increases, which ultimately increases the power required to pump the nanofluids and reduces its heat transfer capability [39]. In order to maintain the same heat transfer rate as delivered by conventional fluids, nanofluids should be pumped at low velocity. So, there is an urgent need to find the optimum concentration of nanoparticles which have minimum viscosity and high thermal conductivity.

Long term stability of nanofluids is also one of the basic requirement for heat transfer applications. Stability of nanofluids is important due to its strong relationship with thermal conductivity enhancement [17,19,40–43]. Stability of nanofluids is dependent on their preparation method. There are various inconsistencies in the reported data of nanofluids stability. The main factor which affects the stability of nanofluids is the proneness of nanoparticles towards coagulation/aggregation due to the presence of strong van der Waals attractive forces [44,45]. Aggregates settle down at the bottom of the nanofluid container and enhanced thermal conductivity start decreasing. This unstability of nanofluids acts as a drawback for its industrialization [46].

Various reviews covering different aspects are available such as preparation and characterization of nanofluids [47–52], thermal conductivity enhancement and its mechanism [22,26,49,53–56], convective heat transfer enhancement, mechanism of heat conduction and its application at laboratory scale [32,54,56–65]. Some reviews are also available on applications of nanofluids like industrial cooling, nuclear reactors, extraction of geothermal power, automotive, electronics, biomedical, etc. at laboratory scale [50,59,62,66–71], but no data is available on industrial scale. In all these reviews stability of nanofluids is not focused. Though few studies on the stability of nanofluids have been reported [45,50,68,72–74].

The main focus of this review is to summarize the methods used to prepare stable nanofluids, factors influencing nanofluids stability and its characterization techniques to investigate the stability.

2. Importance of nanofluids stability

Long term stability of nanofluids is one of the basic requirement for its better utilization in heat transfer applications. Stability of nanofluids depends on the preparation methods, nanoparticle characteristics, type of basefluids, surfactants, pH, ultrasonication, etc. The main factor which makes the nanofluid unstable is the proneness of nanoparticles to coagulation/aggregation due to the presence of high surface charge present on them [45]. According to Yu et al. [68] stability means that nanoparticles do not tend to aggregate at a significant rate. The rate of aggregation of nanoparticles is determined by the frequency of collisions caused by Brownian motion and the probability of cohesion during collision. Aggregation of nanoparticles within the nanofluid can block the channels of heat exchanger used for heat transfer. Also, unstability of the nanofluid can alter its thermo physical properties like thermal conductivity, viscosity, density, etc. with time. This results in depreciation of benefits of nanofluids in heat transfer. Since thermal conductivity is directly or indirectly reduced due to unstability, nanofluids lose their potential benefits. Stability of nanofluids is determined by the sum of van der Waals attractive forces and electrostatic repulsive forces that exist between nanoparticles dispersed in nanofluids. When electrostatic repulsive forces are higher than attractive forces only then stability is achieved [74]. In order to enhance the repulsive forces between nanoparticles, two mechanisms are used: 1. Steric mechanism 2. Electrostatic mechanism.

2.1. Steric mechanism

Certain additives like surfactants/dispersants possess the ability to prevent the aggregation of nanoparticles dispersed in nanofluids. These surfactants cover the surface of nanoparticles with a long loop and tail which extends out into the nanofluids. Sterically stabilized nanofluids remain well dispersed or stable for a longer period. Zhu et al. [75] studied the stability of graphite based nanofluid and found that the protective layer of polyvinylpyrrolidone (PVP) on graphite nanoparticles prevented the formation of agglomerates because the nanofluid was sterically stabilized.

2.2. Electrostatic mechanism

Electrostatic stabilization occurs when nanoparticles present in nanofluids attain some charge due to adsorption of ions. Adsorption of ions creates an electrical double layer around nanoparticles which creates repulsive forces between nanoparticles. This is a pH sensitive method and limited in use [74].

3. Preparation of nanofluids

Nanofluids are the colloidal suspension of nanometer size particles (1–100 nm) dispersed in conventional heat transfer fluids (called basefluids) such as water, ethylene glycol, engine oil, etc. Various combinations of nanoparticles and basefluids reported in literature have been given in Table 1. Nanofluids can be prepared by two methods, namely:

1. One step method, and
2. Two step method.