Preparation Technique of SiO_2/HFE-7000 Nanorefrigerant

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ABSTRACT

Nanorefrigerant, as an engineered colloid consist of a base fluid and nanometer-sized solid particles, has drawn excessive responsiveness from researchers for its higher thermal properties and various potential applications. It can be applied in many devices for better performances. The preparation of nanorefrigerant is a foremost step in the use of nanoparticles for heat transfer performance enhancement of fluids. There are several important requirements into creating a useful nanorefrigerant. However, it is still a challenge to make a homogeneous nanorefrigerant and long-term stable, and without disturbing the thermophysical properties. In this paper, we summarize recent development on the study of /nanorefrigerants, such as the preparation methods, the methods for the stability of nanorefrigerant, and the ways to enhance the stability, and potray the wide range of current and future applications in various fields. The present study of SiO_2/HFE-7000 preparation technique has been discussed and the observation results were presented. At last, the paper recognizes the chances for future research.

Keywords: *Nanorefrigerant; HFE-7000; SiO_2*

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Nomenclature

C_p	Specific heat, $J.kg^{-1}.K^{-1}$
FESEM	Field emission scanning electron microscopy
HFE	Hydrofluoroether
K	Thermal conductivity, $Wm^{-1}K^{-1}$
L_v	Latent heat of vaporization, $kJ.kg^{-1}$
M	Mass, kg
T	Temperature, K
V	Volume, m^3

Greek symbols

ϕ	Volume concentration, %
μ	Dynamic viscosity, $mPa \cdot s$
ρ	Density, $kg \cdot m^{-3}$
σ	Surface tension, $mN.m^{-1}$

Subscripts

f	Fluid
m	Mass fraction
p	Particle
R	Refrigerants
sat	Saturation
v	Volumic fraction
1	Initial
2	Final

Introduction

Nanofluids, as a combination of base fluid and nanoparticles,which is a new concept that has been currently investigated by many researchers. The concept was proposed by Choi in 1995 as an engineered colloid made of a base fluid and solid nanoparticles [1]. Numerous studies have attempted to explain the progress of nanofluid investigation in the past several years [2–6]. It has shown huge potential of applications in wide range of applications. Nanofluids have been found to be able to enhance thermophysical properties such as thermal conductivity, thermal diffusivity, viscosity, and convective heat transfer coefficients compared to those of base fluids. Those properties can be adjusted by changing the particle concentrations to suit different applications. Therefore, the formulation and characterization of the nanoparticles and base fluid are critical stages for the use of such fluids for high performance heat transfer fluids.

One of the nanofluids types is nanorefrigerant. A nanorefrigerant is a specific class of refrigerant in which the nano-sized particles (1–100 nm) are well-dispersed in the base refrigerant. With concern to it being a new application of nanotechnology, most researchers have investigated simple experiments such as heat transfer characteristics inside a horizontal smooth tube [7], nucleate pool boiling heat transfer [8], flow boiling heat transfer [9], and characterization of nanorefrigerant [10-13].

Recent developments in nanorefrigerant have heightened the attentions from researches. One of the most significant present discussions in nanotechnology is the stability of nanofluids, and it stays a major challenge to achieve required stability of nanofluids. The key driving force for nanorefrigerant study relies in a wide range of applications. Nanofluids are not simply binary solid-liquid mixtures. There are several essential requirements into creating a useful nanofluid including the stability, minimal agglomeration of the particles for a durable suspension, and no chemical change of the base fluid. From literatures, there are a quite few research concerned on the experimental and theoretical studies of the thermophysical properties or the convective heat transfer of nanofluids. However, studies on how to make a homogeneous nanorefrigerant are rare to find in literature. The direction of this paper will concentrate on the new preparation methods and stability mechanisms nanorefrigerant using HFE-7000 as a base refrigerant and SiO_2 as nanoparticle in addition to the heat transfer properties of nanofluids.

Background Studies of Nanorefrigerant Preparation

The preparation of nanorefrigerant is the main step in the use of nanoparticles to improve the thermal conductivity of refrigerant. There are two kinds of methods used to produce nanofluids: the single-step method and two-step method [14]. Nanoparticles, the additives of nanofluids, act an important role in altering the thermal transport properties of nanofluids. Here and now, various types of nanoparticles have been used in nanofluid preparation.

The two-steps method is a process where dry particles are dispersed into a base liquid. Nanoparticles, nanotubes or nanofibres are first produced as dry particles by different mechanisms such as inert gas condensation, chemical vapour deposition, mechanical alloying or other suitable techniques. The nanopowder is then scattered into a base fluid which is considered to be the second step of the process. Instead of the one-step method, the two-step technique is usually employed for the preparation of non-metallic nanofluids. This method is the most cost-effective way to produce nanofluids in large scale, because nanopowder synthesis techniques have already been expanded to industrial production levels. As a result of this method, agglomeration of the particles could possibly exist, especially during the process of storage and transportation. Such agglomerations will lead not only to settlement or clogging but also indicate to a change in the thermal properties of the prepared nanofluid. Different techniques, such as ultrasonic agitation, surfactant addition or pH control, can be implement to prevent agglomeration and improve the dispersion behaviour [15]. Due to the high surface area and surface activity, nanoparticles have the tendency to clotted. Therefore, the issue that matter for the dispersion two-step method is the breaking of agglomerations and the prevention of re-aggregation of nanoparticles. The important technique to enhance the stability of nanoparticles in fluids is the use of surfactants.

One biggest drawback of the use of a nanofluid as a heat transfer fluid is its stability. There are two phenomenon that are significant for the stability of the nanofluid: sedimentation and aggregation. The study on stability influenced the properties of nanofluids for its application, and it is essential to investigate and analyze influencing factors to the dispersionstability of nanofluids. As discuss above, one should avoid agglomeration of the nanoparticles. The key to the stability of the nanofluids, is the size of the nanoparticles. To reduce the sedimentation velocity and therefore increase the stability of the nanofluid can include:

- Reducing the size of the nanoparticles
- Increasing the viscosity of the base fluid
- Reducing the density difference between the nanoparticles and the base fluid

It is clear that decreasing the size of nanoparticles will reduce the sedimentation velocity. According to theory in colloid chemistry, the sedimentation will discontinue when the particles become a critical size due to the Brownian motion of nanoparticles [16]. At this point,the nanoparticles reach the equilibrium between sedimentation and dispersion. Although equilibrium is attained, the smaller nanoparticles have higher surface energy and increase the chance of aggregation to occur between the particles. Thus, the key here is to prepare nanofluids that use particles as small as possible and prevent aggregation physically and/or chemically. However, by increase the viscosity of the base fluid or reducing the density difference is not suitable for heat transfer application since the nanoparticles and the base refrigerant are first chosen because of their thermal and physical properties.

There are several ways to enhance the stability of the nanofluids and prevent sendimentation. As clarified before, the two-step method enables easy and fast preparation of nanopowder but also causes an easier agglomeration of the particles duringthe drying process. Even when dispersed into the base fluid, and after sonication tobreak the agglomerates, the particles keep agglomerating because of the Van Der Waals forces.

Some products, known as surfactants or dispersant when used for nanofluids, need to be added to prevent the agglomeration. Two concepts are usually used, steric barrier or charge stabilization. They find their justification inthe interaction between particle theory. When particles dispersed in the base fluid, the particles are subject to molecular interactions such as collision between fluid and particle atoms, the Brownian motion but also uninvited interactions as Van Der Waals forces low range electrostatic interaction. These last phenomena have a unfortunate effect on the colloid stability as it can lessening the effectiveness of the nanorefrigerant. This phenomenon is well justified by Derjaguin Landau, Verwey Overbeek (DLVO) theory [17,18]. Based on it, a possible way to improve the stability of the nanofluids is to stimulate repulsive forces, stronger than the Van Der Waals forces.

Dispersants can evidently affect the surface characteristics of a system in small quantity. According to the composition of the head, surfactants are divided into four classes: nonionic, anionic, cationic and amphoteric surfactants. The question is, how to select suitable dispersants? As this study use HFE-7000 as a base fluid, the solvent have moderately higher dielectric constants. Selection of oil-soluble surfactant is very suitable as we use the nonionic surfactants.

SiO_2/HFE-7000 Nanorefrigerant Preparation

The preparation of the nanofluid is a focal step in this research. For the purposes of this study, experiments have been carried out using HFE-7000 manufactured by 3M as a base refrigerant because of its physical properties. The fluid is odorless, non-explosive, nonflammable, having low phase change enthalpy and low boiling temperature. Characteristics of pure HFE-7000 are given in Table 1.

Table 1: HFE-7000 properties [19]

	T_{sat} $_oC$	L_v $kJ.kg^{-1}$	ρ kg/m^3	k $W.m^{-1}.K^{-1}$	μ $mPa.s^{-1}$	C_p $J.kg^{-1}.K^{-1}$	σ $mN.m^{-1}$
HFE-7000	34	142	1400	0.075	0.448	1300	12.4

This low boiling temperature fluid was chosen due to the safety concerns. It also reduces the heat losses since it controlled amount of heat that will be required to induce the boiling process. The option of the nanoparticles is based on the size, shape and thermal properties of the material. Spherical or nearly spherical nanoparticles with a diameter between 25 and 100 nm have been nominated for this study. In this research, SiO_2 nanoparticles were selected because of their good thermal properties and wide spread use in the research community.

The nanoparticles are supplied in powder form, dry, while the agglomeration of the particles is avoidable. The particles are then dispersed into the base fluid. The mixture is sonicated using an ultrasonic bath for approximately 2.5 hours and Tween-80 is added as a surfactant. After the sonication, it was observed that the volume concentration decrease from 0.1 vol% to 0.02 vol%. It shows that the nanoparticles were diluted during the preparation process. The presence of the Tween-80 surfactant were very helpful on dilution process of nanoparticles. The prepared mixtures were then diluted to acquire nanofluids at 0.005, 0.02 and 0.01 vol% concentration. The volumic fraction of particles, knowing the weight fraction, is as follows:

$$\Phi_v = \frac{\Phi_m}{\Phi_m + \frac{\rho_p}{\rho_f}(1 - \Phi_m)} \quad (1)$$

where, Φ_v and Φ_m are the volumic and mass fraction, respectively, and ρ_p and ρ_f are the particles and fluid density, respectively.

The prepared nanofluids, shown in Figure 1(a), were then left to rest. They were observed to be very stable. Minimal deposition was showed after 90 days (Figure 1(b)). The deposition of particles continually observed from month to month and it still in stable condition.

(a) (b)

Figure 1: Photograph of the prepared nanoparticles of SiO_2 in HFE-7000 (a) First day of preparation, (b) 90 days of preparation (From left for both figures: 0.02%, 0.01% and 0.005% volume concentrations)

The results shows the nanoparticles is expanded their average size from 30 nm to 100 nm. Presence of surfactant, Tween-80 might changes the nanoparticle size to be expanded. Figure 2 shows that FESEM image at X50,0000 magnification, of the spherical shape and size of nanoparticles that have an average size of 100 nm. This result shows a big difference between the insignificant size of the particles (30 nm) and the actual size of the particle or particles agglomeration in the base fluid. Such difference could not explain by the author at the moment, further investigation need to carry out.

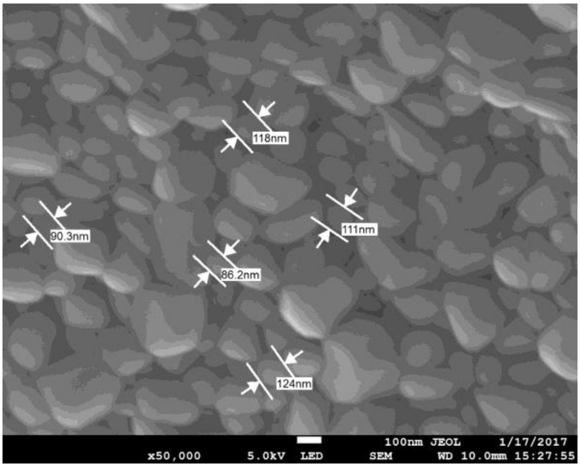

Figure 2: FESEM image of dry nanoparticle at X50,000 magnification.

Conclusion

The technique of preparation SiO_2/HFE-7000 nanorefrigerants is presented in this paper. By using two-step method of preparation, a high stable of SiO_2/HFE-7000 nanorefrigerants was achieved. Three different SiO_2 volume concentrations were prepared i.e 0.005%, 0.01% and 0.02%. From observation, almost none sedimentation of SiO_2 nanoparticles was occurred when observation was made for more than 90 days. With such high stability of nanoparticles was attained in the mixture, this work can be classified as big achievement in nanorefrigerants development. This novel nanorefrigerant has great potential to be applied in refrigerants related applications such as in cooling technologies, in which minimal disturbance of nanoparticles during convection and boiling heat transfer processes could be achieved.

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