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Review

Nanorefrigerants: A comprehensive review on its past, present and future

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ABSTRACT

Nanofluid as a heat transfer fluid has been gaining popularity ever since its inception. Consequently, the researchers and experimentalists from the refrigeration industry could not keep themselves away from the ever growing horizon of nanofluid applications. The research on the refrigerant based nanofluids or a nanorefrigerant is slowly but surely increasing. The boiling heat transfer coefficient data for nanofluids and nanorefrigerants have been inconsistent but, in general, researchers have observed a rise in the boiling heat transfer coefficient that encourages them to pursue their research further in this field. Numerous studies regarding nanorefrigerants have shown that the addition of nanoparticles lead to a better system performance and energy efficiency. This review paper is an attempt to summarise all the aspects of nanorefrigerants such as its preparation, thermophysical properties, pressure drop in nanorefrigerants, boiling heat transfer and performance of nanorefrigerants in various domestic refrigerators.

Les nanofrigorigènes: une synthèse complète de leur passé, présent et futur

Mots clés : Nanofrigorigènes ; Nanofluides ; COP ; Propriétés thermophysiques ; Transfert de chaleur en ébullition ; VCRS

1. Introduction

A nanorefrigerant is a special class of refrigerant in which the nanoparticles are suspended and well-dispersed in the base refrigerant. The concept of dispersing the solid particles into a fluid was first introduced by Maxwell (1873). He dispersed millimetre and micrometre sized particles into the base fluid in order to improve the thermophysical properties of the fluid. But this genre of fluids suffered few major setbacks due to

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Nomenclature

d	diameter of nanoparticles [nm]
G	mass flux [$kgs^{-1}m^{-2}$]
h	boiling heat transfer coefficient [$Wm^{-2}K^{-1}$]
k	thermal conductivity [$Wm^{-1}K^{-1}$]
P	pressure [kPa]
q	heat flux [kWm^{-2}]
T	temperature [K]
x	vapour quality
$x_{n,o}$	CNTs nanolubricant mass fraction

Greek symbols

ω	CNT mass fraction in CNT nanolubricant
ϕ	particle volume fraction

Dimensionless numbers

Nu	Nusselt number

Subscripts

frict	frictional
f	*base fluid*
n	*nanoparticles*
nf	nanofluid
o	lubricating oil
p	particle
r	refrigerant

Abbreviations

CFC	chlorofluorocarbon
CHF	critical heat flux
CNT	carbon nanotubes
COP	coefficient of performance
CTAB	hexadecyl trimethyl ammonium bromide
CVD	chemical vapour deposition
EER	energy efficiency ratio
GWP	global warming potential
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
IGC	inert gas condensation
MNRO	mineral oil based nanorefrigeration oil
MWCNT	multi-walled carbon nanotubes
NBP	normal boiling point
ODP	ozone depletion potential
POE	polyol-ester
SDBS	sodium dodecylbenzenesulphonate
SDS	sodium dodecyl sulphate
SEM	scanning electron microscopy
SWCNT	single-walled carbon nanotubes
VCRS	vapour compression refrigeration system

issues like stability, clogging and erosion. With the advent of nanotechnology, Choi (1995) introduced a new concept of dispersing nanoparticles in the base fluid and called it as nanofluids. The purpose behind the development of nanofluids is to enhance the heat transfer performance of various heat transfer fluids and, lately, this concept has been extended to the refrigerants as well. The key points regarding nanorefrigerants are:

- The use of nanorefrigerants will lead to smaller and lighter refrigeration systems.
- The refrigeration systems functioning on nanorefrigerants will consume less compressor power, i.e. they will be more energy efficient.

The above mentioned points are the direct consequences due to the superior thermophysical properties of nanorefrigerants in comparison to the base refrigerants. The majority of researchers observed an increase in the effective thermal conductivity of the base fluid due to the addition of nanoparticles (Choi, 1995; Wang et al., 1999; Yoo et al., 2007). As expected, same trend was observed in the refrigerant based nanofluids as well, for instance, the thermal conductivity values increased by as much as 104% by addition of CNT nanoparticles in R113 (Jiang et al., 2009). The study of nanofluids is not just limited to the thermal conductivity; in fact, many researchers have studied other thermophysical properties as well such as viscosity, specific heat and surface tension.

The boiling heat transfer is a major area of research when it comes to refrigerants. The study of boiling heat transfer involves complexities and these complexities are only going to increase due to the addition of nanoparticles in the refrigerant. The researchers have observed mixed results for boiling heat transfer measurements of nanofluids and nanorefrigerants but that should not deject researchers by any means. In past, various results have been published in which the boiling heat transfer performance for nanorefrigerants was found to be higher in comparison to that of the base refrigerant without nanoparticles. Both the pool boiling and flow boiling have been studied by numerous researchers but more work has been done on the pool boiling of nanorefrigerants. This review focuses on both the aspects of the boiling heat transfer, i.e. pool boiling and flow boiling of nanorefrigerants.

The nanorefrigerant research fraternity is evenly divided into two groups. The first group of researchers believe in suspending nanoparticles directly to the base refrigerant, whereas the other group of researchers have suspended nanoparticles to the lubricant itself to analyse the system performance. Interestingly, the concept of dispersing nanoparticles in lubricant is also gaining popularity among researchers. They observed a favourable system performance by the addition of nanoparticles into the lubricant. Numerous amount of work has been carried out using refrigerant–nanolubricant pair (Bi et al., 2008; Fu et al., 2008; Sabareesh et al., 2012; Wang and Xie, 2003). Lee et al. (2009) showed that the friction coefficient comes down by as much as 90% when raw oil is replaced by nano-oil and concluded that the nano-oils have better lubricating characteristics in comparison to the raw oil. Xing et al. (2014) worked with a fullerene C_{60} nano-oil and observed an improvement in the COPs of the two compressors by 5.26% and 5.3% respectively. They also observed a decline in the compressor shell temperatures by about 3–5 °C, which is desirable since a lower compressor shell temperature ensures better lubricant stability.

The research work on nanorefrigerants is still in its infancy. Every work, study and experiment, no matter how big or small,