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New positions for an internal heat exchanger in a CO_2 supercritical refrigeration plant. Experimental analysis and energetic evaluation

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HIGHLIGHTS

- A CO_2 refrigerating plant working in supercritical conditions has been tested.
- Two different positions for an IHX have been experimentally analyzed.
- An improvement up to 13% in COP, and up to 12% in cooling capacity, has been reached.
- Regardless the position, a reduction up to 3.65 bar in the optimal rejection pressure has been reached.

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ABSTRACT

IHX is probably, one of the most commonly alternative used to improve cooling capacity and COP in a CO_2 refrigerating plant working in supercritical conditions. The "classical" position at gas-cooler exit has been analyzed by several authors with positive results. The aim of this work is to compare, from experimental approach, the energetic behavior of a refrigerating plant working with several IHX configurations: gas-cooler exit (classical position), liquid receiver exit, and in both positions at the same time. The energetic behavior includes: cooling capacity, power consumption and COP. Moreover, the discharge temperature reached on each position has been analyzed.

From the experimental results, a general improvement in COP and cooling capacity has been observed regardless the position of the IHX. A maximum increment of 13% on COP has been registered working with two IHX at the same time.

1. Introduction

An internal heat exchanger (IHX) or suction to line heat exchanger (SLHX) is a safety device used in refrigerating plants to ensure liquid before entering the expansion device and to avoid liquid at compressor inlet, specially using open-type compressors. As several authors such as Gosney [1] or Radermacher and Hwang [2] have been described and analyzed, the IHX operation allows a heat transfer between liquid and suction line which reduces temperature at inlet expansion device and introduces an extra superheating at suction line. As a consequence of both effects an increment on specific cooling capacity and specific compression work is reached. The combination of both effects could improve or worsen refrigerating cooling capacity and COP, according with the refrigerant, working conditions and IHX dimensions. Domanski and Didion [3] and Aprea et al. [4], developed several simplified criterions to determine the suitability of the use of an IHX in a refrigeration plant according with the refrigerant. Cabello et al. [5] compared, from the experimental point of view, the behavior of a refrigeration plant working with and without IHX according to several R22 drop-in and long-term substitutes. Klein et al. [6] also compared, from theoretical point of view, the influence of the IHX over a range of operating conditions using different refrigerants. Kim et al. [7] and Cho et al. [8] analysed the performance of a transcritical CO_2 refrigerating plant working with IHX varying its length.

Working with CO_2 supercritical cycle, IHX is used, in most of cases, as an element to improve COP and cooling capacity. Several authors have been evidence experimentally and theoretically its improvement according with the classical configuration at gas-cooler exit (Fig. 1). Torrella et al. [9] registered an improvement up to 12% in cooling capacity and COP using water as secondary

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Nomenclature

COP	coefficient of performance
h	enthalpy (kJ kg^{-1})
$\dot{m}$	mass flow rate (kg s^{-1})
N	compressor rotation speed (rpm)
P	pressure (bar)
P_C	compressor power consumption (kW)
$\dot{Q}$	heat transfer rate (kW)
$\dot{q}$	volumetric flow rate (m^3 h^{-1})
SH	superheating (K)
T	temperature (°C)
w	specific compression work

Greek symbols

η	compression global efficiency
Δ	increment

Subscripts

IHX	internal heat exchanger
C	compressor
dis	discharge
ev	evaporator
GC	gas-cooler
glic	water and water/ethylene–glycol mixture
in	inlet/inner
opt	optimum
out	outlet/outer
s	isentropic
suc	suction
w	water

fluid; Aprea and Maiorino [10] reached an improvement in COP up to 10% using air as a heat rejection fluid; Boewe et al. [11] noticed that both the capacity and COP could be increased by up to 25% using IHX in a mobile A/C sytem; Pérez-García et al. [12] compare from a theoretical point of view several CO_2 transcritical configurations recommending the use of the IHX at high gas-cooler outlet temperatures. Nevertheless if a double-stage expansion system is installed, for example in large commercial applications such as supermarkets, three ways to install the IHX is feasible. The first one corresponds with the classical one where IHX is installed previously to the first expansion stage (Fig. 1). The second one installs the IHX previously to the second expansion device (thermostatic valve) (Fig. 2), which is different to the previous one since the IHX high pressure side is working with a subcritical refrigerant liquid. Finally, the last configuration works with both IHX running at the same time (Fig. 3) which allows two IHX working with different fluids: supercritical and liquid.

Taking into account the different configurations, the main objective of this paper is to evaluate the energy performance of the different ones taking as a reference the refrigeration cycle without IHX (Fig. 4). The experimental analysis compares cooling capacity, electrical power consumption, discharge temperature and the maximum COP at different working conditions. According with this, the work has been organized as follows: In Section 2 a description of the experimental refrigeration plant used in this paper and experimental methodology applied, are shown; Section 3 is focused on presenting the results of the different configurations, and finally Section 4 summarizes the main conclusions of the work.

2. Experimental plant and tests

In this section a description of the experimental refrigeration plant and the experimental methodology applied, is presented and commented. Additionally, a complete tests summary is also shown.

2.1. Experimental facility

The experimental plant used to carry out the present work corresponds to a single-stage vapor compression plant commonly used in commercial applications (Fig. 5). The main components installed are: a one-stage semi-hermetic reciprocating compressor (A) with a displacement of 3.5 m^3/h (1450 rpm); two concentric CO_2–water heat exchangers in counter current layout: gas-cooler (B) and evaporator (H); and a two-stage expansion system set up by a presostatic expansion valve (back-pressure) (D), and an electronic expansion valve working as a thermostatic (G) with the thermal sensor placed at the evaporator exit. The first expansion device (presostatic valve), regulates the gas-cooler pressure through expanding supercritical refrigerant over a liquid receiver (E) which allows liquid-phase at the inlet of the second expansion device (thermostatic valve). At the same time, the second expansion device controls the useful superheating at the evaporator.

The internal heat exchanger (IHX) used in Figs. 1–3 (C, D), is an internally corrugated tube-in-tube heat exchanger with counter current layout. In contrast with the traditional arrangement, the high pressure refrigerant flows through the inner tube whereas the vapor refrigerant flows through the annulus between the inner and outer tubes. This arrangement allows more

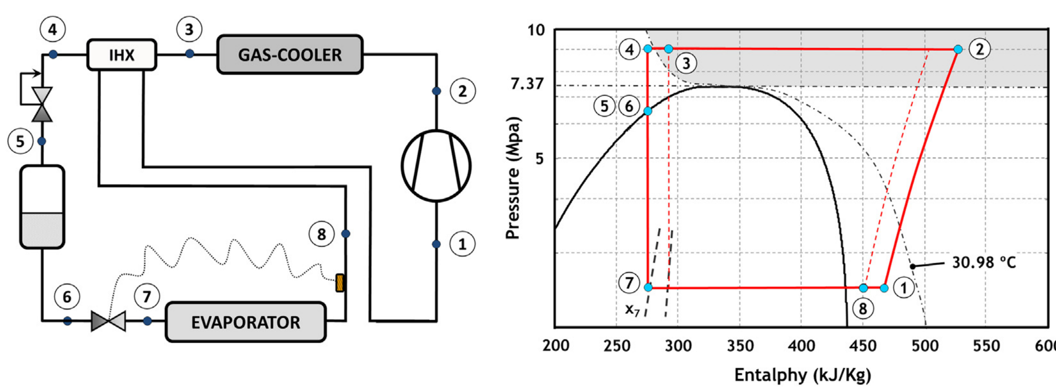

Fig. 1. Internal heat exchanger at gas-cooler exit.