international journal of refrigeration 34 (2011) 881–892

available at www.sciencedirect.com

ScienceDirect

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

Influence of the source and sink temperatures on the optimal refrigerant charge of a water-to-water heat pump

José-M. Corberán[*,1], *Israel Martínez-Galván, Santiago Martínez-Ballester, José Gonzálvez-Maciá, Rafael Royo-Pastor*

Instituto de Ingeniería Energética, Universidad Politécnica de Valencia, Camino de Vera s/n, Valencia 46022, Spain

ARTICLE INFO

Article history:
Received 3 December 2009
Received in revised form
12 August 2010
Accepted 12 January 2011
Available online 20 January 2011

Keywords:
Modelling
Heat pump
Chiller
Refrigerant
Charge
Distribution
Solubility
Oil

ABSTRACT

This paper presents the results of a study carried out to elucidate the influence of the source and sink temperatures on the optimal charge of a propane water-to-water 16 kW heat pump which does not incorporate any liquid receiver. The unit had been fully tested along a previous experimental study, at various refrigerant charges and different condensing temperatures. A detailed mathematical model was then employed to simulate the unit performance. The predicted results were in very good agreement with the experiments, and furthermore, showed the same trends found in a similar unit tested at the KTH (Sweden) when the evaporation temperature was progressively decreased. Then, the model was employed to study the influence of the source and sink temperatures on the optimal charge of the unit. The simulation showed that the great variation of the optimal charge with the variation of the evaporation temperature is mainly due to the variation of the amount of refrigerant in the compressor oil.

Influence des températures de la source et du puits thermique sur la charge en frigorigène optimale d'une pompe à chaleur eau-eau

Mots clés : Modélisation ; Pompe à chaleur ; Refroidisseur ; Frigorigène ; Charge ; Distribution ; Solubilité ; Huile

1. Introduction

Propane (R290) and several hydrocarbon blends have been commercialised and clearly demonstrated as alternative refrigerants with even higher efficiencies than R22 or R410A. Compared with CFCs, HCFCs and HFCs, hydrocarbon refrigerants offer zero ODP and extremely low GWP and, in regard to their performance, they offer, in general, high efficiency,

* *Corresponding author*. Tel.: +34 696483417; fax: +34 963877272.
E-mail address: corberan@ter.upv.es (J.-M. Corberán).
[1] Member of IIR B2 Commission.

0140-7007/$ – see front matter
doi:10.1016/j.ijrefrig.2011.01.009

Nomenclature

A	Cross section area (m^2)
$BPHE$	Brazed plate heat exchanger
$COP = \frac{\dot{Q}_{ev/cond}}{\dot{W}_{elec}}$	Coefficient of performance (–)
D_h	Hydraulic diameter (m)
E	Power input (W)
f	Friction factor (–)
g	Gravity (ms^{-2})
G	Mass velocity($kg\ s^{-1}\ m^{-2}$)
h	Heat transfer coefficient($W\ m^{-2}K^{-1}$)
i	Enthalpy($J\ kg^{-1}$)
$\dot{m}$	Mass flow rate ($kg\ s^{-1}$)
P	Perimeter (m)
p	Pressure (Pa)
$\dot{Q}_{ev/cond}$	Condenser or evaporator capacity (W)
S	Slip ratio (–)
T	Temperature (K)
u	Velocity ($m\ s^{-1}$)
$\dot{V}_s$	Swept volume flow (m^3s^{-1})
$\dot{W}_{elec}$	Compressor electrical consumption (W)
x	Quality (–)
z	Spatial coordinate (m)

Greek

α	Void fraction
η_c	Compressor efficiency
η_v	Volumetric efficiency
ξ	Heat losses ratio to the environment
Φ_f^2	Two phase friction multiplier
θ	Angle with horizontal
ρ	Density ($kg\ m^{-3}$)

Subscripts

f	Saturated liquid
g	Saturated vapour
i	Inlet, cell index
is	Isentropic
j	Cell index
l	liquid
o	Oulet
v	Vapour
w	Wall

reduced charge levels, and lower compressor discharge temperatures.

The only real factor deferring the application of hydrocarbon refrigerants in refrigeration and air conditioning equipment is the safety concern in handling relatively large amounts of flammable fluids. The development of highly efficient and minimum-charge units is then one of the crucial challenges for the future success of hydrocarbon-based refrigeration and air conditioning equipment. The propane unit of this study is able to produce around 16 kW heating or cooling with a propane charge around 450 g, leading therefore to a ratio of 28 g of required charge per kW of unit capacity.

The use of optimised minimum-charge units is an important issue in the development of future sustainable refrigeration and A/C equipment. The charge of the systems is directly related with the direct emissions of substances with high GWP in the case of using synthetic refrigerants, and of potential hazardous substances in the case of employing natural refrigerants as ammonia or hydrocarbons. On the other hand, minimisation of charge cannot be realised in detriment of the COP of the systems since lower efficiencies imply higher electricity consumption and therefore higher CO_2 global production. An integral optimisation of both the equipment design and charge is therefore necessary to lead to the minimum CO_2 global emissions.

A good understanding and modelling of the distribution of the charge among the different components of a refrigeration unit and the influence of the charge on the unit performance are essential to better design and charge future equipment.

Optimum refrigerant charge and refrigerant distribution received little attention in the past. Only, a few papers can be found in the Literature focusing this topic, of which the most cited are: Haberschill and Lallemand (1986), Kuijpers et al. (1988), Farzad and O'Neal (1991) and Robinson and O'Neal (1994).

It is in the early 2000s when this topic starts to deserve a considerable interest due to the general target of reducing the global equivalent CO_2 emissions of refrigeration systems. See for instance the interesting discussion on minimum-TEWI equipment in Barnes and Bullard (2000) and the papers by Colasson et al. (2001), and Goswani et al. (2001). The Zero-Leakage – Minimum Charge Conference held in Stokholm, in 2002, was the first international event focusing the minimization of charge in Refrigeration and Air Conditioning equipment, with very interesting papers on the topic of charge optimization: Barnes and Bullard (2002), Björk et al. (2002), Nowotony (2002), Primal et al. (2002).

In recent years a number of experimental studies have targeted this topic and are supplying very interesting information about it. See for instance: Primal et al (2004), Flohr and Meurer (2004), Choi and Kim (2004), and several papers by Björk and Palm (2006a,b,c).

Among the latest papers on this subject, two papers deserve to be mentioned separately. The first one, Palm (2007), because it summarizes the extensive work done at the Kungliga Tekniska Högskolan (KTH) in Sweden by Prof. Palm on this subject. The paper presents a very interesting series of results and conclusions about the possibilities for charge reduction and minimization of leakages in refrigeration equipment. The second one, Poggi et al. (2008), because it presents a very complete review on the subject and an excellent discussion on all aspects related with charge reduction.

Additionally, a number of mathematical models incorporate now a detailed discretization of the evaporator and condenser which allows the estimation of the amount of refrigerant contained in each component and of the subcooling, which have proved to be useful to understand the refrigerant distribution and the problematic of the refrigerant charge optimization. See for instance: Shen et al. (2006), Jiang et al. (2006) and Corberán et al. (2008).