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Experimental performance of LPG refrigerant charges with varied concentration of TiO_2 nano-lubricants in a domestic refrigerator

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A B S T R A C T

This article present an experimental investigation of varied mass charges of Liquefied Petroleum Gas (40 g, 50 g, 60 g and 70 g) enhanced with varied TiO_2 nanoparticle/mineral oil concentrations (0.2 g/L, 0.4 g/L and 0.6 g/L nano-lubricants) in a R134a compressor of a domestic refrigerator. Performance tests investigated at steady state included: pull down time, power consumption, compressor power input, cooling capacity and coefficient of performance (COP). Analysis was based on temperature and pressure readings obtained from appropriate gauges attached to the test rig. Refrigerant property characteristics were obtained using Ref-Prop NIST 9.0 software. Results obtained showed almost equal evaporator air temperatures and reduction in power consumption for all tested nano-lubricant concentrations except at 70 g charge of LPG using 0.6 g/L nano-lubricant. Furthermore, the lowest compressor power input was found to be 21 W and obtained using 70 g of LPG with either of 0.2 g/L or 0.4 g/L nano-lubricants. At 70 g of LPG using 0.6 g/L concentration of nano-lubricant, highest cooling capacity index of 65 W was obtained while the highest COP of 2.8 was obtained with 40 g charge of LPG using 0.4 g/L concentration of nanolubricant. In conclusion, LPG-TiO_2 nano-lubricant mixture works safely and efficiently in domestic refrigerators without modification of capillary tube length, but requires adequate optimization.

1. Introduction

Recently, the devastating effects of climate change have become a vivid discussion in world leaders meetings. UNEP 2015 gap report affirms concerns stating that the year 2014 emission index was 52.7 gigatonne carbon dioxide ($GtCO_2$) in variance to estimated safe target of 44 $GtCO_2$. Currently, deviation from average global temperature range, of 1.5–2 °C is experienced; hence, aggressive mitigation strategies are required [1]. Domestic refrigerators have been identified as an immense emission contributor globally, by both the Montreal and Kyoto protocols due to their chlorine or fluorine based working fluid (refrigerant). Classes of refrigerant compounds such as: chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs) were noted to be responsible for Ozone depletion (OD) and global warming effect [2,3]. There is thus the need for replacement that is

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Table 1
Specification of refrigerant classes.

S/N	Class	Refrigerant	Critical pressure (MPa)	Critical temperature (K)	OD potential (Yes/No)	GW potential	ASHRAE flammability classification
1	CFCs	R32	5.78	351.26	Yes	675	A2
		R22	4.99	369.3	Yes	1810	A1
2	HCFCs	R11	4.41	470.96	Yes	4750	A1
		R12	4.14	384.97	Yes	10900	A1
3	HFCs	R134a	4.06	374.21	No	1430	A1
		R152a	4.52	386.41	No	124	A2
4	HCs	R290	4.25	369.89	No	3	A3
		R600a	3.63	407.81	No	4	A3
6	HC Blend	R436a	4.27	389.04	No	3	A3

environmentally friendly [see Table 1]. Detailed retrofit assessment of past conventional refrigerants with natural refrigerants, especially hydrocarbons due to considerations for environmental and system efficiency optimization can be found in Calm [4]. Recently, workability of hydrocarbons including LPG in existing domestic refrigeration system, with or without slight modification and their high energy efficiency has been the major justification for their application in domestic refrigerators [5–10]. In spite of the fact that flammability of hydrocarbons has been a major concern, maximum charge limit of 150 g has been recommended as a safe limit charge for hydrocarbon refrigerant in domestic refrigerators irrespective of their location [11].

Applications of nanoparticle in refrigeration systems using hydrocarbons have been found to improve their efficiency considerably. Numerous experimental investigations have been performed recently [12]. Venkataramana et al. [13], experimentally studied the effect of using 0.1 g/L TiO_2 nanoparticle and mineral oil mixture as replacement for POE (polyol-ester) oil in a vapour compression domestic refrigerator, charged with different refrigerants (R436A, R436B and R134a), and observed under varied ambient temperature conditions. The reported results showed improved irreversibility and energy efficiency indexes. In the work of Tao et al. [14], the performance of a domestic refrigerator system using varied nano-oil compositions ($MoFe_2O_4$-$NiFe_2O_4$ nanoparticle added with and without fullerene nanoparticle addition in mineral oil) alongside different refrigerant types including: R134a and R600a, were experimentally investigated. Result showed identical behaviour for R134a refrigerant and 5.33% improved coefficient of performance (COP) for R600a refrigerant when working with $MoFe_2O_4$-$NiFe_2O_4$ nano-oil composition. However, research work involving the performance of nanoparticle behaviour in naturally occurring hydrocarbon mixtures like liquefied Petroleum Gas (LPG) is very sparse. This work thus presents an experimental energetic and efficiency study of varied TiO_2 nanoparticle concentrations in mineral compressor oil and varied LPG charges in a domestic refrigerator system.

2. Methodology

2.1. Experimental rig and environment

A 50 l domestic refrigerator originally charged with R134a was employed for this experimental investigation. Technical specification and Instrumentation of the test rig can be found in Table 2 and Fig. 1. The experiment was carried out in a conditioned laboratory space having an ambient temperature range of 29–32 °C controlled using a 10 t HP air conditioner and monitored using Rototherm surface temperature thermometers. The uncertainty and measurement range of measuring instruments such as digital thermocouple K used to observe suction (T_1), discharge (T_2), condensing (T_3) and evaporator air (T_{AIR}) temperatures and digital pressure gauges for suction and discharge pressures (P_1 and P_2) while power consumption of the refrigerator was monitored using a digital wattmeter (see Table 3 for measuring instrument details).

Table 2
Specification of the test rig.

S/N	Components	Units
1	Evaporator Size	50 l
2	Refrigerant type	R134a
3	Compressor type	HFC
4	Defrost Type	Manual
5	Power rating	80 W
6	Frequency rating	50 Hz
7	Freezing power	6 kg/24 h
8	Condenser type	Air cooled
9	Door type	Single