available at www.sciencedirect.com

ScienceDirect

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

Practical methods for measuring refrigerant mass distribution inside refrigeration system

Guoliang Ding[a,*], Xiaokui Ma[a], Ping Zhang[a], Weizhe Han[a], Shinichi Kasahara[b], Takahiro Yamaguchi[b]

[a]Institute of Refrigeration and Cryogenics, Shanghai Jiaotong University, No. 800 Dongchuan Road, Shanghai 200240, China
[b]Daikin Air-Conditioning R&D Laboratory, Ltd., 1304 Kanaoka-cho, Sakai, Osaka 591-8511, Japan

ARTICLE INFO

Article history:
Received 9 March 2008
Received in revised form
26 April 2008
Accepted 4 May 2008
Published online 13 May 2008

Keywords:
Refrigeration system
Compression system
Process
Measurement
Refrigerant charge

ABSTRACT

The purpose of this paper is to present methods for measuring refrigerant mass distribution inside a refrigeration system conveniently and accurately. The quasi on-line measurement method (QOMM) was presented for measuring refrigerant mass inside heat exchangers. Compared with the existing liquid nitrogen method (LNM), QOMM can avoid the refrigerant waste and accelerate the measurement process. For measuring refrigerant mass inside the compressor, QOMM was used together with the oil level observation method. The liquid level method (LLM) was used to measure the refrigerant mass inside the accumulator and the receiver. In order to verify the accuracy of the measurement methods, not only the deviation of the measurement method for refrigerant in single component was analyzed, but also the prediction of the total refrigerant charge in an air conditioner was verified. The results showed that the maximal prediction deviation of the refrigerant charge in the whole refrigeration system is 1.7%.

Méthodes pratiques pour mesurer la masse du frigorigène à l'intérieur d'un système frigorifique

Mots clés : Système frigorifique ; système à compression ; Procédé ; Mesure ; Charge en frigorigéne

1. Introduction

The performance of a refrigeration system is affected by the refrigerant charge inventory and refrigerant mass distribution among components. The refrigerant mass distribution of the refrigeration system during the start up process is different from that during the shut down process, and the refrigerant migration during dynamic process can cause energy loss by 5–37% (Janssen et al., 1992; Jakobsen, 1995; Coulter and Bullard, 1997). In order to decrease such energy loss, it is necessary to study the characteristics of refrigerant distribution inside the refrigeration system experimentally, and a convenient and accurate method for measuring the refrigerant mass distribution is needed.

* *Corresponding author*. Tel.: +86 21 34206378; fax: +86 21 34206814.
E-mail address: glding@sjtu.edu.cn (G. Ding).
0140-7007/$ – see front matter © 2008 Elsevier Ltd and IIR. All rights reserved.
doi:10.1016/j.ijrefrig.2008.05.002

Nomenclature

LLM	liquid level method
LNM	liquid nitrogen method
OMM	on-line measurement method
QOMM	quasi on-line measurement method
W_1	the weight of sampling cylinder before collecting (kg)
W_2	the weight of sampling cylinder after collecting (kg)
W_3	the weight of refrigerant in the heat exchanger (kg)
W_r	the weight of residue refrigerant gas in the heat exchanger (kg)

Greek symbols

ε_{LNM}	the error of LNM
ε_r	the error brought by the residue refrigerant gas in the heat exchanger
ε_m	the error brought by measurement
δW_1	the measurement error of weighting sampling cylinder before collecting
δW_2	the measurement error of weighting sampling cylinder after collecting

Refrigerant is distributed inside components of the refrigeration system, including heat exchangers (evaporator and condenser), compressor, accumulator, receiver, filter, pipes and expansion valve. Normally, most of the refrigerant of the refrigeration system exists in the heat exchangers (Björk and Palm, 2006). For refrigerant mass measurement inside heat exchanger, the existing methods are liquid nitrogen method (LNM) (Tanaka et al., 1982; Mulroy and Didion, 1983, 1985) and on-line measurement method (OMM) (Janssen, 1989). With LNM, the refrigerant is drawn into the sampling cylinder with the low pressure caused by the low temperature of liquid nitrogen, and the refrigerant mass is the difference between the weight of the sampling cylinder with refrigerant and that without refrigerant. LNM has the advantage of high accuracy. But LNM is time consuming because the refrigerant mass in the system is decreased after one measurement and must be replenished before next measurement. With OMM, the heat exchanger is weighted directly. It is very convenient. But it is not accurate because of the following two reasons. One is that the weight of heat exchanger is much bigger than that of refrigerant in the heat exchanger, and the other is the vibration of the heat exchanger. The refrigerants in compressor include vapor-phase refrigerant in the cylinder and refrigerant dissolved in the compressor oil, and they can be calculated separately (Harm et al., 2003). For refrigerant in the cylinder, the mass can be calculated by the inner volume of cylinder and the density of refrigerant. For refrigerant in the compressor oil, the refrigerant mass can be calculated by the oil mass in compressor and solubility of refrigerant in oil. Normally, some oil in the compressor will be carried into the system. In order to obtain the actual oil mass in the compressor, Winandy and Cuevas (2003) used a liquid level meter to measure the oil volume, and then calculated the oil mass using the density of pure oil as the actual oil density in the compressor. The calculated result may deviate from the actual one because the oil in the compressor contains refrigerant and its density is different from the density of pure oil.

The purpose of this paper is to present methods for measuring refrigerant distribution inside refrigeration system conveniently while the accuracy is satisfied.

2. Quasi on-line measurement method (QOMM) for measuring refrigerant mass in heat exchanger

2.1. Analysis on existing methods for measuring refrigerant mass in heat exchanger

The existing methods for measuring refrigerant mass in heat exchanger are LNM and OMM.

LNM is a kind of refrigerant mass measurement method, which uses low temperature environment generated by liquid nitrogen to draw the refrigerant inside a component into the sampling cylinder. Fig. 1 shows the schematic of LNM. The operation steps are as follows. (1) Vacuum the sampling cylinder and weigh it as W_1. (2) Connect the sampling cylinder to a discharge port and evacuate air in the connecting hose. (3) Start the air conditioner and make it reach the test condition. (4) Shut down the air conditioner and close the solenoid valves and stop valves. (5) Put the sampling cylinder into the liquid nitrogen tank, and open the stop valve at the discharge port, making the refrigerant in the heat exchanger flow into the sampling cylinder. (6) When the pressure in the heat exchanger becomes stable, close the stop valve at the discharge port. (7) Disconnect the sampling cylinder from the discharge port, and weigh it as W_2. (8) Open the valve on the sampling cylinder slightly and discharge the refrigerant slowly. The refrigerant mass W in the heat exchange is: $W = W_2 - W_1$.

The error of LNM, ε_{LNM}, can be estimated by Eqs. (1)–(3).

$$\varepsilon_{LNM} = \varepsilon_r + \varepsilon_m \tag{1}$$

$$\varepsilon_r = \frac{W_r}{(W_2 - W_1) + W_r} \times 100\% \tag{2}$$

$$\varepsilon_m = \frac{\delta(W_2 - W_1)}{(W_2 - W_1)} = \frac{\delta W_2 + \delta W_1}{(W_2 - W_1)} \tag{3}$$

where ε_r is the error brought by the residue refrigerant gas in the heat exchanger, ε_m is the error brought by measurement, W_1 is the weight of the vacuumed sampling cylinder, W_2 is