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Review

A review of nanorefrigerants: Flow characteristics and applications

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ABSTRACT

The heat transfer performance of various thermal devices may be augmented by active and passive techniques. One of the passive techniques is the addition of ultrafine particles (called nanoparticles) to the common heat transfer fluids so that the thermal transport properties of the prepared suspension (called nanofluid) will be enhanced as compared to the base fluid. Nanorefrigerants are a special type of nanofluids which are mixtures of nanoparticles and refrigerants and have a broad range of applications in diverse fields for instance refrigeration, air conditioning systems, and heat pumps. In this paper, a review is performed in order to clarify effect of nanorefrigerant properties (such as nanoparticle type, size and concentration) on heat transfer and pressure drop compared to pure refrigerant. Moreover, studies related to the thermophysical properties, flow and pool boiling, and applications of nanorefrigerants to some specific areas such as domestic refrigerators, heat pipes and air conditioners are also summarized.

Un passage en revue des nanofrigorigènes: caractéristiques d'écoulement et applications

Mots clés : Nanofrigorigènes ; Transfert de chaleur ; Chute de pression ; Propriétés thermophysiques ; Ebullition ; Applications

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Nomenclature

CNT	carbon nanotubes
COP	coefficient of performance
Dnp	nanoparticle diameter [nm]
EG	ethylene glycol
h	heat transfer coefficient [W m^{-2} K^{-1}]
k_f	thermal conductivity of pure fluid refrigerant [W m^{-1} K^{-1}]
k_{eff}	thermal conductivity of nanofluid nanorefrigerant [W m^{-1} K^{-1}]
MNRO	mineral-based nano-refrigeration oil
PAG	poly alkylene glycol
POA	poly-alfa-olefin
POE	polyol-Easter oil
q	heat flux [kW m^{-2}]
SWCNH	single wall carbon nanohorns
T	Temperature [°C]
TEM	transmission electron microscope
Vol	volume
υ_p	predicted liquid kinematic viscosity [mm^2 s^{-1}]
wt	weight
x_{np}	mass fraction of nanorefrigerant
x_s	mass fraction of surfactant

1. Introduction

Nanotechnology is a section of science and technology regarding the modification and use of particles in the atomic and molecular order. In this aspect, a particle is considered a tiny thing that acts as a single piece with respect to its carriage and specifications. While fixed physical properties are expected from bulk material, the properties of materials alter in relation to their nano scale size. These particles can be categorized, based on their diameter, into three groups, including coarse particles (10,000–2500 nm), fine particles (2500–100 nm), and ultrafine particles or nanoparticles (1–100 nm). Especially in heat transfer applications, the use of ultrafine particles is required because using the particles with a higher size leads to some problems like fouling, sedimentation, erosion and higher pressure drop.

Normally, the use of common heat transfer fluids such as water, engine oil, and ethylene glycol results in the limitations in efficiency and performance of the thermal devices with a given size. The heat transfer augmentation can be enabled by the treatment of suspended solid particles into these conventional fluids as a chemical additive. Thermal conductivity is considered the most important thermophysical property to enhance the heat transfer performance of these suspensions. Suspending nanoparticles in a base fluid, where the thermal conductivity of particles is remarkably higher than the base fluid, is used to enhance the thermal conductivity of conventional fluids. The composition of nanoparticles and the base fluid is called nanofluids, which are an advanced type of heat transfer fluids.

Moreover, a new concept described as the application of nanoparticles as additives into refrigerants which the obtained suspension is called "Nanorefrigerant." Refrigerant is a material used in heat transfer cycles which undergoes a phase change most of the time due to excessive heat transfer rate experienced during the process. Despite most of the fluids can find themselves a place in refrigeration cycles, only fluorocarbons or chlorofluorocarbons considered as refrigerant according to general opinion. Two methods (one-step method and two-step method) are used for synthesis of nanorefrigerants. Two-step method is commonly used to prepare nanorefrigerants. In this method, the nanomaterials are synthesized as dry powders by thermal decomposition and photochemical methods, transition metal salt reduction, ligand reduction and displacement from organometallics, metal vapor synthesis and electrochemical synthesis methods (Botha, 2007). After production, the nanosized powder is put into the oil to form nanoparticle/oil mixture. Then, this mixture is dispersed by using different type of dispersion techniques such as ultrasonic agitation, magnetic force agitation, homogenizing, high-shear mixing (Yu and Xie, 2012). In one-step method, vapor phase nanophase powders are condensed into a liquid having low vapor pressure and dissolved in liquid at the same time. The nanoparticles are produced by applying a physical vapor deposition method or liquid chemical method (Sundar et al., 2013).

The potential of some refrigerants to mix with nanoparticles are mentioned as follows: Hydro fluorocarbons (HFCs) and hydrocarbons (HCs) are the most commonly used substitute refrigerants in refrigeration units of domestic refrigerators, chillers, air conditioners, and so on. When the refrigerants are mixed with nanoparticles, the system performance is enhanced while the energy consumption is reduced as compared to the pure refrigerant. Polyolester (POE) oil, another type of refrigerant, is preferred over mineral oil for use in lubricant applications due to its strong chemical polarity. In addition, the use of suspended nanoparticles in the lubrication of compressors increases the system's efficiency, causing no choking in the system.

This review paper focuses on the latest advances in the augmentation of heat transfer by using nanorefrigerants. Studies related to the thermophysical properties, heat transfer, pressure drop, flow and pool boiling, and applications of nanorefrigerants are reviewed. Tables 1–6 provide a summary of the review performed in this paper. It can be seen from Tables 1–6 that Al_2O_3, CuO, TiO_2, Cu, Ti, Al, diamond, SiO_2 nanoparticles having different concentrations were used with the R134a, R600a, R113, R141b, R123, R12, R410a in order to form a nanorefrigerant.

2. Studies on nanorefrigerants

The studies on nanorefrigerants are classified into seven sections. The first section concerns research on the thermophysical properties, and the following sections review the, pressure drop, flow boiling, pool boiling, and the applications of nanorefrigerants.

2.1. *Thermophysical properties of nanorefrigerants*

Measurement of thermophysical properties of nanorefrigerants, such as thermal conductivity, viscosity, heat