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Development of nanorefrigerants for various types of refrigerant based: A comprehensive review on performance☆

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ABSTRACT

Nanorefrigerants and nanolubricants are formed when nanoparticles are dispersed in refrigerant/lubricant based. The use of nanorefrigerants or refrigerant with nanolubricant mixtures is one of the passive techniques in enhanced heat transfer performance and reducing energy consumption. This paper reviews the augmentation of heat transfer, enhancement of coefficients of performance (COP) and energy efficiency of various nanoparticle dispersions in the refrigerants or lubricants based on refrigerant type. From the results available in the literatures, it shows that nanorefrigerants and refrigerant/nanolubricant mixtures enhances the heat transfer coefficient. Furthermore, the augmentation of heat transfer coefficient depends on the concentrations and size of the particles. Increment of concentration also increases the viscosity, and consequently, the pressure drop. Moreover, from the review, most of the researchers tend to use R134a hydrofluorocarbon (HFC) as the refrigerant base. Even though the use of chlorofluorocarbon (CFC) refrigerant had been banned, it is still favored by some researchers as it is easy to prepare the nanorefrigerant mixtures in a liquid state with atmosphere pressure and room temperature. The limited research of nanorefrigerants in using hydrocarbon (HC) refrigerant base is due to its flammability issues. Nevertheless, it is strongly suggested that the research based on this environmental friendly refrigerant such as HC need to be conducted extensively.

1. Introduction

Refrigerants are extensively used in refrigeration and air conditioning systems in commercial buildings, industries and automotive. Throughout the previous decades, chlorofluorocarbons (CFC) have been comprehensively used in refrigeration and air-conditioning applications. However, because CFC is harmful and destroys the stratospheric ozone layer, CFC has been banned by the Montreal protocol. In order to fill the gap caused by the phase out of CFCs, HFC/134a has been effectively developed and adopted in automotive air-conditioning systems for the past decade. However, in the last two decades, the global warming issues were raised and the Kyoto protocol was proposed to control greenhouse gases including hydrofluorocarbon (HFC) [1]. Therefore, HFC based refrigerants including R134a had to be substituted by environmentally friendly refrigerants as soon as possible. The replacement of HFC/134a was strongly kept in action until the EU F-Gases Regulation and MAC directive forbids the use of this refrigerant. Starting from 2011, all mobile air conditioning of newly manufactured vehicles were banned from using HFC refrigerants for the sake of environmental protection [2]. MAC directive also particularly banned the employment of fluorinated greenhouse gases that has global warming potentials (GWP) of higher than 150.

Nanorefrigerants and nanolubricants are produced when nanoparticles are dispersed in the refrigerant/lubricant base. The three main advantages of using nanoparticles in refrigerants are [3]; (i) Nanoparticle as additives can enhance the solubility between the refrigerant and the lubricant. (ii) Thermal conductivity and heat transfer characteristics of the refrigerant can be improved. (iii) The friction coefficient and wear rate can diminish when nanoparticles are dispersed into the lubricant. Nanorefrigerants or refrigerant/nanolubricants mixtures have the potential to improve heat transfer rates thus, smaller heat exchangers in air conditioning and refrigeration systems are attainable. Studies on nanorefrigerants [4–7] have indicated that dispersing nanoparticles into refrigerants can improve the heat transfer of the refrigerant base.

Nanorefrigerants are classified according to refrigerant base type as shown in Fig 1. As mentioned earlier, after the Montreal protocol, alternative refrigerants to replace CFC were sought and were divided into two major categories; conventional based nanorefrigerants and alternative based nanorefrigerants. Refrigerants R11, R12 and R113 are the

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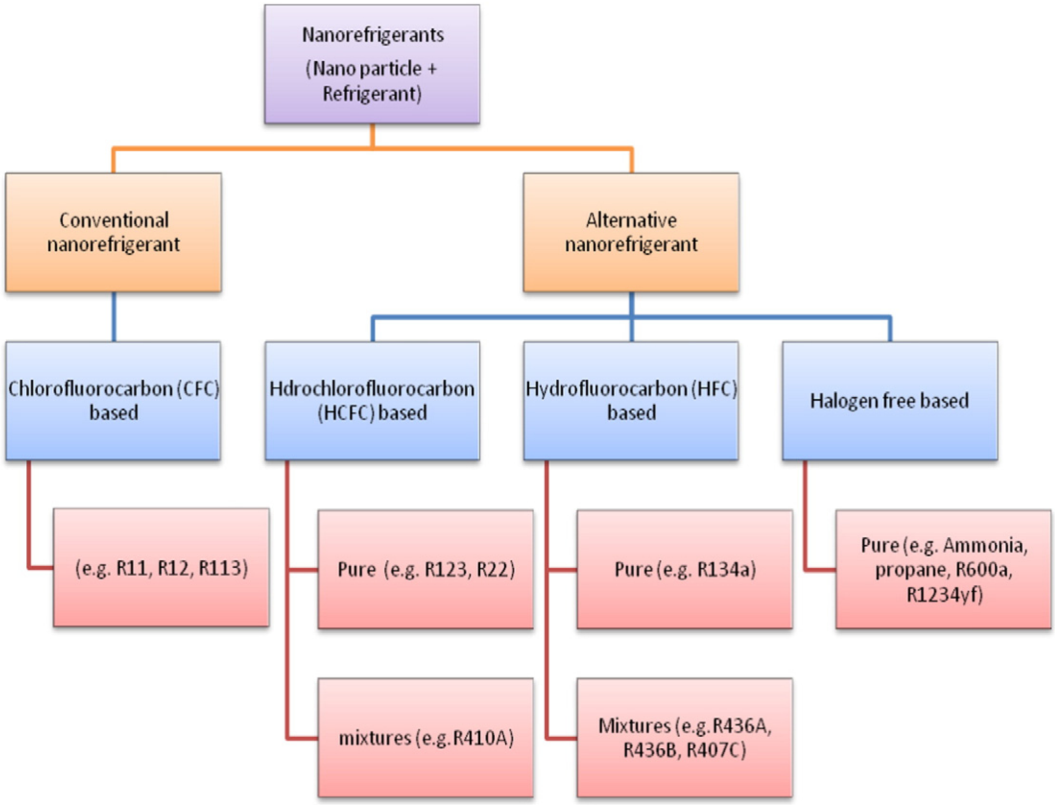

Fig. 1. Nanorefrigerants classification according to refrigerant based.

examples of CFC based nanorefrigerants that contain chlorine. The alternative based nanorefrigerants are divided into three categories; hydrochlorofluorocarbon (HCFC) based, HFC based and halogen free based nanorefrigerants. Table 1 shows the main characteristics of the selected refrigerants.

Even though CFC was banned, there are still few nanorefrigerants scholars that carried out their research based on this refrigerant [5,8,9], as the nanorefrigerants are easily prepared in the liquid state with atmosphere pressure and room temperature. Naphon et al. [8] studied R11 nanorefrigerant based and mixed with Titanium (Ti) in order to observe the heat pipe efficiency. While Peng et al. [9,5] used the R113 refrigerant base mixed with Copper oxide (CuO) to study the frictional pressure drop and heat transfer characteristic flow boiling inside a horizontal smooth tube. Other researchers focused on HCFC nanorefrigerant bases in their study [6,10,11]. Sun and Yang [6] used R141b in the evaluation of the flow boiling heat transfer characteristics of R141b/Cu, R141b/Al, R141b/Al_2O_3, and R141b/CuO in an internal thread copper. Mahbubul et al. [10] investigated the viscosity of HCFC refrigerant R123 mixed with TiO_2 nanoparticles. Meanwhile, Tang et al. [11] used R141b/δ-Al_2O_3 nanorefrigerants to study the pool boiling heat transfer characteristics of nanofluids in nucleate pool on a horizontal flat square copper surface. HFC is the most common refrigerant that was utilised. Moreover, HFC/134a has been accepted as an alternative refrigerant for long term use. Nowadays, most of the researchers are focused on HFC as their base in nanorefrigerant studies. Park and Jung [4] used R134a and R123 to study the effect of carbon nanotubes (CNTs) on nucleate boiling heat transfer. Mahbubul et al. [7] utilised R134a and mixed it with Al_2O_3 nanoparticle to investigate the thermo-physical properties, pressure drop and heat transfer performance of the nanorefrigerants. Bi et al. [12] investigated the reliability and performance of a domestic refrigerator with HFC/134a refrigerants mixed with TiO_2 and Al_2O_3 nanoparticles.

The use of nanoparticles dispersed in various types of refrigerant bases is known as nanorefrigerants and has been investigated by various researchers. Therefore, the objective of the present work is to provide a comprehensive review on the development of nanorefrigerants for various types of refrigerant bases and its performance. The augmentation of heat transfer and energy consumption reduction using nanorefrigerants is reviewed based on types of refrigerant. This study is divided into the types of nanorefrigerants in refrigeration systems. Furthermore, the

Table 1
The property characteristics for various types of refrigerants.

Properties	Unit	R141b [23]	R113 [5,9,16]	R123 [10]	n-pentane [20]	R134a [39,44]
Chemical formula	–	CH_3CCL_2F	$Cl_2FC\text{-}CClF_2$	$CHCl_2CF_3$	C5H12	CH2FCH3
Molecular mass	g/mol	116.95	187.37	153	72.15	102.03
Normal boiling point	°C	32.06	47.6	27.8	36.1	−26.1
Freezing point	°C	−103.5	–	107	–	–
Critical temperature	°C	204.50	214.1	184	196.4	101.1
Critical pressure	MPa	4.25	3.39	3.67	3.37	4.06
Density	kg/m^3	1220.30	1527	1458.8	606	1199.7
Thermal conductivity	W/mK	0.0888	0.06363	0.075862	–	0.09208
Dynamic viscosity	mPa s	0.3780	0.5375	0.40805	0.191	0.1905