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Mapping the energy consumption of household refrigerators by varying the refrigerant charge and the expansion restriction

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ABSTRACT

In this work the thermodynamic behavior of a household refrigerator was experimentally studied by simultaneously varying the refrigerant charge and the expansion restriction. A special charging device was designed and constructed for this purpose comprised of a cylinder, a load cell and two solenoid valves. In addition, the original capillary tube was replaced with a larger-diameter capillary tube and installed in series with a metering valve. The expansion restriction was varied by adjusting the capillary tube–metering valve pair to settings higher and lower than that of the original system. A total of 95 energy consumption measurements were recorded with different combinations of refrigerant charge and expansion restriction. A minimum energy consumption region comprised of several combinations of refrigerant charge and expansion restriction was clearly identified. It was also observed that an improper combination of expansion restriction and refrigerant charge may increase the energy consumption by up to 30%.

Cartographie de la consommation énergétique des réfrigérateurs domestiques grâce à la variation de la charge frigorifique et la restriction de la détente

Mots clés : Réfrigérateurs domestiques ; Détente ; Capillaire ; Charge en frigorigène ; Consommation énergétique

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Nomenclature

Roman

COP	coefficient of performance, dimensionless
EC	energy consumption, kWh $month^{-1}$
Q_e	thermal load, W
Q_t	cooling capacity, W
t_{on}	time of compressor on, s
t_{off}	time of compressor off, s
T	temperature, K
UA	overall thermal conductance, WK^{-1}
VP	valve position, dimensionless
W	power, W

Greek

τ	compressor duty cycle, dimensionless
ΔT	temperature difference, K

Subscripts

a	ambient
e	evaporation
coil	evaporator surface
comp	compressor
fan	evaporator fan
ff	fresh food compartment
fz	freezer compartment
k	compressor
sup	superheating
syst	system

1. Introduction

In Brazil, household refrigeration is responsible for 30% of the average household electricity consumption and this account for approximately 6% of the national electricity production. This relatively high fraction is due to the large number of units in operation and also to the inherent low thermodynamic efficiencies of such products.

It is well known that household refrigerators have highest efficiency when operating with certain combinations of expansion restriction and refrigeration charge (Gonçalves and Melo, 2004; Vjacheslav et al., 2001). Such parameters are normally determined at a late stage in the development process after all other system components have been designed or selected. The common procedure is to use a trial-and-error approach, with the energy consumption measured according to the ISO 15502 (2007) standard. However, such a procedure is time consuming – an energy consumption test may last more than 48 h – and does not always produce the expected results.

Dmitriyev and Pisarenko (1982) suggested a method to calculate the optimum refrigerant charge for household refrigerators based only on the evaporator and condenser internal volumes. The authors concluded that regardless of the ambient temperature, there was always a particular refrigerant charge that provided the maximum coefficient of performance (COP).

Jakobsen (1995) simulated the effect of varying the expansion restriction and the refrigerant charge on the COP of a particular household refrigerator. He found that the COP was more sensitive to a deficit of charge and to an excess of expansion restriction than the opposite scenario.

Vjacheslav et al. (2001) presented a model to estimate the optimum refrigerant charge for refrigeration systems. The authors modeled each component separately, exploring the effect of refrigerant charge on each of them and consequently on the system performance. Similarly to Dmitriyev and Pisarenko (1984, 1982), they found that the system performance was strongly affected by the refrigerant charge.

Björk and Palm (2006) conducted a series of experiments with a household refrigerator working under cyclic conditions in an attempt to identify the ideal combination of expansion restriction and refrigerant charge. Based on a database of 600 data points they concluded that the energy consumption had a minimum for certain combinations of expansion restriction and refrigerant charge and that this minimum was flat and wide. To the contrary of Dmitriyev and Pisarenko (1984, 1982) they also found that the optimum charge increases with lower ambient temperatures.

This study follows very closely the research work of Björk and Palm (2006), but with some differences: i) the test sample is a top-mount refrigerator with a no-frost evaporator and without a low side accumulator; ii) the energy consumption is measured under steady-state conditions; and iii) the expansion restriction is substantially decreased in respect to that imposed by the original capillary tube.

2. Experimental apparatus

The experimental apparatus is basically comprised of a charging device connected to the suction and discharge lines, through which refrigerant is added to or removed from the system in a controllable way. In addition, the original internal heat exchanger, also known as the capillary tube-suction line heat exchanger, was modified by replacing the original capillary tube with another of the same length but with a larger internal diameter. A metering valve was also installed in series with the capillary tube in order to vary the expansion restriction. This arrangement, which provides mass flow rates higher and lower than that provided by the original system, is shown in Fig. 1.

The experiments were carried out with a 403 L top-mount refrigerator, originally charged with 47 g of HC-600a and comprised of a 9.66 cm^3 reciprocating-type compressor, a natural draft wire and tube condenser, a tube-fin forced-draft no-frost evaporator, a concentric internal heat exchanger (2.05 m length) and a capillary tube (3.32 m length, 0.70 mm I.D.).

The charging device consisted essentially of a cylinder suspended in a load cell from which refrigerant enters and exits under the control of two solenoid valves connected to the discharge and suction lines through two 0.9 mm I.D. capillary tubes. The refrigerant pressure inside the cylinder, which corresponds to the saturation pressure at ambient temperature, always lies between the suction and discharge