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Research Paper

Experimental research on particle aggregation behavior in nanorefrigerant–oil mixture

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HIGHLIGHTS

- Time evolutions of the hydrodynamic diameter of aggregates in nanorefrigerant–oil mixture were measured.
- The presence of lubricating oil inhibits the aggregation of nanoparticles.
- The inhibition of oil on aggregation is strengthened with the increase of oil concentration.
- Larger primary particle size or concentration leads to larger hydrodynamic diameter of aggregate.
- The hydrodynamic diameter of aggregate is enlarged with the rise of temperature.

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ABSTRACT

The objective of this study is to experimentally investigate the effects of primary particle size, primary particle concentration and temperature on particle aggregation behavior in nanorefrigerant–oil mixture. The nanoparticles, refrigerant and lubricating oil for experiments were TiO_2, R141b and ATMOS NM56, respectively. Experimental conditions included primary particle size from 25 to 100 nm, primary particle concentration from 50 to 500 mg L^{-1}, temperature from 6 to 27 °C, and oil concentrations of 1, 3 and 5 wt%. Time evolutions of the hydrodynamic diameter of aggregates were measured by dynamic light scattering (DLS) method. It is shown that the presence of lubricating oil inhibits the particle aggregation, and the inhibition is strengthened with the increase of oil concentration; the hydrodynamic diameter of aggregates is enlarged with the increase of primary particle size, primary particle concentration or temperature, and the enlargement increases with the increase of oil concentration.

1. Introduction

Nanorefrigerant–oil mixture is a special kind of nanofluid which is prepared by dispersing nanoparticles in refrigerant–oil mixture. As the addition of nanoparticles remarkably increases the thermal conductivity and the boiling heat transfer coefficient, nanorefrigerant–oil mixtures have better heat exchange performance compared to conventional refrigerant–oil mixtures [1–3], and have great potential for improving the energy efficiencies of vapor compression refrigeration systems [4–8]. However, the nanoparticles in refrigerant–oil mixture are likely to form aggregates due to strong Brownian motion and high surface free energy. The aggregation of nanoparticles accelerates the sedimentation process and then reduces the long-term stability, which will hinder the actual application of nanorefrigerant–oil mixtures. In order to develop the technology for maintaining the long-term stability of nanorefrigerant–oil mixture, the particle aggregation behavior in nanorefrigerant–oil mixture should be known.

The effects of primary particle parameters (size and concentration) and temperature should be considered during the investigation on the particle aggregation behavior in nanorefrigerant–oil mixture due to the following reasons. Firstly, the primary particle parameters (size and concentration) affect the interaction between particles. Secondly, the variation of temperature alters the thermophysical properties of refrigerant–oil mixture as well as Brownian motion of nanoparticles, which leads to the change of particle aggregation behavior.

The existing researches on particle aggregation behavior focus on the nanofluids with the base fluids of water [9–17], aqueous solution [9,13,18], ethylene glycol [12,19,20], silicon oil [15], gear oil [21] and refrigerant [22–24], as summarized in Table 1. The experimental methods for evaluating the particle aggregation behavior include dynamic light scattering (DLS) [9,11–24], zeta potential analysis [9,11,13–15,19,23], UV–vis spectrophotometer [10,24], transmittance measurement [22], sedimentation picture capturing [11,14,19,22,24], hydrometer [12], scanning electron microscope

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Table 1
Existing studies on particle aggregation behavior in nanofluids.

Researchers (year)	Base fluid	Nanoparticle	Evaluation method	Investigated factors	Ref.
Hong et al. (2006)	EG	Fe	DLS	Time elapse	[20]
Bi et al. (2007)	R113, R141b, R123	TiO_2	DLS, sedimentation picture capturing, transmittance measurement	Temperature, time elapse	[22]
Li et al. (2007)	Water	Cu	DLS, zeta potential analysis, sedimentation picture capturing	pH, surfactant type and concentration	[11]
Hwang et al. (2008)	Water, silicon oil	Carbon black, Ag	DLS, zeta potential analysis, TEM	Preparing method, pH	[15]
Jiang et al. (2009)	Water	TiO_2 (anatase)	DLS, zeta potential analysis	pH, ionic strength, surface charge and surface coating	[13]
Suttiponparnit et al. (2010)	Water	TiO_2 (0–100% anatase), TiO_2 (P25)	DLS, zeta potential analysis	Primary particle size, pH, ionic strength, surface area, crystal phase	[9]
Pastoriza-Gallego et al. (2011)	Water	CuO	UV–vis spectrophotometer, TEM, SEM,	Primary particle concentration, pH, time elapse	[10]
Kole et al. (2011)	Gear oil	CuO	DLS	Primary particle concentration	[21]
Gharagozloo and Goodson (2011)	Water	Al_2O_3	DLS	Primary particle size and concentration, temperature, time elapse	[17]
Ismay et al. (2012)	Water	TiO_2 (rutile)	DLS, zeta potential analysis, sedimentation picture capturing, TEM	pH, sonication time	[14]
Lee et al. (2013)	NaCl aqueous solution	Al_2O_3	Sedimentation picture capturing, DLS, SEM	Primary particle concentration, temperature, ultrasonication time	[18]
Witharana et al. (2013)	PG, EG, water/PG, water/EG	TiO_2, Al_2O_3, ZnO	DLS, zeta potential analysis, sedimentation picture capturing	Base fluid type, day light	[19]
Lee et al. (2014)	Water, EG	Al_2O_3, Ag, ZnO	DLS, hydrometer	Type of nanofluids, time elapse	[12]
Gomez-Merino et al. (2014)	Water	TiO_2 (anatase)	DLS, TEM	Time elapse	[16]
Peng et al. (2015)	R141b	TiO_2 (anatase)	DLS, zeta potential	Primary particle size and concentration surfactant, time elapse	[23]
Lin et al. (2015)	R141b	MWCNTs	Sedimentation picture capturing, UV–vis spectrophotometer, DLS	Surfactant type and concentration, ultrasonication time, time elapse, primary particle concentration	[24]

(SEM) [10,18] and transmission electron microscope (TEM) [10,14–16]. The results indicated that the aggregation behavior are affected by some factors such as primary particle size and concentration, temperature, base fluid type, time elapse, pH value, surfactant type and concentration, ionic strength, and ultrasonication time.

The particle aggregation behavior in nanorefrigerant-oil mixture may be different from those in the oil-free nanorefrigerant and other non-refrigerant-based nanofluids revealed by the above existing researches, based on the following two reasons. Firstly, the interaction between the oil molecules and the refrigerant molecules could change the particle aggregation behavior. Secondly, the physicochemical properties (viscosity, Hamaker constant, etc.) of refrigerant–oil mixture are different from the base fluids in the existing researches, causing different motion of nanoparticles and interaction between nanoparticles, which leads to the change of aggregation behavior.

In order to know the particle aggregation behavior in nanorefrigerant–oil mixture, the experiments using refrigerant–oil mixture as base fluid are carried out in the present study, considering the effects of primary particle parameters size, primary particle concentration and temperature.

2. Experimental materials and method

2.1. Preparation of nanorefrigerant–oil mixture

The materials used for preparing the nanorefrigerant–oil mixtures include nanoparticles, pure refrigerant and lubricating oil.

Titania (TiO_2) nanoparticles with primary particle sizes of 25, 40, 60 and 100 nm (purchased from Aladdin Industrial Corporation, Shanghai, China) were used, which are in accordance with those used by Peng et al. [23]. Titania nanoparticles could enhance the heat transfer performance of refrigerant and have stable chemical and physical properties, so they have been widely used in nanorefrigerant researches [5,22,25–28]. The properties of the TiO_2 nanoparticles are listed in Table 2.

R141b (1,1–Dichloro–1–fluoroethane) was used as the base refrigerant, based on the following reasons. As the nanorefrigerant is usually prepared by two-step method under ambient condition [2,3], it is better to choose those refrigerants in liquid state under ambient condition. However, the common refrigerants such as R410A and R134a are in vapor state under ambient condition, so the experimental nanorefrigerant cannot be prepared by these refrigerants.

Table 2
Properties of TiO_2 nanoparticle.

Primary particle size (nm)	Specific surface area (m^2 g^{-1})	Molecular weight (g mol^{-1})	Density (kg m^3)	Purity (%)	Crystal phase	Appearance
25	250–400	79.9	3780	100	Anatase	White powder
40	100–200					
60	30–60					
100	15–20					