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Theoretical evaluation of trans-critical CO_2 systems in supermarket refrigeration. Part I: Modeling, simulation and optimization of two system solutions

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ABSTRACT

Using CO_2 trans-critical system solutions in supermarket refrigeration is gaining interest with several installations already running in different European countries. Using a computer simulation model, this study investigates the performance of two main system solutions: centralized with accumulation tank at the medium temperature level and parallel with two separate circuits for low and medium temperature levels. Both system solutions are presented and the simulation model is described in details. Calculations have been performed to design the systems and optimize their performances where basic layout and size of each solution have been defined. For ambient temperature range of 10–40 °C, the reference centralized system solution shows higher COP of about 4–21% than the reference parallel solution. Using two-stage compression in the centralized system solution instead of single stage will result in total COP which is about 5–22% higher than that of the reference centralized system and 13–17% higher than that of the improved two-stage parallel system. The two-stage centralized system solution gives the highest COP for the selected ambient temperature range.

Evaluation théorique des systèmes frigorifiques de supermarché au CO_2 transcritique. Partie I : modélisation, simulation et optimisation de deux solutions

Mots clés : Système frigorifique ; Supermarché ; Système à compression ; Dioxyde de carbone ; Cycle transcritique ; Système biétagé ; Réservoir ; Modélisation ; Simulation ; Optimisation

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Nomenclature

C	heat capacity rate ($W K^{-1}$)
COP	coefficient of performance
CR	circulation ratio
dT	temperature difference (°C)
DX	direct expansion
IHE	internal heat exchanger
P_1	condensing pressure (bar)
P_2	evaporating pressure (bar)
T	temperature (°C)
T_1	condensing temperature/gas cooler exit temperature (°C)
T_2	evaporating temperature (°C)
x	vapor quality
ε	heat exchanger effectiveness
η	efficiency

Subscript

air	for air
amb	ambient
app	approach temperature
c	cold fluid
Equal,PR	equal pressure ratios
gc	gas cooler
h	hot fluid
i	in
inter	intercooler
is	isentropic
L	low temperature/freezer
min	minimum
o	out
opt	optimum
product	for product
product,air	temperature difference between product and air

1. Introduction

The three main solutions where CO_2 is applied in supermarket refrigeration are the indirect, cascade and the trans-critical systems. The indirect system solution with CO_2 as secondary fluid is used for low temperature applications where pressure levels are reasonably low and conventional components can be used. In recent years, components for CO_2 became more available which paved the way to install cascade and trans-critical systems in supermarkets. The cascade arrangement implies that a temperature difference will exist in the cascade condenser, which decreases the evaporating temperature on the high stage and reduces its COP. An efficient trans-critical CO_2 system will by pass the need for the cascade condenser, which may improve the COP. In order to evaluate CO_2 trans-critical system solution against other alternatives, such an efficient CO_2 system should be defined.

It is not practically hard to measure the performance of a field installation but it is difficult to compare two real field installations since operating parameters, system requirements and ambient conditions are not usually identical. Therefore, a computer simulation model seems to be a convenient tool as a first step in the direction of evaluating the trans-critical solution.

The two main possible system solutions where CO_2 can be used in supermarket applications are the parallel and centralized arrangements. As can be seen in Fig. 1, the parallel solution consists of two separate circuits: one serves the medium temperature level cabinets and the other serves the freezers. Direct expansion (DX) is applied on both temperature levels and two-stage compression is used for the low temperature circuit. This will decrease the discharge temperature, minimize losses in the compression work, and reduce the enthalpy difference across the compressors. Since the temperature lift is presumed to be small on the medium temperature circuit, single stage compression is used. System with similar solution has been presented by Girotto et al. (2003).

In the centralized system solution, Fig. 2, the three circuits in the system merge in the accumulator/tank. Thereby, in this solution the medium temperature cabinets' evaporators are flooded with CO_2 which is circulated by a pump while DX is used in the freezers. Compression on the high stage is done in one stage. Similar system has been discussed and investigated by Schiesaro and Kruse (2002).

The parallel system seems to be more applicable mainly due to its similarity to conventional DX systems. The fact that there are two separate circuits makes it more convenient

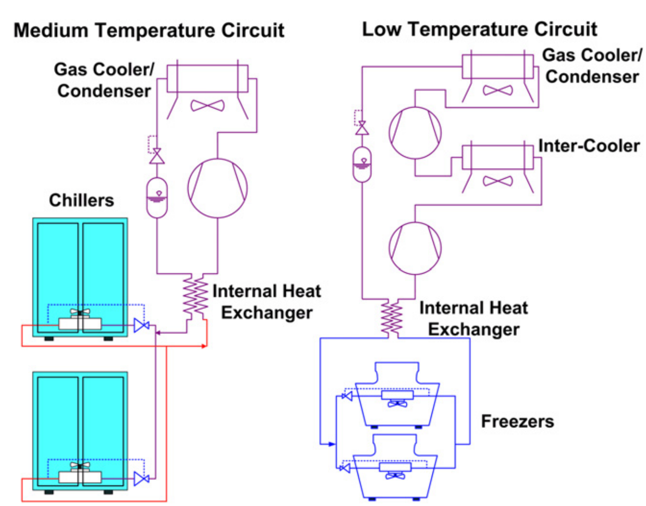

Fig. 1 – Parallel system solution with single stage compression on the medium temperature level with internal heat exchanger (IHE) on both circuits. Similar solution can be found in Girotto et al. (2003).