Experimental study on the polytropic exponent of a scroll type hermetic compressor running on refrigerant mixtures R410A, R452B and R454B and refrigerant R32

David Fernando Marcucci Pico – dmarcucci@ufu.br
Enio Pedone Bandarra Filho – bandarra@ufu.br
Universidade Federal de Uberlândia, www.ufu.br.
José Alberto Reis Parise – parise@puc-rio.br
Pontifícia Universidade Católica do Rio de Janeiro, www.puc-rio.br.

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Abstract.

The paper presents an experimental study on the polytropic exponent of a hermetic scroll compressor. The objective of the experiment was to measure the influence of the: (i) discharge-to-suction pressure ratio; (ii) electric motor angular velocity; and (iii) frequency and refrigerant composition on the compressor overall polytropic exponent. Experimental data of an existing apparatus were taken from previous publications by the authors. They included pressure and temperature at both compressor suction and discharge sides, also an electric motor input power frequency was measured. In the present work the polytropic exponent was calculated from the power-law equation that defines a thermodynamically polytropic process and the corresponding refrigerant equation of state. In a previous work, results taken from different compressors running on air, R12, R22 and two binary mixtures, showed a fairly constant value for each one of the compressors. All of them were of the open compressor type. Contrarily to open compressors, as previously tested, this time with a single hermetic scroll compressor a linear behavior was found for the increment of the discharge-to-suction pressure ratio and a non-linear relationship with the input of power frequency. A statistical curve fit model was prepared using the data collected to obtain a mathematical representation of the compression process of a scroll-type compressor running with different refrigerants. The model is accurate enough to predict the discharge temperature of the compressor within a maximum difference of 3 K. Good agreement was thus obtained between the model predictions and experimental values,

Keywords: *Polytropic exponent; R410A, R32, R452B, R454B.*

1. INTRODUCTION

Global warming and climate changes issues are forcing refrigeration and air conditioning industries to undergo an unprecedent effort towards, among other things, the reduction of direct (leakage) and indirect (energy consumption) emissions of greenhouse gasses. The urgency of the problem calls for the use of advanced technologies including new materials and new refrigerants. In this respect, the use of computer simulation of process and thermodynamics cycles has been a valuable design tool for the research and development of more environmentally friendly technologies (e.g. (Parise, 1986)). This paper is concerned with the study of the polytropic exponent, a parameter that is commonly used in the simulation of refrigeration and heat pumps cycles as well as heat engines. The size and capacity of computer programs varies significantly with the HVAC-R application. The polytropic exponent is a parameter commonly used in data-based simulations, in which a thermodynamics process can be represented by means of Eq. (1) (Maxwell, 1904).

$$PV^n = constant \tag{1}$$

Experimental results presented in literature showed that the polytropic exponent in open-type refrigeration compressors can be considered constant at different pressure ratios (Becerra *et al.*, 2008; Pereira; Motta; Parise, 1995) This work presents the experimental determination of the polytopic exponent of a scroll type compressor running on refrigerant R410A and their low-GWP alternatives R32, R452B and R454B.

2. METHODOLOGY

2.1 Experimental apparatus

The experimental test setup used by the data collection has been presented and fully explained in a previously publication (Panato; Pico; Filho, 2021; Panato, 2020). The apparatus was developed with the purpose to investigate alternative fluids to R410A. Moreover, the data collected was further analyzed in this paper, to study the polytropic exponent of the compressor with different refrigerants. The compressor, still in use, is a commercial model for operation with the baseline refrigerant, R410A. Fig. 1 illustrates the schematic layout of the setup, which can be used for a comprehensive understanding of the experiment.

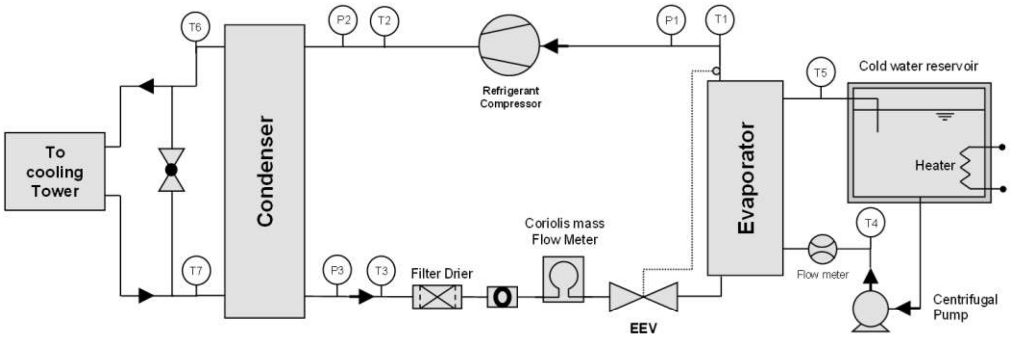

Figure 1: Schematic drawing of the experimental setup. Source: (Panato *et al.*, 2021).

PT−100 type temperature sensors were used. The pressure sensors were of the piezoresistive type, both in evaporation (3024, IFM) and in condensation (CS-PT730, Italmanometri). The Coriolis-type mass flow meter (RHM06-4FS1PN, Metroval) was used to measure the flow of refrigerant and installed in the liquid line between the condenser outlet and the expansion device.

The compressor is a scroll type version (ZP49K5E−TF5, Copeland), designed to operate in air conditioning condition, with evaporation temperature above -24 °C and condensation temperature up to 65.5 °C. The heat exchangers were of the brazed plate type, with countercurrent flow, both in the evaporator (AEK070-40, APEMA) and in the condenser (AEK095-60, APEMA).

An electronic expansion valve (E2V24SSF10, CAREL) was used as the expansion device. The expansion valve allowed to control the superheating at the evaporator outlet. This parameter was controlled to the value of 10 K. The experimental setup was also composed of a chilled water circuit that has a reservoir coupled to a set of electric heaters, with a capacity of up to 17 kW, to keep the evaporator water inlet temperature constant. The condenser circuit consists of an evaporative cooler and two water pumps in series. A bypass valve located between the condenser inlet and outlet allows to control the condensing temperature at 41 °C. The experimental test conditions collected from the data set are presented in the Table 1.

Table 1. Experimental test conditions collected from the data set. Source: (Panato; Pico; Filho, 2021; Panato, 2020).

Parameter	Test condition
Compressor input power frequency, (Hz)	40, 50 60
Refrigerant, (-)	R410A, R32, R452B, R454B
Superheating, (K)	10
Evaporation temperature, (°C)	-5, -3, 3, 5
Condensing temperature, (°C)	41

2.1 Polytropic exponent calculation

The data used for the calculation of the polytropic exponent was presented in an early paper. As suggested by Pereira et al (1995), the empirical polytropic exponent, n, that allow a simple simulation model of the compressor, can be calculated using Eq. (2) from the experimental results at suction discharge states. Both refrigerant states can be defined by a simple measurement of the temperature and pressure at compressor inlet and outlet.

$$n = \frac{\ln\left(\frac{P_2}{P_1}\right)}{\ln\left(\frac{v_1}{v_2}\right)} \tag{2}$$

In equation, P_1 and P_2 represent the inlet and outlet absolute pressures of the refrigerant measured; v_1 and v_2 are the specific volumes at inlet and outlet. The thermodynamics and thermophysical properties of the refrigerant mixtures were obtained using the Coolprop Software version 6.4.1 (Bell *et al.*, 2014).

3. RESULTS

As above mentioned, the polytropic exponent of the compressor operating with R410A was calculated using Eq. (2) and has been plotted in Fig. 2 as a function of the pressure ratio and input power frequency. As can be seen from Fig. 2, the polytropic exponent cannot be considered constant with the variation of the pressure ratio for a scroll hermetic compressor, as has been reported in the literature for reciprocating open compressor (Üçer A.S.; Benson, 1977). Instead, for a scroll hermetic compressor, the exponent presented an almost linear relationship with the pressure ratio, with an average variation of 3%. It can also be observed that the polytropic exponent increases significantly as the input power frequency is reduced from 60 to 40 Hz, with a maximum increment of 6%. The increment in the polytropic exponent with the reduction of the input power frequency can be explained by the increase in refrigerant superheating directly at the suction of the compression chamber (Cui; Sauls, 2008; Groll, 2004). This increase, concerning the refrigerant superheating, is a consequence of the heat exchange of the refrigerant with the compressor shell and the electric motor at low mass flow rates (Dardenne *et al.*, 2015). On the other hand, the power losses of the electric motor at lower rotation speed are incremented with the reduction of the input power frequencies (Burt *et al.*, 2008).

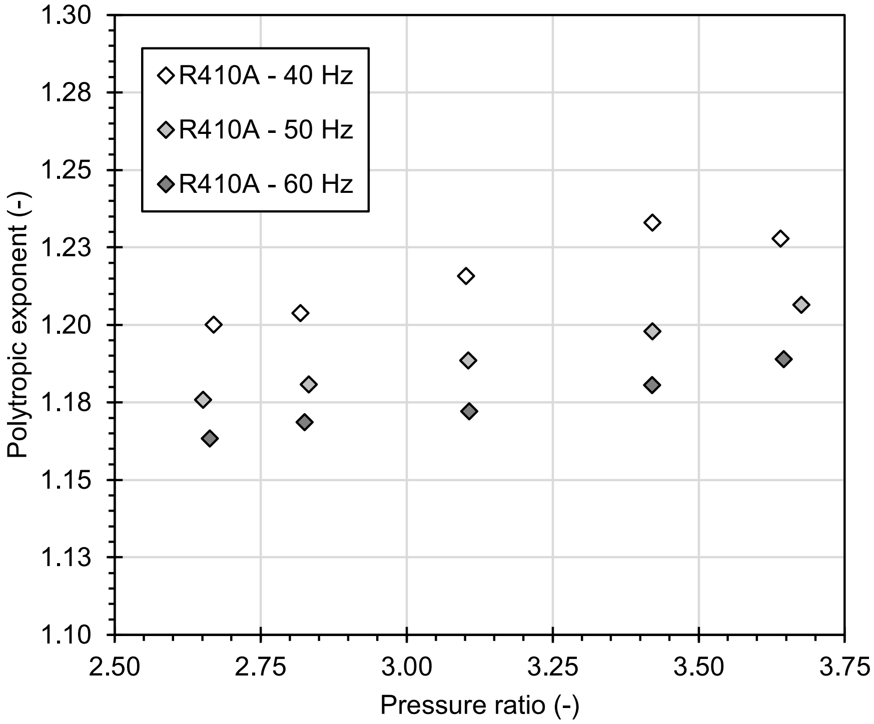

Figure 2. Experimental polytropic of compression process of the R410A at different compressor input power frequencies.

Using the data for the R410A alternative refrigerants, R32, R452B and R454B, their polytropic exponent were calculated and plotted in Fig. 3. The R32 refrigerant presented the higher polytropic exponent as compared to the other analyzed refrigerants. This can be explained by the higher discharge temperature found during the test runs, ranging from 98 to 125 °C. Different authors have reported a similar behavior also using the R32 refrigerant in R410A compressors. This behavior was explained by the higher isentropic exponent (Guo *et al.*, 2012; Tsujii, 2013). Refrigerants R452B and R454B have a similar polytropic exponent as compared to R410A. This can be confirmed through Fig. 5, in which those refrigerants have also similar compressor discharge temperatures.

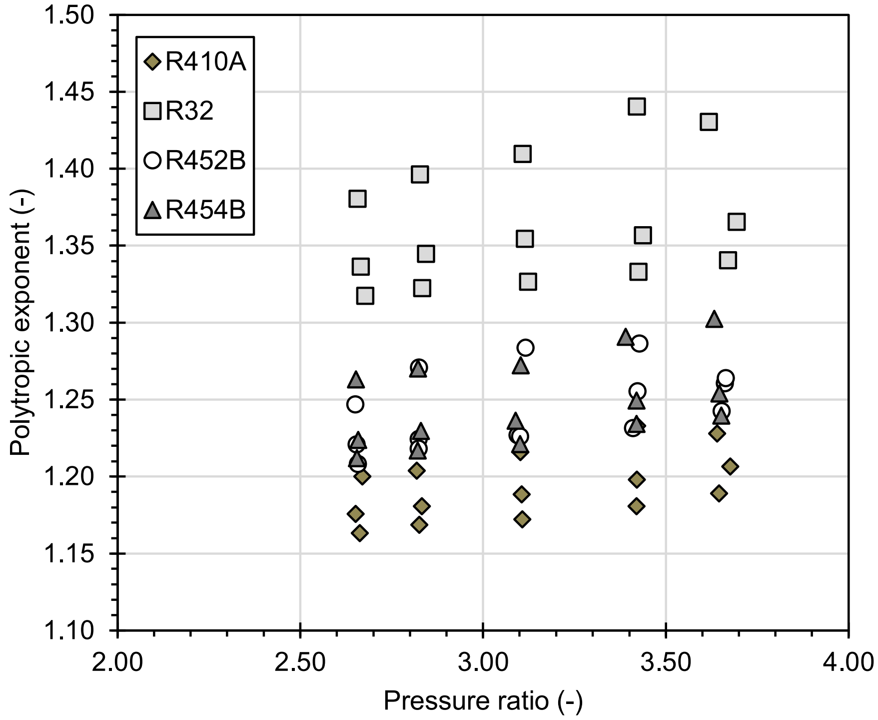

Figure 3. Experimental polytropic exponent as a function of the pressure ratio for the analyzed refrigerants.

The Eq. (3) was proposed to predict the polytropic exponent of the analyzed compressor for the analyzed refrigerants, R410A, R32, R452B and R454B. Equation 3 can be used at input power frequencies ranging from 40 to 60 Hz and at pressure ratios between 2.65 to 3.74. The equation uses as input parameters the specific volumes, in kg m^{-3}, and absolute pressures, in kPa, at the compressor inlet and outlet states, as suggested by Eq. 2. The correlation has a has an average deviation of 0.000364 and a standard deviation of 0.0000076. The equation is in good agreement with the experimental data as can be observed in the comparison plot, presented in Fig. 4. It is important to highlight that this model can be used only to predict the polytropic exponent for the analyzed hermetic scroll compressor, further investigation is necessary to evaluate the model with similar compressors from different manufactures and with different displacements values.

$$n_{predicted} = 1.996779 - 1.82634\left(\frac{v_1}{v_2}\right) + 0.2492\left(\frac{v_1}{v_2}\right)^2 + 1.07205\left(\frac{p_2}{p_1}\right) - 0.11201\left(\frac{p_2}{p_1}\right)^2 \quad (3)$$

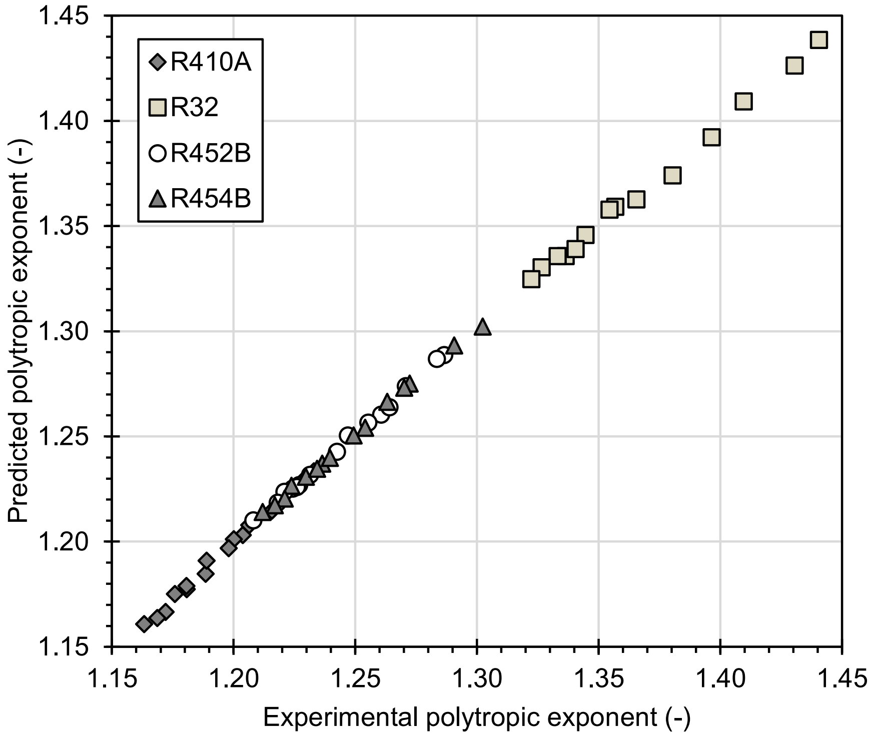

Figure 4. Experimental versus predicted polytropic exponent using the proposed model.

3.1 Compressor discharge temperature prediction

The discharge temperature of the compressor was calculated following a polytropic process, in which PV^n is constant throughout the compression process to determine the outlet specific volume. Once the discharge specific volume is obtained, the discharge temperature is calculated from the real gas equation of state as a function of the outlet specific volume and pressure. Figure 5 presents the predicted discharge temperature calculated from the polytropic exponent predicted versus the directly measured discharge temperature during the test runs for the R410A and R32 refrigerants. The maximum and average deviation between the predicted and measured discharge temperature obtained by this procedure were 3.91 and 1.52 K, respectively. It can be concluded that this methodology can be followed to discharge temperature with good coherence and precision for the range of pressure ratio and input power frequency analyzed in this paper at a constant superheating of 10 K. Moreover, further investigation is necessary to evaluate the impact of the superheating in the prediction of the discharge temperature using this procedure.

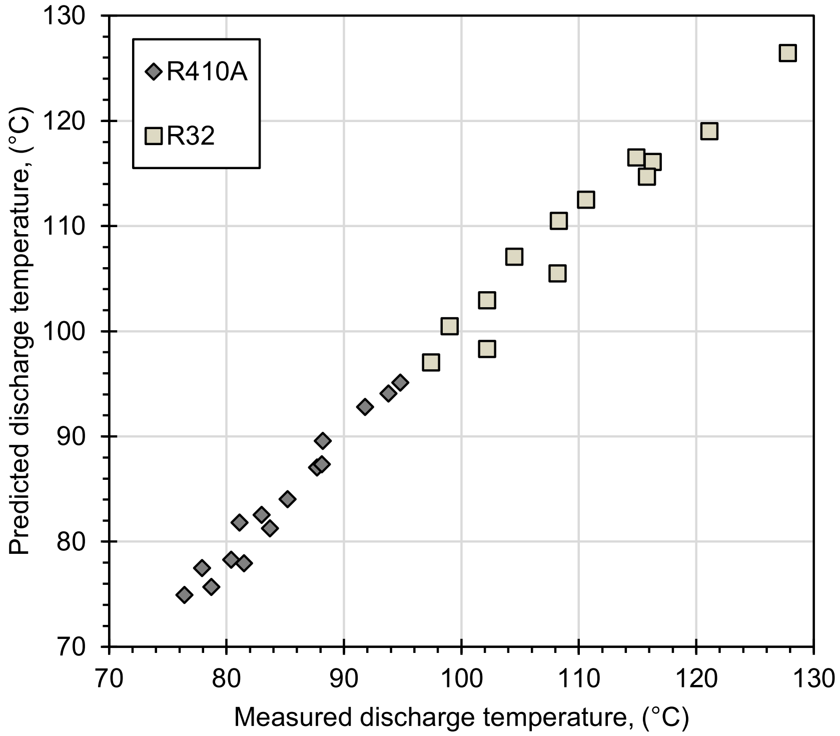

Figure 5. Experimental versus predicted discharge temperature of the compressor.

4. CONCLUDING REMARKS

The following conclusions can be drawn from this work:

- the operation of a scroll type hermetic compressor can be characterized by a polytropic compression process $PV^n = cte$ at different operating conditions, input power frequency and refrigerants;
- The polytropic exponent can be estimated by measurement of both discharge and inlet compressor thermodynamic states;
- The accuracy of the calculation method is not adversely affected by the use of the model and this model presented is more accurate than the hypothesis of a constant polytopic exponent for this compressor;
- Using this model, the compressor discharge temperature can be predicted at different input power frequencies, refrigerants and pressure ratios with a maximum deviation of 3.5 K.

5. AUTHORIZATION / AKNOWLEDGES

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