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Comparative performance analysis of the low GWP refrigerants HFO1234yf, HFO1234ze(E) and HC600a inside a roll-bond evaporator

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ABSTRACT

This paper presents the comparative performance analysis of the low GWP refrigerants HFO1234yf, HFO1234ze(E) and HC600a inside a commercial roll-bond evaporator for household refrigerators. The vaporisation performances were evaluated at two evaporation temperatures, −15 and −20 °C, and different refrigerant mass flow rates and compared with those of the traditional refrigerant for domestic refrigeration HFC134a. The performance analysis was carried out using both thermocouples installed on the rear side of the roll-bond evaporator and an IR thermo-camera. Each of the low GWP refrigerants tested can be considered a good substitute for HFC134a, provided that the compressor displacement is adjusted to deliver the proper refrigerant mass flow rate. Only HFO1234yf exhibits performance similar to HFC134a at the same mass flow rate, therefore it can be considered a direct drop-in substitute for HFC134a.

Analyse comparative de la performance des frigorigènes à faible GWP, HFO1234yf, HFO1234ze(E) et HC600a dans un évaporateur à plaque et serpentin

Mots clés : GWP ; Frigorigènes ; Evaporateur ; Réfrigérateurs domestiques ; Analyse infrarouge

1. Introduction

The global annual production of domestic refrigerators and freezers is more than 80 million units (Björk et al., 2010) and a great number uses roll-bond type evaporators. The roll-bond evaporator consists of a plate formed by two powder-coated aluminium sheets, with channels in which the refrigerant evaporation takes place, while air natural circulation occurs at the outer side. Despite that, only few scientific studies are focused on this component, while a greater number of works examine the whole refrigerator system (James et al., 2008).

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Nomenclature

A	surface area (m^2)
f.s.	full scale (–)
h	heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
j	specific enthalpy ($J\ kg^{-1}$)
k	coverage factor (–)
K	overall heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
L	roll-bond length (m)
m	mass flow rate ($kg\ s^{-1}$)
M	molar mass ($kg\ kmol^{-1}$)
p	pressure (bar)
p^*	reduced pressure (–)
q	heat flux ($W\ m^{-2}$)
Q	heat flow rate (W)
R	refrigerant mass flow rate ratio
R_p	roughness (μm)
T	temperature (°C)
W	roll-bond width (m)
X	refrigerant vapour quality (–)

Subscript

a	air
c	condensation
e	evaporation
in	inlet
IR	infrared
max	maximum
out	outlet
r	refrigerant
sub	sub-cooling

Da Silva et al. (1999) measured the heat transfer performance of a plate-type-evaporator varying the position in the food compartment of a domestic refrigerator. Porkhial et al. (2004) studied the transient performance of a round-bound evaporator in a household refrigerator with variable speed compressor. Björk and Palm (2006) reports experimental results of an ON/OFF cycling domestic refrigerator at varied expansion device capacity, quantity of charge and ambient temperature. Björk and Palm (2008) investigated the flow boiling heat transfer in a plate-type-evaporator of a typical domestic refrigerator varying the mass flux, the heat flux and the inlet vapour quality. Hermes et al. (2008) developed a mathematical model to investigate the thermal behaviour of a roll-bond evaporator based on an experimental study.

In the last years variable speed compressors have been applied to several refrigeration systems and this technology is going to be applied also to domestic refrigerators. Traditional domestic refrigerators were based on ON-OFF control and several works are available in the open literature concerning this type of regulation, for example Porkhial et al. (2004), Hermes et al. (2008), and Berger et al. (2012). Only few studies investigate the dynamics of variable speed compressor refrigeration systems. For example Piedrahita-Velasquez et al. (2014) found that a variable speed compressor refrigeration unit allows 15% energy saving with respect to an equivalent conventional refrigerator system ensuring also a more stable temperature control.

The European Commission has recently approved a new release of the F-Gas regulation (Regulation (EU) No 517/2014), stating that refrigerants with GWP > 150 cannot be anymore used in new domestic refrigerators starting January 2015. According to Öko-Recherche (2011), although HFC emissions are trending downward in the domestic refrigerators and freezer sector, additional measures that ban the placing on the market of HFC-based equipment would ensure that this trend is not reversed and prevent a further 285 kt/CO2-eq. emissions through 2050. So it is mandatory to find a suitable low GWP substitute for HFC134a, which dominates this type of application and exhibits a GWP around 1430.

HydroCarbons (HC) refrigerants, such as HC600a (Isobutane) and HC290 (Propane), are widely used in small domestic refrigerators and drink-coolers especially in Europe and in Asia. In the literature it is possible to find some performance comparisons between HFC134a and pure hydrocarbons or hydrocarbon mixtures. For example: Jung et al. (2000) investigated Propane/Isobutane mixture, Fatouh and El Kafafy (2006) considered Propane/Butane mixture, Rasti et al. (2012) and (2013) considered a mixture Propane/Isobutane named R436a, Mohanraj et al. (2009) investigated Propane/Isobutane system, Mohanraj (2013) considered a mixture R152a/Isobutane named R430A, and Joybari et al. (2013) analysed Isobutane. In all these works it is possible to appreciate a slight performance enhancement and a reduction of the optimum amount of refrigerant charge for hydrocarbons with respect to HFC134a, however hydrocarbons are flammable and in some countries their use in domestic refrigerator is forbidden.

An interesting low GWP substitute for HFC134a is HFC152a, the unique HFC refrigerant with a GWP lower than 150 showing working pressures suitable for use in household appliances. Bolaji (2010) experimentally investigated the substitution of HFC134a with HFC152a and HFC32 in domestic refrigerators. The performance of HFC152a was constantly better than those of HFC134a and HFC32 both under cooling capacity and COP point of view.

The HydroFluoroOlefin (HFOs) refrigerants, especially HFO1234yf and HFO1234ze(E), are other suitable candidates for HFC134a replacement in domestic and small refrigerators. Yana Motta et al. (2010) found that both HFO1234yf and HFO1234ze(E) were suitable for drop-in replacement of HFC134a in small refrigerators. Karber et al. (2012) experimentally investigated the performance of HFO1234yf and HFO1234ze(E) as drop-in replacements for HFC134a in domestic refrigerators. HFO1234yf exhibits COP and cooling capacity similar to HFC134a, whereas HFO1234ze(E), although it performs favourably in term of COP, has a cooling capacity significantly lower than HFC134a and therefore it is unsuitable for direct drop-in replacement of HFC134a. Leighton et al. (2012) developed a simulation model of a commercially available HFC134a household refrigerator to evaluate the drop-in performance of several low GWP alternative refrigerants. HFO1234yf seems to be the most promising direct drop-in replacement for HFC134a in domestic refrigeration.

This paper presents the comparative performance analysis of the low GWP refrigerants HFO1234yf, HFO1234ze(E) and HC600a inside a commercial roll-bond evaporator for household refrigerators.