Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/ijrefrig

Optimal design of a light commercial freezer through the analysis of the combined effects of capillary tube diameter and refrigerant charge on the performance

Alessandro Pisano [a], *Santiago Martínez-Ballester* [a,*], *J.M. Corberán* [a], *Alfonso William Mauro* [b]

[a] *Universitat Politècnica de València, Instituto de Ingeniería Energética, Camino de Vera, s/n, Valencia 46022, Spain*
[b] *University of Naples "Federico II", Dept. of Industrial Engineering, P. le Tecchio 80, Napoli 80125, Italy*

ARTICLE INFO

Article history:
Received 23 July 2014
Received in revised form 26 December 2014
Accepted 28 December 2014
Available online 8 January 2015

Keywords:
Freezer
Optimization
Capillary tube
Refrigerant charge
Numerical

ABSTRACT

In this work, a discussion on a methodology to optimize the performance of a commercial freezer by using a simulation tool is presented. In order to provide a practical tool for deciding the best combination of refrigerant charge and capillary tube diameter, the results of the numerical studies are shown in the form of two-dimensional maps. The usefulness of this type of representation lies in the possibility of selecting the best operating point of the system, taking into account not only the efficiency or the power consumption but also the technical constrictions imposed by parameters such as the suction line temperature, the condenser subcooling, the evaporator superheat, and the run-time ratio. The discussion leads to the conclusion that the useful performance map is drastically reduced when all the operation requirements must be satisfied. Once the system design had been optimized, an additional numerical study, aimed at identifying the influence of the external conditions on the system behavior, was performed. The results show that the performance reduction can be effectively minimized modifying the refrigerant charge.

Conception optimale d'un congélateur commercial léger à travers l'analyse des effets combinés du diamètre d'un tube capillaire et de la charge en frigorigène sur la performance

Mots clés : Congélateur ; Optimisation ; Tube capillaire ; Charge en frigorigène ; Numérique

* *Corresponding author*. Tel.: +34 963 879 121; fax: +34 963 879 126.
E-mail address: sanmarba@iie.upv.es (S. Martínez-Ballester).
http://dx.doi.org/10.1016/j.ijrefrig.2014.12.023
0140-7007/

Nomenclature

A	heat transfer area (m^2)
CE	electric consumption (kWh/24 h)
COP	coefficient of performance
h	specific enthalpy (J kg^{-1})
$\dot{m}$	mass flow rate (kg s^{-1})
n	rotation speed (rev min^{-1})
$\dot{Q}$	thermal power (W)
$\dot{Q}_{load}$	heat gain (W)
T	temperature (K)
t	time (s)
U	overall heat transfer coefficient (W m^{-2} K^{-1})
V	volume (m^3)
$\dot{V}$	flow rate (m^3 s^{-1})
$\dot{W}$	power input (W)

Greek symbols

ρ	density (kg m^{-3})
η	efficiency (–)
η_v	volumetric efficiency (–)
τ	running time ratio

Subscripts

amb	ambient
comp	compressor
evap	evaporator
suct	compressor suction
dew	dew point
cabinet	refrigerator cabinet

1. Introduction

Growing interest in the problems concerning the exploitation of energetic resources and preservation of the environment is leading many researchers to identify technological solutions aimed at reducing both energy consumption and pollutant emissions. To this end, the application of natural refrigerants such as hydrocarbons instead of synthetic fluids in refrigeration systems is becoming a potential option. The former have good thermodynamic properties, but their flammability means more attention must be paid to refrigerant charge reduction in order to avoid fire risks in case of accidental leaks. As experimentally tested on several types of refrigerator systems by different authors (De Rossi et al., 2011; Kim et al., 2014; Kim and Braun, 2012; O'Neal and Farzard, 1990; Palmiter et al., 2011; Poggi et al., 2008), the variation of the refrigerant charge involves the reduction of the performance of a vapor compression system in terms of both energy efficiency and cooling capacity.

Usually, when designing the refrigerant loop of a freezer, the heat exchangers and compressor are selected first. These components have clear trends; for example, the larger the area of a heat exchanger is, the lower the temperature lift that we can achieve. A compressor with higher efficiency is always welcomed, but for a capillary tube and refrigerant charge there is not such a clear trend as there is for heat exchangers or compressors. Thus, the capillary tube and the refrigerant charge can be determined with an optimization process. Björk and Palm (2006) and Boeng and Melo (2014) studied experimentally the energy consumption of a household refrigerator when the expansion capacity of the capillary tube and the refrigerant charge were varied. They presented energy consumption maps identifying the optimum region of expansion device capacity (EDC) and refrigerant charge in order to minimize the consumption. Björk and Palm (2006) directly measured the energy consumption of the tested system during the cycling operation of the system, whereas Boeng and Melo (2014) estimated the energy consumption from the power consumption measured in steady-state tests (as proposed by Hermes et al., 2013).

In both works (Björk and Palm, 2006; Boeng and Melo, 2014), a needle valve placed at the condenser outlet was used to vary the EDC while considering its degree of opening as variable in the results. The use of a needle valve is due to practical reasons, that is, the need to easily handle different EDCs without requiring substitution of the capillary tube. The characterization of the valve was performed with nitrogen (Boeng and Melo, 2012), looking for a capillary tube with a certain diameter able to draw up the same nitrogen flow rate as the needle valve for a given degree of opening. Then, it is assumed that, considering the same operating conditions, the same refrigerant mass flow rate of the tested needle valve will flow in this equivalent capillary tube. This procedure is completely correct for adiabatic capillary tubes but, when a capillary tube–suction line heat exchangers (CT-SLHX) is used, the same procedure could be inappropriate since the heat transfer modifies the mass flow rate slightly with regard to the adiabatic tube. Liu and Bullard (1997) studied how the mass flow rate changed in a CT-SLHX when the position of the heat exchanger in contact with the suction line was varied while keeping the total capillary length and the heat exchanger length constant. The results showed variations of up to 45% in the mass flow rate when only the distribution of the lengths was changed.

In this work, a methodology to decide on the optimum combination of refrigerant charge and capillary tube by means of a simulation tool (IMST-ART, 2010) is proposed and discussed.

IMST-ART is a software for detailed simulation of a vapor compression system based on a semi-empirical model that applies a finite volume methodology (FVM) to discretize the heat exchangers. The model was validated (Pisano et al., 2012) with a set of experimental data obtained by testing a prototype of a commercial household freezer equipped with R290 (Mastrullo et al., 2012).

The results of the simulations are provided in terms of two-dimensional maps as a function of the capillary tube diameter and refrigerant charge but, in addition to the previous works, others considerations about the limitations introduced by technical parameters such as condenser subcooling, evaporator superheat, suction temperature, and run-time ratio are discussed and commented on. As it will be examined in depth later, these constrictions drastically reduce the useful region of the performance map and thus the ranges of refrigerant charge and capillary tube diameter that can be selected in reality.