Applied Thermal Engineering 50 (2013) 260–267

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Energy influence of the IHX with R22 drop-in and long-term substitutes in refrigeration plants

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HIGHLIGHTS

- ► Three substitutes of HCFC-22 in compression refrigeration plants are analysed.
- ► A reduction in capacity and COP exist when using HCFC-22 substitutes.
- ► Using an IHX is positive to shorten the reductions.
- ► Usual criteria to select the IHX remain valid with the new refrigerants.

ARTICLE INFO

Article history:
Received 6 October 2011
Accepted 4 June 2012
Available online 12 June 2012

Keywords:
HCFC replacements
Drop-in refrigerants
Internal Heat Exchanger
Energy efficiency
R22

ABSTRACT

This work focuses on the investigation of new drop-in or long-term refrigerants for low evaporating temperatures that can be used as substitutes for HCFC-22, which is gradually being phased-out. This process is already in progress in European countries (Regulation CE-1005/2009) and has been accelerated in Article 5 Countries of the Montreal Protocol. Specifically, in this work the energy influence of the suction line/liquid line heat exchanger on the new substitute fluids is addressed from an experimental approach.

The study has been based on experimental measurements in a single-stage vapour compression refrigeration plant, which has been tested in the same external conditions operating with and without an Internal Heat Exchanger (IHX). The energy influence of the IHX working with R22 and three potential substitutes for low temperature applications, the chlorine-free drop-in fluids R417B and R422A and the chlorine-free long-term substitute R404A has been analysed.

From the experimental results, reductions in capacity and COP have been observed when R22 is replaced by the drop-in fluids, although the presence of an IHX can help to lessen these reductions. Furthermore, the criteria that are usually employed to determine the energy advantage or disadvantage of the use of the IHX with the new refrigerants have been tested, the results confirming that they remain valid for them.

1. Introduction

The world community has committed itself to eliminating the refrigerant HCFC-22 to a series of deadlines in accordance with the agreements reached during the 19th Montreal Protocol meeting in September 2007 [1]. The first involves European countries, where Regulation CE-1005/2009 has banned the use of virgin HCFC-22 as of 31st December 2009 and only allows existing equipment to be refilled with this refrigerant up to 31st December 2014 if it is recycled. The second is for non-Article 5 countries, whose time limit is 2020, and finally 2040 for Article 5 countries. In 2009, this refrigerant, R22, accounted for around 97 per cent of the total amount of HCFC substances used in the refrigeration and air-conditioning sectors [2] and it is supposed there will be a shortage of this refrigerant in the near future because of the accelerated phase-out and the need to refill these systems due to maintenance operations.

At the moment, there are three options available to be able to keep using R22 plants after 2010: use recycled R22, replace it by new drop-in refrigerants or undertake a retrofit process with a long-term R22 substitute. All the options have their advantages and disadvantages, the best possible solution being determined by a combination of the positive properties of R22 that match the system under consideration, as shown in Table 1 [3].

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http://dx.doi.org/10.1016/j.applthermaleng.2012.06.008

Nomenclature

c_p	specific isobaric heat capacity (kJ kg^{-1} $°C^{-1}$)
COP	coefficient of performance
C_r	flow stream capacity ratio
NTU	number of transfer units
T	temperature (°C)
ΔT_v	temperature increase of the vapour in the IHX (°C)
p	pressure (kPa)
$\dot{Q}_o$	cooling capacity (kW)
q_o	specific refrigerating effect (kJ kg^{-1})

Greek symbols

ν	specific volume (m^3 kg^{-1})
ε	IHX thermal effectiveness
λ	latent heat of phase change (kJ kg^{-1})
Δ	increment

Subscripts

exit	exit of the element
k	condenser
l	saturated liquid
l,in	liquid inlet to the IHX
max	maximum
min	minimum
o	evaporator
suc	compressor suction
v	saturated vapour
v,in	vapour inlet to the IHX
g,o	secondary fluid of the evaporator
w,k	secondary fluid of the condenser

Superscripts

IHX	parameters when the IHX is used

Recycled R22 should be taken seriously into consideration as the best alternative for systems with a short remaining life, since it will cause the fewest problems during further temporary operation.

Drop-in, however, is understood as the pure exchange of the refrigerant without the need for any major retrofitting work in the refrigeration cycle, in particular the existing lubricant oil, which can remain in the refrigeration cycle and be used together with the new drop-in refrigerant. Drop-in refrigerants are an interesting alternative to the recycled fluid for plants with medium-length remaining lives. Nonetheless, the main drawback of using drop-in refrigerants is that the refrigerating capacity and the COP of the system can be reduced, as were analysed by Torrella et al. [4] and Llopis et al. [5,6]. In air-conditioning, R422D (61.1%-R125/31.5%-R134a/3.4%-isobutene, in mass) and R417A (46.6%-R125/50%-R134a/3.4%-butane, in mass) are two of the most widely recommended fluids, which were analysed by Fernández-Seara et al. [7], Rosato et al. [8], Aprea et al. [9] and Torrella et al. [4]. In refrigeration at low temperatures, however, two of the most recommended drop-in fluids are R422A (Table 2) and R417B (Table 2), which were analysed by Llopis et al. [5] in a double-stage refrigerating plant.

On the other hand, the retrofitting process is understood as an active adaptation of the refrigeration system to the new long-term R22 substitute. This is often done with the complete exchange of the compressor's oil and an overhaul of the whole system. A retrofit is only reasonable when longer remaining lives are envisaged, the availability of the plant is of importance (e.g. as part of an industrial process) and changeover and operation costs are of relevance.

Finally, there is an additional solution, that is, the complete renewal of the system by replacing it with a new one that promises greater advantages with regard to efficiency and safety. However, the investment cost is higher than in the previous possibilities and is often a difficult alternative due to spatial or procedural reasons.

In this communication, which analyses the performance of R22 substitutes in a single-stage vapour compression refrigeration plant, the drop-in fluids R417B and R422A have been tested, together with one of the fluids used for the retrofitting process at low evaporating temperatures: the R404A. With regard to this last fluid, the only modification required by the plant was the substitution of the thermal expansion valve, since all the refrigerants operated with the same POE lubricant oil. The main properties of the refrigerants analysed in this work are detailed in Table 2.

Regarding the use of an Internal Heat Exchanger (IHX), from an initial comparison of the thermodynamic cycles, it can be seen that the main performance implications of the adoption of an IHX are both positive and negative [12]. The main benefits of the liquid-line/suction-line heat exchanger are: an increase in the refrigerating effect in the evaporator, ensuring subcooled liquid refrigerant at the inlet of the expansion device, and minimization of the risk of the presence of liquid refrigerant at the compressor inlet. On the other hand, the possible disadvantages can be: the increase in the specific suction volume at the entrance to the compressor, a decrease in the refrigerant mass flow rate, an increase in the compressor discharge temperature, increased pressure drops in

Table 1
Options for R22 substitution [3].

Option	Remaining life		Evaporator		Cost	
	<5 yr.	>5 yr.	Dry DX	Flooded	Investment	Operation
Recycled R22	+ +	−	+ +	+ +	+ +	+
Drop-in	+ +	+	+	−	+ +	−
Retrofit	−	+	+	+ +	+	+

Table 2
Physical, environmental and safety characteristics of R22, R422A, R417B and R404A [10,11].

Composition (% wt)	HCFC-22	HFC-422A		HFC-417B		HFC-404A	
	$CHClF_2$	85.10%	R125	79.00%	R125	44.00%	R125
		11.50%	R134a	18.25%	R134a	4.00%	R134a
		3.40%	R600a	2.75%	R600	52.00%	R143a
Molecular weight (g mol^{-1})	86.47	113.60		113.07		97.60	
Normal boiling point (°C)	−40.81	−44.03		−41.51		−46.2	
Critical temperature (°C)	96.14	71.73		75.18		71.0	
Critical pressure (bar)	49.90	37.46		37.78		37.29	
Glide[a] (°C)	0.00	2.46		3.43		0.75	
λ (T = −30 °C)	226.81	167.44		172.70		189.51	
λ (T = 40 °C)	166.60	104.80		111.17		120.26	
ODP	0.05	0.00		0.00		0.00	
$GWP_{100\ years}$	1810	3100		3027		3921	
ASHRAE safety group	A1	A1		A1		A1	

[a] Glide evaluated at saturation temperatures under standard atmosphere pressure (101.325 kPa).