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Experimental analysis of energy performance of modified single-stage CO_2 transcritical vapour compression cycles based on vapour injection in the suction line

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ABSTRACT

This work presents the experimental evaluation of the energy performance of a modified single-stage CO_2 transcritical refrigeration plant with an internal heat exchanger (IHX) based on vapour injection in suction line. This modification, which is only applicable to refrigeration plants with an expansion process divided in two stages with a liquid receiver between them, consists of extracting saturated vapour from the liquid receiver in order to: decrease the vapour quality at the evaporator inlet, and reduce the superheating degree at the compressor suction by means of the expansion and following injection of the extracted refrigerant. Three different injection points have been evaluated experimentally: before the IHX, after the IHX and just before the suction chamber of the compressor. The experimental measurements show that the cooling capacity and COP can be enhanced in 9.81% and 7.01%, respectively. Furthermore, a reduction in the discharge temperature of the compressor up to 14.7 °C has been measured inside the evaluation range.

1. Introduction

One of the most important drawbacks for CO_2 transcritical vapour compression cycles is its lower COP in comparison with the values achieved by conventional subcritical cycles using HFCs or HC as working fluids when the heat is rejected to medium and hot environmental temperatures. However, its safety and environmental properties [1] and its high heat transfer coefficients [2] make CO_2 one of the possible alternatives to the HFCs, especially in heat pumps [3] or in applications with important leakage rates, such as mobile air conditioning and commercial refrigeration [4].

Efficiency improvement of CO_2 transcritical vapour compression cycles has been tackled from two points of view: First, focussing on the optimization of the components of the plants, such as compressors [5], heat exchangers, expansion devices [6], etc… Second, trying to improve the COP by means of modifications of the basic thermodynamic cycle, for example the introduction of IHXs, as done by Torrella et al. [7], Aprea and Mariorino [8] or Zhang et al. [9] which all demonstrated its possibilities, or using two-stage compression systems [10] to benefit the compression process.

The aim of this work is to present the experimental evaluation of a modified CO_2 single-stage transcritical vapour compression cycle, with a two-stage expansion system (Fig. 1). The modification, consists of extracting saturated vapour from the liquid receiver placed between expansion stages (point 7, Fig. 1), and the subsequent injection of the expanded vapour in suction line. The effect of this cycle modification on the Ph diagram is shown in Fig. 1.

As can it be deduced from the Ph diagram (Fig. 1), as more quantity of vapour is extracted from the receiver, lower the liquid receiver pressure, lower the evaporator inlet enthalpy and lower the compressor suction temperature will be. However, all those positive effects are counteracted by a reduction of the refrigerant mass flow rate through the evaporator, since a part of them is extracted from the receiver. The interaction between these opposite effects will lead to an increase or to a reduction of the cooling capacity and the COP of the refrigeration cycle.

This experimental study intends to contribute to the understanding of the possibilities of enhancing the performance of CO_2 single-stage transcritical vapour compression cycles with small cycle modifications. For the first time, this study focuses on the analysis of a modified CO_2 transcritical single-stage double expansion cycle based on the extraction of refrigerant from the intermediate liquid receiver. In this work, three different injection points of the extracted refrigerant have been analysed

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