ENCIT 2018

ABCM
Associação Brasileira de Engenharia e Ciências Mecânicas

17th Brazilian Congress of Thermal Sciences and Engineering
November 25th-28th, 2018, Águas de Lindóia, SP, Brazil

ENCIT-2018-0113
CHARACTERIZATION AND ANALYSIS OF THE EFFICIENCY OF A HERMETIC COMPRESSOR

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Abstract. *An analysis of the energy efficiency of an alternative hermetic compressor used in refrigeration cooling system with R-22 is presented. The variations of the surface temperatures of the compressor housing and on its suction and discharge temperatures were investigated. It was determined how the mass flow rate, the electric power consumed and the cycle performance coefficient have varied as a function of the surface temperature increase of the compressor. In addition, the behavior of volumetric, electromechanical, isentropic efficiencies and an exergetic analysis as main indicators of the device's performance were analyzed. In order to determine these parameters, the natural convection coefficient for certain significant areas of the compressor housing was estimated. The main results were compared with similar compressor data available in the literature and were found to be acceptable. It was possible to observe a drop trend in mass flow rate during the period of operation of this hermetic compressor and how this reduction affects other properties.*

Keywords: *hermetic compressor, efficiency analysis, refrigeration system, temperature*

1. INTRODUCTION

Hermetic reciprocating compressor is one of the most important components in a household refrigeration system. Even a small increase in the performance of the hermetic compressor can affect the overall efficiency of the refrigeration system (Kerpicci et al. 2013). According to Ooi and Phua (1988) thermal consideration are among the many aspects that determine hermetic compressor performance and reliability. A proper understanding of heat transfer and the temperature distribution of the compressor helps to determinate the geometric parts, materials selection, and consequently, improves the efficiency of this equipment (Ooi, 2003; Ooi and Phua 1988).

Several works in the literature present numerical models to predict heat transfer in the refrigeration compressor. Navarro *et al.* (2007) developed a model to predict compressor efficiency and volumetric in terms of ten parameters that represent the main sources of loses inside the compressor. The maximum deviation found using Monte Carlo method was 3%. Li (2012) investigated a simple model for hermetic and reciprocating compressors based on the thermodynamic principles and calibrated with experimental data. The model exhibited a very good extrapolation capability to also be applied on a rotary compressor. Ooi (2003) and Todescat (1992) based their models on lumped formulation, in which the compressor domain is divided into control volumes with mass and energy balance applied.

On the other hand, Meyer and Thompson (1990), Kim *et al.* (2000), Pérez-Segarra *et al.* (2005) and Dutra (2013) proposed that the heat transfer and the efficiency analysis of reciprocating compressors could be experimentally investigated by measuring temperature at strategically chosen positions and applying energy balances.

Then, this paper aims to report the results of an experimental investigation to characterize a small reciprocating compressor, which operates in a vapor compression cycle. The analysis of temperature distribution is presented as well the volumetric efficiency, the isentropic efficiency, the combined mechanical-electrical efficiency and the exergy analysis related to the heat transfer losses and gains. The influence of the temperature on the mass flow rate, coefficient of performance and power consumed is presented. In addition, the results obtained are compared with others in literature.

2. METHODOLODY

The workbench refrigeration system is installed at the Thermodynamics and Heat Transfer Laboratory in Itaúna's University. The system operates on a simple vapor compression refrigeration cycle with R-22. The system has two finned heat exchangers, one capillary tube and reciprocating hermetic compressor as it can be seen in Fig. 1.

Figure 1. Compression refrigeration cycle workbench

In each one of the four device's outlet, manometers and thermocouples were installed. Another thermocouple was also installed on the cooled air outlet duct. The *LabVIEW* system design software was implemented to collect the experimental data and the instrument's uncertainty were analyzed. In addition, all the proprieties of the refrigerant fluid were obtained from EES (*Engineering equations solve*).

Table 1 shows the compressor data sheet and Fig.2 the distribution of significant areas for measuring the surface temperatures of the hermetic compressor. Those areas were selected considering a reasonable number of divisions in which it would be acceptable to consider an isothermal surface temperature.

Table 1. Compressor Characteristics.

Equipment	Brand	Frequency (Hz)	Phases Number	Voltage (V)	Displacement Volume (cm³)	Power (W)	Mass (kg)	Angular velocity (rpm)
Hermetic Compressor	Tecumseh	60	1	220	25,95	1360	19,4	1200

Figure 2. Distribution areas for analysis of surface temperature of the compressor

Each temperature on the surface of the compressor was measured using K-type thermocouples with ±1°C of uncertainty. All the thermocouples were located at the compressor housing with a layer of silicon sealant coated between the sensor and the metal to offer excellent heat conductivity, later on, they were insulated. Each test was carried out for one hour.

3. PRELIMINARY RESULTS AND DISCUSSION

Figure 3 shows the temperature variation of the significant areas of the compressor as a function of its operating time.

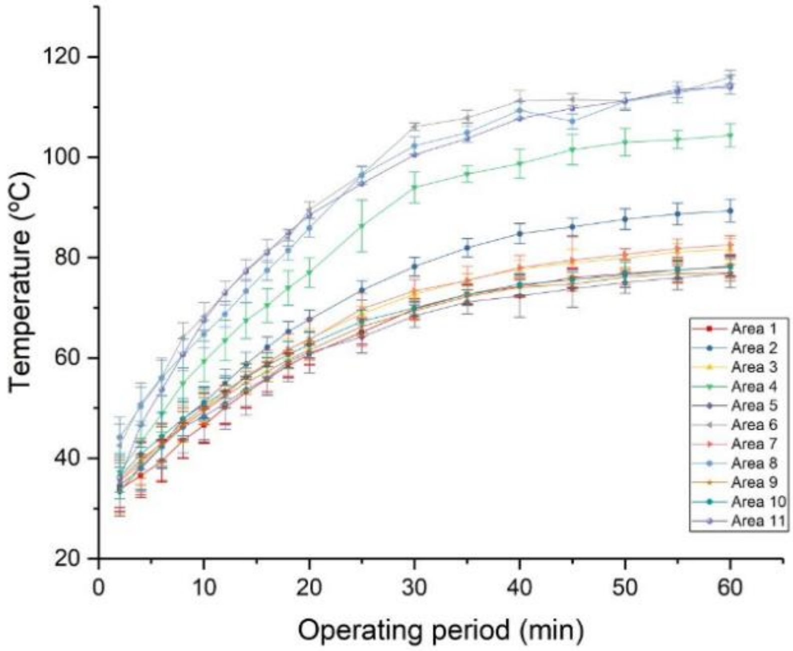

Figure 3. Temperature variation function of the operation time

It can be noticed that the areas in the lower part of the compressor housing, areas 2, 4, 6, 8 and 11, operated at a higher temperature than the upper part. This occurrence is attributed to two main factors: the positioning of the electric motor and the presence of the lubricating oil. Dutra *et al*. (2013), also reported the same behavior in their study. In Tab. 2 can observed the highest temperature obtained for each area throughout the operating period.

Table 2. Maximum temperatures reached by region.

Region	Maximum Temperature (ºC)	Standard Deviation	Region	Maximum Temperature (ºC)	Standard Deviation
Area 1	78.3	±1.7	Area 7	82.6	±1.2
Area 2	89.4	±1.9	Area 8	114.5	±1.6
Area 3	81.7	±2.0	Area 9	77.0	±1.7
Area 4	104.4	±1.9	Area 10	78.2	±1.5
Area 5	76.9	±2.1	Area 11	114.0	±2.1
Area 6	116.0	±2.6			

During the operation, it is also very important to analyze the variation of the compressor discharge and suction temperatures. Figure 4 shows the behavior of those temperatures. The suction temperature exhibits a decrease, approximating linear behavior, while the discharge temperature approximates an inverse exponential function.

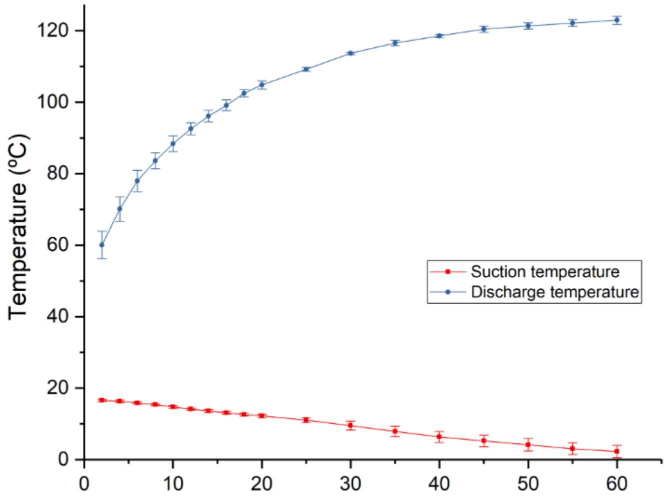

Figure 4. Compressor suction and discharge temperatures

It was observed from the analysis of the compressor suction and discharge temperature that a steady-state condition can be considered after the twentieth minute of operation. The higher suction and discharge temperature of the compressor were, respectively, 1.4°C and 122.9°C with a standard deviation of ±1.7°C. The increase of the ratio of variation between the suction and discharge temperatures, as well the increase of surface temperatures is related to the inefficiencies of this equipment.

The mass flow of refrigerant decreases due to the increase in the average surface temperature of the compressor. The reject heat is higher, and consequently, the difference between the inlet and outlet specific enthalpy increases. Therefore, the mass flow rate reduces respecting the conservation of energy as showed in Fig.5 (a,b).

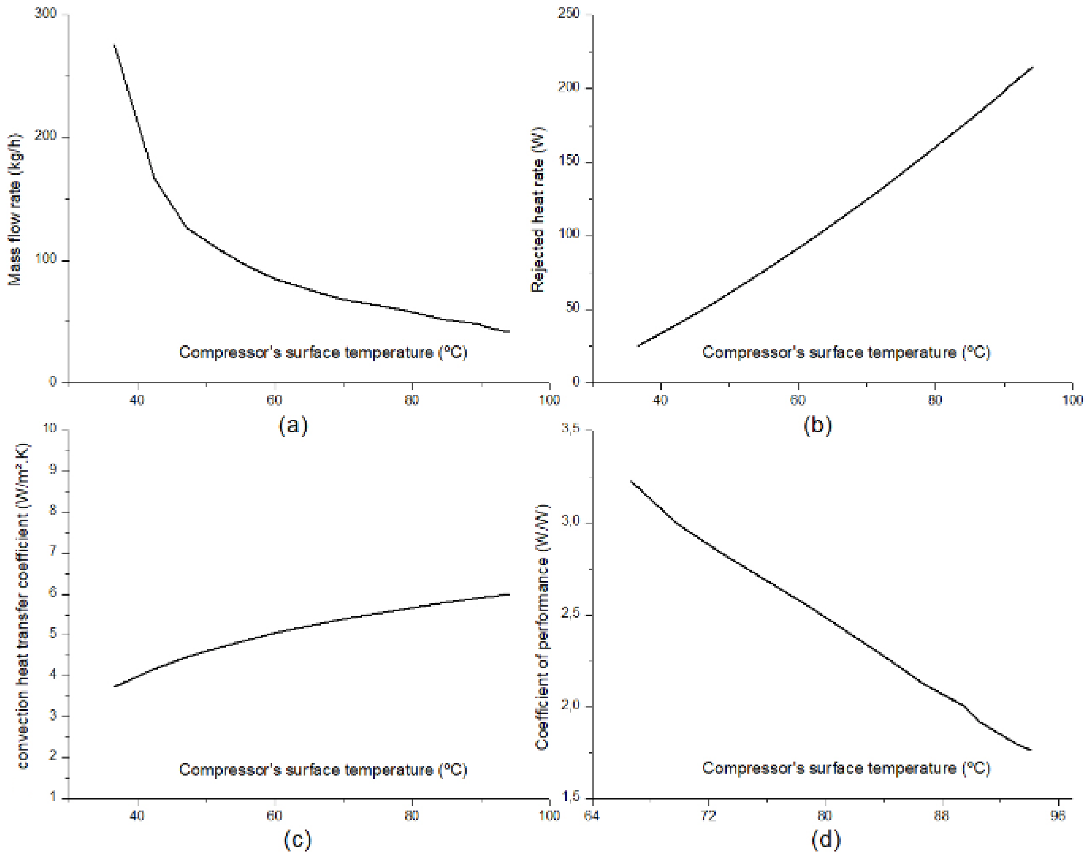

Figure 5. Compressor's surface temperature function of mass flow rate (a), reject heat rate (b), convection heat transfer coefficient (c), coefficient of performance (d)

In addition, it can noticed in Fig 5 (c,d) the approximately linear decreasing behavior of the cooling cycle performance coefficient and a slightly increase of the convection heat transfer coefficient. This reduction is directly related to the decrease in the mass flow rate in the cycle (-42.83%), which is much more significant than the small increase in compressor consumption (5%) and the decrease in the latent heat value available in the evaporator (-6.93%). The results were very similar compared to the ones presented by Incropera and Dewitt (2014).

Figure 6 shows the volumetric, isentropic, electromechanical and exegetic efficiency. The volumetric efficiency values, considering steady-state condition, are low. It decreased from 57.73% to 32.09%, at the end of the operation, when the average surface temperature reached approximately 95°C. These values are very similar to the results obtained by Navarro *et al*. (2007), which found approximately 60.0% for a compression ratio of 5, similar to the compressor of this work (5.79).

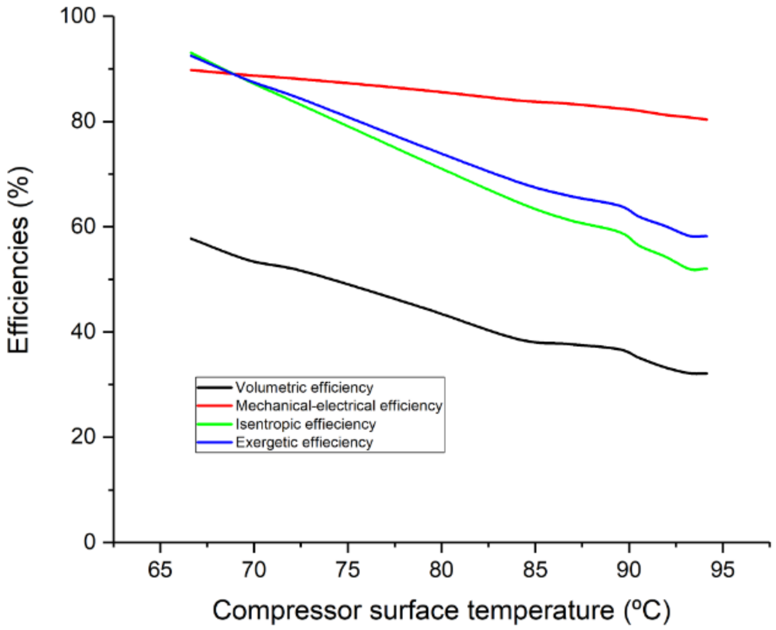

Figure 6. Analysis of compressor efficiencies

The electromechanical efficiency values were higher than expected. This is due to the impossibility of measuring the compressor axis work, the rates of transfer of heat supplied to the refrigerant in the space between the housing and the motor-compressor assembly, the compression chamber and along the discharge line. However, the value obtained at the end of the operating time was 80.37%, similar to those determined by Pérez-Segarra *et al.* (2005) for a compressor using R-134a.

The isentropic efficiency and the exergetic analysis have similar behaviors. The isentropic efficiency presents an average value of 61.28%. The exergetic efficiency was calculated based on the values available in the literature. The average value found was 65.88%, while the value determined in Pérez-Segarra *et al.* (2005) research was 56.60%. These differences can be attributed to the different ambient temperatures considered during the analysis.

4. CONCLUSION

The characterization and efficiency analysis are very important for a compressor in a refrigeration cycle since it plays an important role in the coefficient of performance of the system. It can observed that with the increase of average discharge and surface temperatures, the overall efficiency of the hermetic compressor reduces. As expected, the lower part of the compressor presented higher temperatures due to the electric motor and lubricating oil. For higher compressor's surface temperature, the reject heat transfer rate increases and the mass flow rate reduces. In that way, the coefficient of performance is affected having its value reduced from 3.224 to 1.762.

5. ACKNOWLEDGEMENTS

Authors acknowledge financial support from FAPEMIG.

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7. RESPONSIBILITY NOTICE

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