The discharge and shell temperatures in hermetic compressors during its operation in tropical weather conditions

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Abstract. Hermetic compressors are essential components of domestic refrigerators and freezers and are usually designed to operate in ambient temperatures under 32°C. This study measures the discharge and shell temperatures of hermetic compressors at different ambient temperatures. To this end, calorimetric tests are conducted in three different hermetic compressors to define the impact of tropical ambient temperatures on the discharge and shell temperatures. Environmental temperatures of 35, and 38°C and voltages of 93, 115, and 127 V were considered during the tests. The results are compared to the nominal parameters at 32°C and 115V. Furthermore, to identify if the wear-out of the different components affect the discharge and shell temperatures, the three compressors were tested in the calorimeter after an accelerated life test. In all cases, the evaporation temperature was controlled at -23 °C. Results show that the discharge and shell temperatures of hermetic compressors increase with the ambient temperature. Additionally, it is evidenced that the technology of hermetic compressors strongly influences the discharge and shell temperatures.

Keywords: hermetic compressors, discharge temperature, shell temperature, domestic refrigerators

1. Introduction
Hermetic compressors are essential components of the vapor-compression refrigeration systems used in domestic refrigerators and freezers. In 2019, some 201.11 million of new compressor units were produced, for a market value of 111,130 million USD, estimating the growth for the annual production of 2.5% (Statista, 2020). In total, the electricity demand of domestic refrigerators and freezers account for an estimated 6% of the global electricity production (Negrão and Hermes, 2011). Thus, defining the best approach to operate them in a tropical climate towards higher efficiency and reliability standards is essential to reduce their electricity use. Therefore, to reduce the demand for electricity in domestic refrigerators and freezers the adequate discharge and shell temperatures of hermetic compressors must
be defined (Arencibia, 2004). The discharge temperature is the temperature of the exit flow of refrigerants in hermetic compressors, while the shell temperature is the temperature of the compressor’s shell. The discharge temperature is used to control the flow of refrigerant in refrigerators to optimize its performance (Huang et al., 2019).

The performance of hermetic compressors is usually assessed using the coefficient of performance (COP). The COP of domestic refrigerators and freezers is strongly dependent on ambient temperature (Harrington et al., 2018), which in turn affects the discharge and shell temperatures in hermetic compressors. There is evidence that several domestic refrigerators worldwide are running at temperatures higher than the recommended values (James et al., 2017). This results in higher condensation temperatures, lower efficiency of compressors, and increased temperatures of the motor winding (Masjuki et al., 2001; Todescat et al., 1992). Another factor affecting the performance of hermetic compressors is the requirement that it must be properly ventilated, to facilitate the heat transfer by convection (Meza et al., 2017). Otherwise, the heat it rejects combined with the heat rejected by the condenser increases the ambient temperature, which in turn reduces the COP of the cycle (Bassiouny, 2009). Adequate ventilation needs over 200 mm of free space around the condenser, which seems unlikely during domestic exploitation (Bassiouny, 2009).

The recirculation of hot air, causing high temperatures, is accountable for over half of the burnout hermetic compressors (Alarcón, 1998). Furthermore, high temperatures reduce the thermal stability of refrigerants, while the oil reduces its lubrication capacity (Brignoli et al., 2017; Karnaz and Seeton, 2018). Extended periods of high temperatures affect the performance of the entire cycle (Mohd Yunus et al., 2016; Yin et al., 2014). Additionally, increasing the ambient temperature at 1°C increases in 5.6% of the electricity use of domestic refrigerators (Anjana et al., 2015). Ambient temperature is the main factor affecting the electricity demand of domestic refrigerators (Geppert and Stamminger, 2013). Additionally, some studies point that in tropical weather hermetic compressors operate at higher compression ratios, leading to higher discharge temperatures, and thus to lower COP. Domestic refrigerators operating between 15 and 35 °C in Sri Lanka showed differences in the electricity demand of up to 54% (Anjana et al., 2015).

Although the discharge and shell temperatures affect the lifespan of hermetic compressors and the electricity demand of domestic refrigerators and freezers, they are however overlooked in the assessment of these units (Hundy et al., 2016). Even catalogs from manufacturers fail to include this information for the operation of domestic refrigerators and freezers for tropical temperatures (Negrão et al., 2011). Until recently, most tests of refrigerating units were developed at a single ambient temperature (Harrington et al., 2018), frequently at 32°C. Therefore, reliable data on the electricity demand of domestic refrigerators and freezers as a function of the ambient temperature is limitedly available. Tropical regions are characterized by mean ambient temperatures between 20 and 30°C, with a maximum of 40°C (Meteoblue, 2020). In several tropical regions temperatures during the day are higher than 32°C, thus affecting the performance of hermetic compressors. Consequently, this study aims at measuring the discharge and shell temperature of hermetic compressors at different ambient temperatures, considering temperatures values typically from tropical regions. Following a literature review is developed to identify the state of the art on this topic. Next, the materials and methods used in this investigation are depicted, and next the results are presented and discussed.

2. Literature review

Measuring the performance of scroll compressors for two values of ambient temperature (i.e. 18 and 25 ° C), it was found that the pressure ratio is the main factor affecting the temperature change of refrigerants during the process (Winandy et al., 2002). Moreover, the heating-up experienced by refrigerants at the suction of compressors is the main factor affecting the mass flow rate. Moreover, during an experimental study developed in a small domestic refrigerator, measuring the refrigerating demand and the ambient temperature, an overheating was detected in different components of the compressor (Torchio and Anglesio, 2004). While the results of a survey of domestic refrigerators show that factors like ambient temperature and opening frequency strongly impact the performance of the refrigerator (Rahman et al., 2005). Likewise, experimental results showed that the power demand in hermetic compressors increases linearly with the discharge temperature (Cuevas and Lebrun, 2009). A
A semi-empirical model can be used to predict the mass flow, power, and discharge temperature for hermetic compressors considering different refrigerants and ambient temperatures (Li, 2012).

The energy demand of standard-size domestic refrigerator and freezers was forecasted to increase around 102,575 GWh, based on a survey of over 1,500 domestic refrigerators and freezers (Greenblatt et al., 2013). The main factor affecting the energy demand of domestic refrigerators is mostly influenced by the ambient temperature, which was highlighted during the experimental study of four domestic refrigerators (Geppert and Stamminger, 2013). In fact, for domestic refrigerators operating at ambient temperatures between 35 and 38°C for most of the year, the energy loss of hermetic compressors increases from 7 up to 15%, reducing its cooling capacity by some 10% (Arencibia and Tricio, 2014). Furthermore, some 90% of the refrigerators operated at voltages with differences of ± 10% as compared to the nominal voltages of compressors.

Ambient temperatures over 32°C result in higher discharge temperatures. High discharge temperatures in hermetic compressors can cause a breakdown of refrigerant oils, reducing its lubrication capacity (Myszka et al., 2014). However, there are limited studies in this area, and a lack of standardization of these studies (Almeida et al., 2016). Domestic refrigerators are essential in the cold chain, and its inadequate operation is often a factor in food poisoning, yet, worldwide domestic refrigerators operate at temperatures higher than recommended (James et al., 2017). Regardless of the domestic refrigerator technology, they show a similar response to variations in the ambient temperature (Harrington et al., 2018).

Overall, most studies focus on optimizing the design and operation of domestic refrigerators. However, the discharge and shell temperatures of hermetic compressors resting from the operation of domestic refrigerators and freezers in tropical weather, are seldom considered.

3. Materials and methods

3.1. Compressors

Three different hermetic compressors (i.e. different make and models) were tested during the experiments. The main characteristics of the compressors are depicted in Table 1.

| Compressors | Frigorific Capacity (W) | Coefficient of Performance (W/W) |
|-------------|-------------------------|----------------------------------|
| I           | 95.4                    | 1.04                             |
| II          | 94.7                    | 1.17                             |
| III         | 100.7                   | 1.03                             |

3.2. Calorimeter

A calorimeter permits to simulate different ambient temperatures during the operation of the hermetic compressor. Additionally, it permits to measure the discharge and shell temperatures of hermetic compressors.

The calorimeter was properly isolated to guarantee heat losses under 5% of the compressor power (Masjuki et al., 2001). The tests were developed according to the ASHRAE standard (UNE, 2000), which includes a subcooling process. The calorimeter used during the experiments is described in Figure 1.
During the experimental tests, the calorimeter operates as the heat source in the refrigeration cycle (see Figure 1a) to measure the operating parameters of the hermetic compressors under defined operating conditions. The thermodynamic cycle is depicted with subcooling and without subcooling in Figure 1b. The precision and uncertainty of measurements are according to UNE-EN 13771-1: 2017.

3.3. Methods

Calorimetric tests are conducted in three different compressors to define the impact of ambient temperatures typical from tropical weather on the discharge and shell temperatures in hermetic compressors. Moreover, to identify if the wear-out of the different components affect the discharge and shell temperatures, the compressors were tested in the calorimeter after an accelerated life test. The accelerated life test, which is used to assess the reliability of hermetic compressors, was developed at a defined temperature and pressure during 678 h.

Based on the increased inefficiency of domestic refrigerators operating at ambient temperatures between 35 and 38°C for most of the year (Arencibia and Tricio, 2014), two environmental temperatures (i.e. 35 and 38 °C) were considered during the tests in the calorimeter. Additionally, considering the influence of voltage that was measured between 93 and 127 V in tropical regions (Arencibia and Tricio, 2014), three voltages levels were considered during the experiments (i.e. 93, 115, and 127 V) to assess the influence of low and high voltages on the compressors, and compare it to the nominal operation. The discharge and shell temperatures measured during the experiments are compared to the nominal operation of the hermetic compressors (i.e. at 32° and 115 V). Therefore, the operation of the hermetic compressors is measured at 32°C and 115 V (UNE, 2000). In all cases, the temperature of evaporation was controlled at -23 °C.

4. Results and discussions

Figure 2 depicts the shell temperatures measured during the experimental tests for the three compressors, for the different voltages and ambient temperatures considered. Additionally, it shows the shell temperature measured at nominal conditions (i.e. 32°C and 115 V).
The results show that, at the same ambient temperature, the voltage variation causes an increase in the shell temperature of compressors between 11.6 and 12.9% in compressor I, between 0.3 and 0.9% in compressor II, and between 1.3 and 2.9% in compressor III. Moreover, as compared to the nominal operation, the temperature reduces from 1 to 12% in compressor I, increases from 3 to 6% in compressor II, and from 1 to 6% in compressor III. Thus, the ambient temperature has more influence on the shell temperature than the voltage. As shown by the variation of the shell temperature in compressor II as compared to compressors II and III, the design and materials used during manufacturing also influence the shell temperature. While compressor I shows the highest shell temperature at 115 V, compressors II and III show a similar behavior at the three voltages for the different ambient temperatures. Although the three compressors have similar characteristics, compressor II operates at lower shell temperatures, which might be a result of its higher efficiency. Furthermore, compressor I has lower shell temperatures at 93 and 127 V as compared to its shell temperatures at 115 V. While compressor III shows the highest temperatures, with little variations for the different conditions. Overall, except for compressor I, the voltage variations have limited influence on the shell temperature. Other factors, like designs, lubrication systems, and materials used for each compressor, which influences the performance, were excluded from the assessment. Overall, the results of the calorimetric tests permit to deduce that for ambient temperatures of 35 and 38 °C the heat rejection from compressors increases, which reduces its operation efficiency. Furthermore, the results show that the technology of the compressor influences its discharge temperature for given operating conditions.

Likewise, Figure 3 depicts the discharge temperatures measured during the experimental tests for the three compressors, for the different voltages and ambient temperatures considered.
The results show that, at the same ambient temperature, the voltage causes an increase in the discharge temperature of compressors between 0.3 and 1.6%. Moreover, as compared to the nominal operation, the temperature increases from 6 to 9% in compressor I, from 1 to 3% in compressor II, and from 9 to 12% in compressor III. The results show that the discharge temperature of compressors depends on both the voltage and ambient temperature. However, the variations of the discharge temperature with the voltage and ambient temperatures are lower as compared to the variations of the shell temperature. Likewise, the compressor technology influences its discharge temperature for given operating conditions. Similarly, compressor II operates at lower discharge temperatures, which might be a result of its higher efficiency, while compressor III operated at the highest temperatures. Compressors III operate at temperatures over 90 °C, which is the maximum temperature recommended for hermetic compressor manufacturers. Overall, the voltage variations have a limited influence on shell temperature.

The temperatures in hermetic compressors are influenced by heat loss, which is mainly influenced by the fluctuation of the environmental temperature. Additionally, the heat losses because of the friction of the moving components and the lubrication system in the compressor have a significant influence on the shell and discharge temperatures, evidenced in the different performances observed for compressors from different manufacturers.

The calorimetric tests results show that in tropical weather conditions, the performance of compressors deteriorates, significantly increasing its shell and discharge temperature, because of the reduction of its dissipation capacity. The increase of the discharge temperature over the limits recommended by the manufacturer increases the condensation temperature, reducing the COP of the cycle. Additionally, these temperatures accelerate the deterioration of the lubricant oil and the coolant, reducing the lifespan of the compressors. Furthermore, the reduction of the COP in the cycle causes a reduction of its cooling capacity, because of the higher enthalpy at the input of the evaporator, moving the performance of compressors away from nominal conditions. These results highlight the need to adequate the current compressor tests to include tropical weather conditions and different electricity quality parameters, which is closer to the actual operating conditions of hermetic compressors in developing countries with tropical conditions.
5. Conclusions.

Although different studies have discussed the influence of environmental conditions on the energy demand and performance of hermetic compressors in domestic refrigerators and freezers, these are usually evaluated at nominal operation conditions (i.e. at 32°C and 115 V). The results of the calorimetric tests show that for environmental temperatures between 35 and 38°C, the operation of hermetic compressors is affected by higher discharge and shell temperatures. This is influenced mostly by the ambient temperature, and to a lower extent by the voltage variations. Furthermore, the technologic characteristics of hermetic compressors strongly influence its performance, as shown in the calorimetric tests for the compressors assessed, where differences over 15 °C were observed for the discharged and shell temperature for the different compressors. These results highlight the need to address the operation and performance of hermetic compressors operating under tropical temperature conditions, to control the variations of the discharge and shell temperatures within adequate values.

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