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A critical analysis of the characterization of scroll compressors energy consumption

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ABSTRACT

This paper presents the analysis of the energy consumption of scroll type compressors. The study has included the data of several AHRI reports: (especially AHRI-11 and AHRI-21) as well as data from other source. A total of 8 different scroll compressors, of different size, some of them tested with various refrigerants (R134a, R32, R410A, R404A…) have been considered in the study.

The values of the compressor consumption, and of the corresponding compressor efficiency, and the shape of the corresponding response surfaces, for all the studied compressors and refrigerants, have been analyzed with the objective of understanding better the dependence of the energy compressor consumption on the operating conditions and the refrigerant. The analyzed data include tests following different superheat control, i.e. constant superheat or constant return temperature, so the effect of the inlet temperature on the energy consumption and efficiency are also discussed.

The paper includes the analysis of the compressor consumption as dependent of the temperatures of the tested points, and alternatively as dependent of the corresponding pressures, and as a result it will be shown that the representation as a function of pressures is more universal than the one made with temperatures.

Two simple correlation polynomials, based on suction and discharge pressures, are presented, which require less empirical information and have better interpolation-extrapolation characteristics than the AHRI standard correlation.

1. INTRODUCTION

Nowadays, the use of mathematical models allows the estimation of the systems performance and therefore are very useful in assisting the systems design, analysis and control. The heart of any refrigeration or HP system is the compressor; therefore, the estimation of its performance is of particular importance in the evaluation of the system performance. Numerous models have been proposed in the Literature to estimate the compressor performance. There could be classified as: theoretical, based in some way on the modelling of the thermodynamics of the involved processes across the compressor, or fully empirical, i.e. based on functionals (for instance polynomials) which are fitted to performance data. Theoretical models can be purely theoretical, based only on physical principles, or on the integration of the corresponding conservation equations, or theoretical but adjusted in some way by some empirical coefficients, which help to fit the results to performance data, adjusting for effects which have not been represented, adequately enough, in their formulation. We will call this last type of models semi-empirical.

A thorough review of compressor models has been included in several recent papers/reports, for instance in Byrne et al., 2014 and Hermes et al., 2019

Although a good number of semi-empirical models have been proposed over the years, fully empirical models are still in use, and it is the way that most of the compressors manufacturers report their compressor performance. In fact, as reported in Cheung & Wang, 2018 when semi-empirical models have been compared with empirical models, in the cases where a large number of experimental data points are available all across the compressor envelope, the fully empirical models show better agreement in the representation of the compressor performance. The reason for this is that the semi-empirical models employ a pre-defined functional, with some coefficients which need to be adjusted to experimental data, but with dependences on the input variables which are implicit to the functional and therefore, cannot be changed along the fitting. Whereas, fully empirical models, involve no physics so that they require of experimental data to be fitted to, but are more flexible to adapt their shape to the actual compressor performance surface if enough experimental data is available.

Semi-empirical models are, in contrast, able to catch up the influence of the most important variables, for instance pressure ratio, in the performance and hence, are able to give a reasonable good estimation of the compressor performance with a reduced amount of experimental data, see for instance Jähnig et al., 2000, Cuevas & Lebrun, 2009, Navarro-Peris et al., 2013, and the recent paper by Hermes et al., 2019, but cannot reproduce the actual compressor performance with high accuracy.

The classical fully empirical model employ to characterize the compressor performance is the 10 coefficients third degree AHRI polynomial (ANSI/AHRI 540, 2015). These polynomials are able to provide a very accurate prediction of the compressor performance: refrigerant mass flow-rate and compressor energy consumption, across its entire working envelope by fitting the 10 coefficients. There has always been a discussion about, how many experimental data points and where to place them, are necessary in order to reach a reasonable good accuracy all across the compressor envelope. This topic was recently researched by Aute et al., 2015, Aute & Martin, 2016 and Cheung & Wang, 2018.

A few authors have proposed other empirical models, with the objective of reducing the amount of experimental data points required for their fitting, and maybe additionally improving the interpolation and extrapolation capabilities of the functionals in comparison with the AHRI polynomial. Among this, it should be first mentioned the more compact 2nd degree polynomial proposed by Shao (in Shao et al., 2004), the functional proposed by Aute in (Aute et al., 2014) and the proposed by Navarro (Navarro-Peris et al., 2013).

This paper presents an analysis of the energy consumption of scroll compressors, in order to better understand its shape and dependence on the operating parameters, with the objective of developing a functional for its characterization better than the 10 coefficients AHRI polynomial in the sense of requiring a lower number of experimental points for an accurate characterization of the performance and also maybe better extrapolation capabilities.

2. COMPRESSOR PERFORMANCE DATA

A few years ago, AHRI disclosed a series of results of performance of different compressors, scroll and piston, with conventional and new refrigerants and mixtures. These experimental results are included in several reports within the AHRI Low-GWP Alternative Refrigerants Evaluation Program. This study has considered all those AHRI reports containing scroll compressor tests: AHRI-11 (Shrestha, Mahderekal, et al., 2013), AHRI-21 (Shrestha, Sharma, et al., 2013), AHRI-24 (Rajendran & Nicholson, 2013), AHRI-33 (Shrestha et al., 2014), AHRI-34 (Rajendran & Nicholson, 2014a), AHRI-36 (Rajendran & Nicholson, 2014b), AHRI-38 (Rajendran & Nicholson, 2014c), AHRI-39 (Rajendran & Nicholson, 2014d), AHRI-58 (Rajendran et al., 2016a), AHRI-65 (Rajendran et al., 2016b), and AHRI-66 (Suindykov et al., 2016), and additionally the performance data published in Cuevas & Lebrun, 2009; totaling 8 different scroll compressors, and a huge variety of refrigerants: R134a, R32, R410A, R404A, R447A, R454B, DR5, DR7, L40, L41a, L41b, ARM31a, D2Y65.

From the analysis of all the compressor consumption data, we have found two different behaviors depending on the application range: at moderate-high evaporation temperatures M-HT, the compressor consumption is quite independent of the evaporation temperature, sometimes showing a slight increase, sometimes a slight decrease. While, at low evaporation temperatures LT, the compressor consumption increases significantly with the decrease of the evaporation temperature with a certain hyperbolic behavior. AHRI -11 is characteristic of the first kind: M-HT, while AHRI -21 is characteristic of the second kind: LT. Those reports have been selected for discussion in this paper because they include many experimental test points, covering the entire operating domain of the respective compressors. The compressor studied in Cuevas (Cuevas & Lebrun, 2009) belong the M-HT category.

Table 1 summarizes the main characteristics of the compressors tested in AHRI-11, AHRI-21, and Cuevas & Lebrun, 2009. Finally, the Table 2 shows the Mass% compositions of the tested refrigerants' mixtures. The thermophysical properties of the mixtures analyzed has been obtained with the NIST's Refprop software package (Lemmon et al., 2018), evaporation and condensation temperatures considered at dew point.

Table 1. Main compressor characteristics and tested refrigerants

<table>
<tr><th>Source</th><th>Model</th><th>Manufac.</th><th>Disp. (freq.) (cm^3) (Hz)</th><th>Refrigerants tested</th><th>Test points</th><th>Conditions by refrigerant test</th></tr>
<tr><td>AHRI 21</td><td>ZS21KAE-PFV</td><td>Copeland</td><td>50.96 (60)</td><td>R404A/ARM31a/D2Y65/L40/(R32+R134a)</td><td>191/186/183/173/133</td><td rowspan="2">SH=11ºK
SH=22ºK SC=6ºK
Tsuc=18ºC</td></tr>
<tr><td>AHRI 11</td><td>ZP21K5E-PFV</td><td>Copeland</td><td>20.32 (60)</td><td>R410A/R32/DR5</td><td>196/166/189</td></tr>
<tr><td>Cuevas(2009)</td><td>-</td><td>-</td><td>54.25 (50)</td><td>R134a</td><td>18</td><td>SH=6.8K</td></tr>
</table>

New refrigerants composition (mass %)

Source	Name	Composition
AHRI 21	ARM-31a	R-32/R-134a/R-1234yf (28/21/51)
	D2Y-65	R-32/R-1234yf (35/65)
	L-40	R-32/R-152a/R-1234yf/R-1234ze(E) (40/10/20/30)
	R-32/R-134a	R-32/R-134a (50/50)
AHRI 11	DR-5	R-32/R-1234yf (72.5/27.5)

2. COMPRESSOR PERFORMANCE ANALYSIS

The analyzed data includes tests following different superheat control, e.g. constant superheat or constant return temperature, so the effect of the inlet temperature on the compressor consumption and efficiency are also discussed
One of the possibilities to characterize the compressor consumption has always been to characterize the compressor efficiency, η_c. This presents the advantage of being a non-dimensional parameter quite independent of the size of the compressor and mainly dependent on the pressure ratio.

$$\eta_c = \frac{\dot{m} \cdot \Delta h_{is}}{\dot{W}_c}$$

In fact, many authors have employed this approach to characterize the compressor. Moreover, both compressor and volumetric efficiencies are quite characteristic of the compressor and they can even be used to estimate the compressor performance with a different refrigerant. Some authors have proposed non-dimensional parameters, similar to the efficiencies, which are even more general and provide a slightly better estimation of the compressor performance (Pierre, 1982; and Navarro-Peris et al., 2013)

Figure 1, shows the compressor efficiency of compressor ZS21KAE-PFV versus pressure ratio, for all the tests points included in AHRI 21 for the reference refrigerant R404A. Three sets of data were measured, corresponding to three different conditions at the suction: constant superheat of 11.11 K (SH11), constant superheat of 22.22 K (SH22), and constant return temperature 18 ºC (T18). Figure 2 shows the same experimental data separating in different boxes the tests performed at the same evaporation temperature (left side of the figure), or separating in different boxes the tests performed at the same condensation temperature (right side of the figure).

Figure 2 shows that for a constant superheat, and if one performs the tests at a constant evaporation temperature and varies only the condensation temperature, then one obtains a clear curve with pressure ratio with a maximum at a certain pressure ratio. This is not the case, if the tests are performed the other way around, keeping constant the condensation temperature and varying the evaporation temperature (right side).

Compressor efficiency has the typical shape as a function of the pressure ratio (with a maximum at a given pressure ratio) only for compressors working at a more or less constant evaporation temperature (see figure 2), which is just the case of compressors for air conditioning or chillers.

Figure 1 also shows that the suction temperature clearly affects compressor efficiency, with a trend to increase with the increase of the superheat. The highest efficiencies are the ones corresponding to SH22, with exception of some points at low evaporation temperatures where at return temperature 18ºC the superheat is higher than 22.

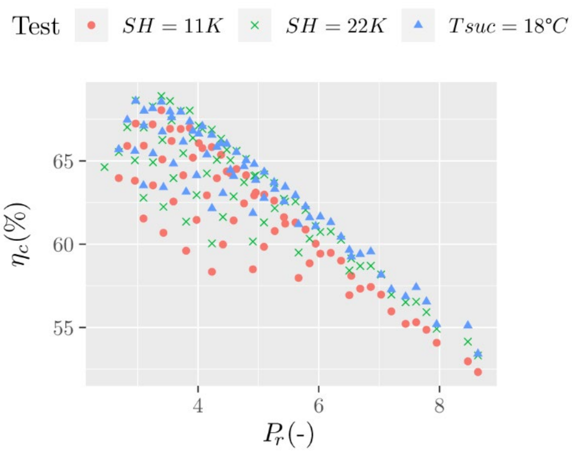

Figure 1: Compressor efficiency versus pressure ratio of compressor ZS21KAE-PFV, for all the tests points included in AHRI 21 for the reference refrigerant R404A

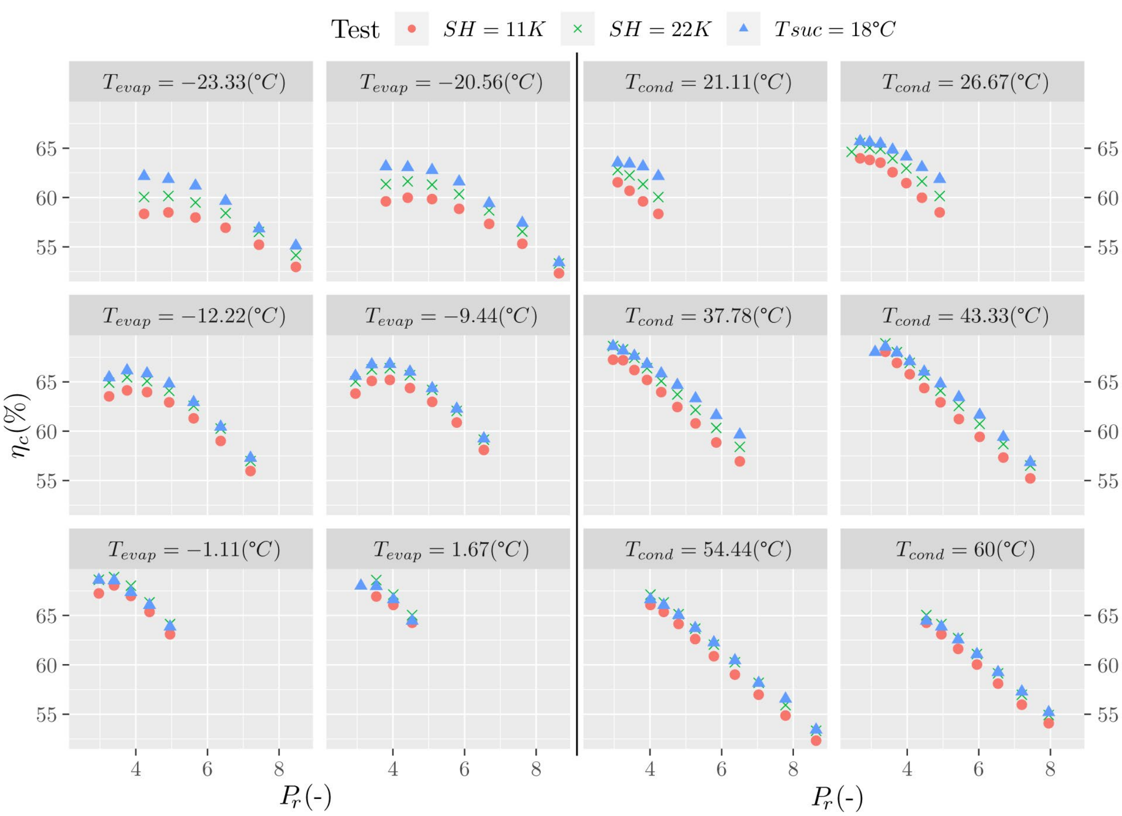

Figure 2: Compressor efficiency versus pressure ratio of compressor ZS21KAE-PFV with refrigerant R404A. Left side: compressor efficiency at given evaporation temperatures. Right side: compressor efficiency at given condensation temperatures.

In other words, compressor efficiency is a complex function of evaporation and condensation conditions plus the superheat. In contrast, if one represents the compressor consumption versus the evaporation and condensation temperatures (see figure 3) it is hard to see any influence of the superheat. Figure 3 shows the AHRI-21 compressor consumption vs. condensation temperature at various constant evaporation temperatures at the left side, and the compressor consumption vs. evaporation temperature at various constant condensation temperatures at the right side.

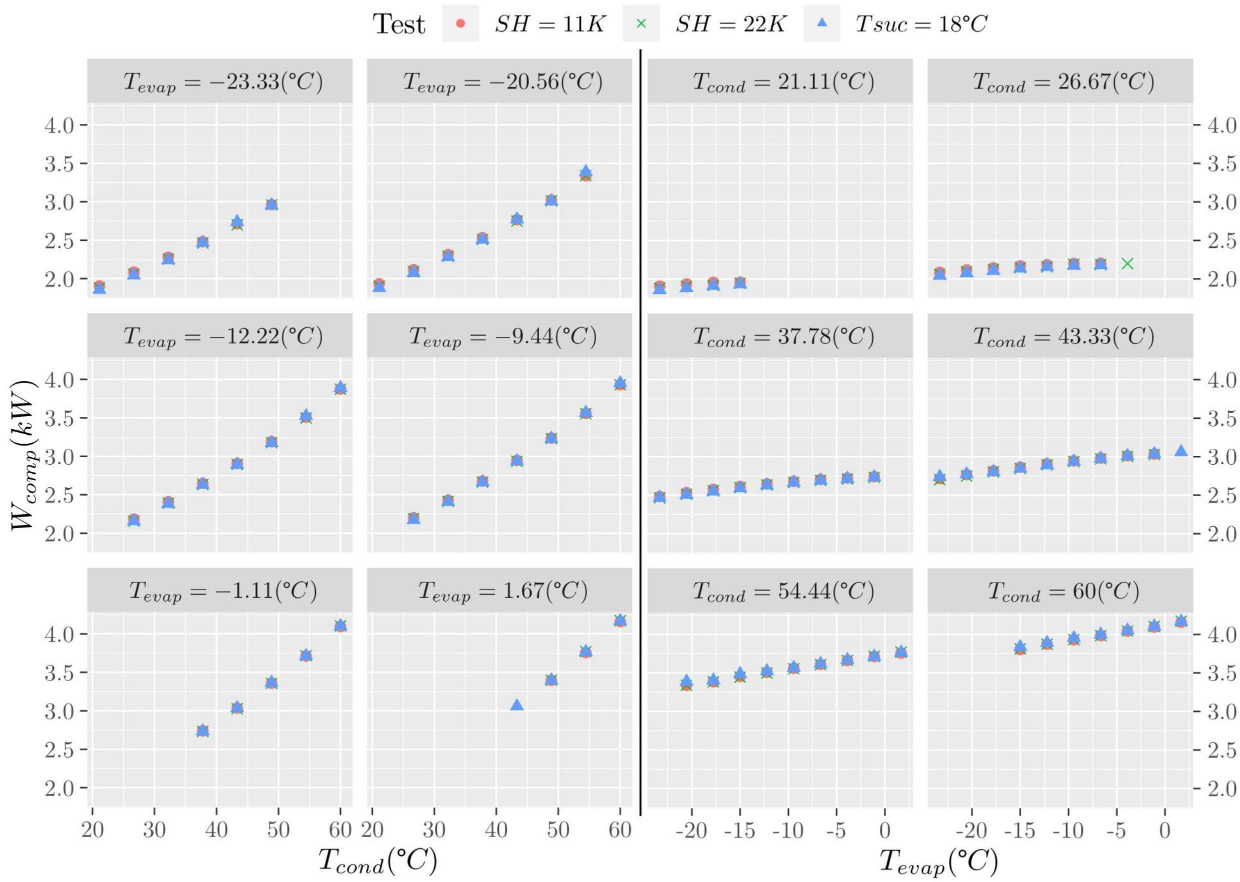

Figure 3: Compressor consumption versus evaporation or condensation temperatures of compressor ZS21KAE-PFV with refrigerant R404A. Left side: compressor efficiency at given evaporation temperatures. Right side: compressor efficiency at given condensation temperatures.

Figure 4 shows the energy consumption of compressor ZS21KAE-PFV with refrigerant R404A in a 3D plot as a function of evaporation and condensation temperatures. As it can be observed the compressor consumption surface is quite smooth. Figures 3 and 4 show that the energy consumption of scroll compressors is mainly dependent on the condensation temperature, increasing with it, with a slight dependence on the evaporation temperature.
Figure 5 shows the compressor consumption maps of compressors ZS21KAE-PFV (AHRI-21) and ZP21K5E-PFV (AHRI-11) for their reference refrigerant, R404A and R410A respectively.
As can be seen, and as mentioned above, the energy consumption of scroll compressors mainly depends on the condensation temperature with a slight dependence on the evaporation temperature. AHRI-21 compressor, which has been tested at low temperatures, show a decreasing trend of the consumption with the evaporation temperature, while AHRI-11 compressor shows a slight increasing trend with the evaporation temperature.

All M-HT analyzed scroll compressors of the referenced AHRI reports, and the one tested by Cuevas & Lebrun, 2009, show this slight decrease of the compressor consumption, almost linear, with the increase of the evaporation temperature. While the compressors of reports AHRI-21, AHRI-34 and AHRI-36 show the consumption decreasing trend with the evaporation temperature. It should be pointed out that the compressors of reports AHRI-21, AHRI-34 are for LT applications and in fact they are Liquid injection type. Therefore, it can be concluded that the dependence of the scroll compressors consumption with the evaporation temperature is weak and it depends on the application range, slightly hyperbolic decreasing for LT applications while it is slightly linear increasing for MT-HT applications.

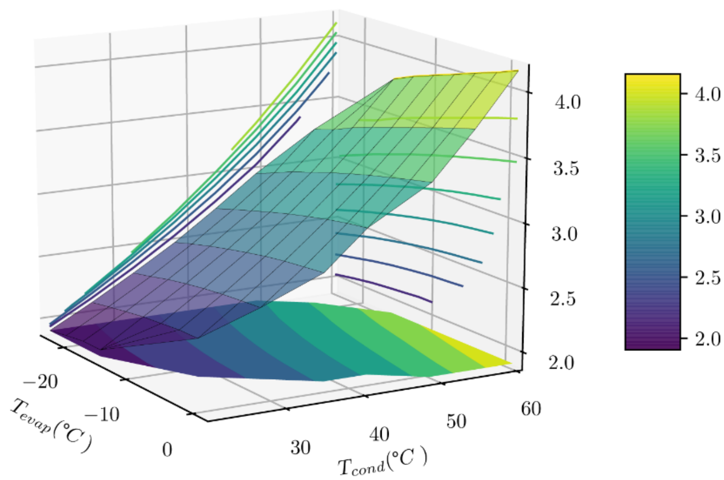

Figure 4: 3D plot of compressor consumption versus evaporation and condensation temperatures of compressor ZS21KAE-PFV with refrigerant R404A (SH=11K).

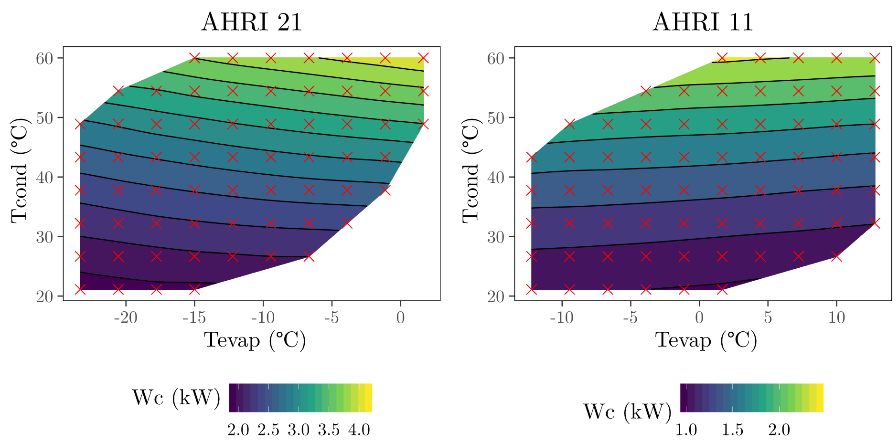

Figure 5: Compressor consumption maps of compressors ZS21KAE-PFV (AHRI-21) and ZP21K5E-PFV (AHRI-11) for their reference refrigerant, R404A and R410A respectively (SH=11K).

3. COMPRESSOR CONSUMPTION CORRELATION

3.1 Correlations employed

If one observes the surface representing the compressor consumption versus the condensation and evaporation temperatures shown in figure 4, it is easy to understand why the 10 coefficients AHRI polynomial (ANSI/AHRI 540, 2015) is able to reproduce the response surface so well when enough experimental data points are available for the fitting and they are well distributed all across the operation domain. In fact, the authors have employed the more compact polynomial proposed by Shao et al., 2004 and have found that it provides the same ability to represent the surface with only 6 coefficients. The polynomial proposed by Shao employs only the main terms of the AHRI polynomial and in the experience of the authors, it is able to represent very well the energy consumption of scroll and rotary compressors.

$$W_c = b_1 T_c^2 + b_2 T_c + b_3 T_c T_e + b_4 T_e^2 + b_5 T_e + b_6$$

In the mentioned paper, Shao proposes a correlation for variable speed compressors based on the described functional at the nominal speed and a correction with the speed, which also works very well.

However, when one plots the compressor consumption for different refrigerants the surfaces show different levels depending on their respective refrigerant properties. The authors have found that if alternatively, the consumption is plotted as a function of the refrigerant pressure, instead of the temperatures, it turns out that the surfaces are much more similar with each other. Figure 6 shows the compressor consumption for the compressor ZS21KAE-PFV of AHRI-21, for 4 different refrigerants. From figure 6, one can see that the representation versus the pressures is much more universal than versus the temperatures.

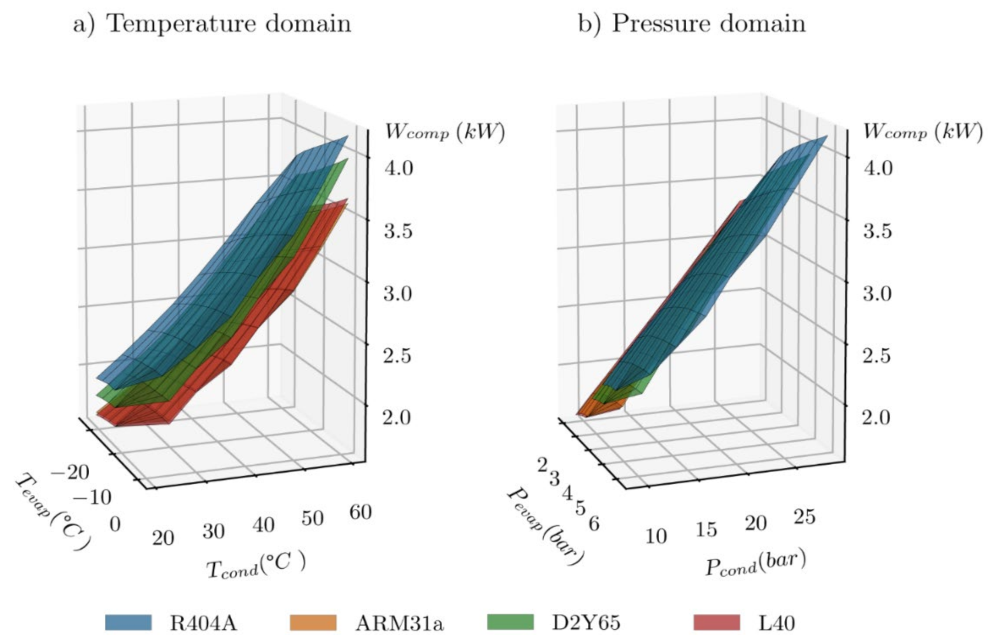

Figure 6: Left side: 3D plot of compressor consumption versus evaporation and condensation temperatures of compressor ZS21KAE-PFV for 4 different refrigerants. Right side: 3D plot of compressor consumption versus evaporation and condensation pressures of compressor ZS21KAE-PFV for 4 different refrigerants (SH=11K).

The representation of figure 6 vs. evaporation and condensation pressures have been performed for the wide range of refrigerants included in the referenced reports and has proven that that representation of the compressor consumption is much more independent of the refrigerant hence more representative of the compressor. Furthermore, the authors have found that the correlation of polynomials based on the condensation and evaporation pressures is as effective as the one based on the dew temperatures. Therefore, we propose to correlate the performance as a function of the evaporation and condensation pressures.

As it can be observed in figure 6 right side, the compressor consumption is a quite flat surface when represented versus the evaporation and condensation pressures. The authors have found that a simple linear polynomial containing linear terms on both evaporation and condensation pressures and one cross-term with their product leads to a very robust correlation with very decent accuracy for all the analyzed compressors and refrigerants.

Correlation 1: $W_c = C_0 + C_1 P_e + C_2 P_c + C_3 P_e P_c$

This polynomial will be referred as to Correlation 1 in the following comparison of results. If one wants to increase the accuracy of the correlation, one should add first at second order dependence on the condensation pressure, since it has most of the influence on the consumption, and it becomes a bit quadratic at high condensation pressures. Also, the authors have found that a second order on the evaporation temperature is good for LT compressors. Adding those two terms to Correlation 1, one gets the second correlation proposed by the authors:

Correlation 2: $W_c = C_0 + C_1 P_e + C_2 P_c + C_3 P_e^2 + C_4 P_c^2 + C_5 P_e P_c$

Finally, we will compare the results with the same correlation but employing the dew temperatures instead of the pressures. This correlation is exactly the one proposed by Shao et al., 2004. We will name this one, correlation 3.

Correlation 3: $W_c = C_0 + C_1 T_c^2 + C_2 T_c + C_3 T_e^2 + C_4 T_e + C_5 T_e T_c$

3.2 Comparison of correlations

The described correlations, 1 2 and 3, were fitted to the compressor consumption results included in all the available AHRI reports with scroll compressors, mentioned in the first section, and to the set of the test points of Cuevas & Lebrun, 2009 corresponding to 50 Hz constant compressor frequency.

The results of the fitting were very good for all the analyzed compressors and refrigerants. We also did the fitting to the original 10 coefficients AHRI polynomial but the results did not improve, and a big portion of the coefficients did not have significance enough. Table 2 shows a summary of the correlation results for compressors ZS21KAE-PFV (AHRI-21) and ZS21KAE-PFV (AHRI-11) for 4 different refrigerants each, and for the compressor tested by Cuevas & Lebrun, 2009, for the three correlations defined above. The Table includes the values of the coefficients (estimates) for correlation 1, 2 and 3, as well as the maximum relative error (MRE) in (%) and the Root Mean Square Error (RMSE) in W. For each compressor and refrigerant, the correlations are fitted to all available test points, including all different suction conditions. The coefficients are meant to provide the compressor consumption in kW with temperatures expressed in ºC and pressures in bar.

As can be seen in table 2, both MRE and RMSE are very low with practically all the analyzed correlations, providing a very good representation of the compressor consumption across the entire envelope. The highest accuracy is reached with Correlation 2, proving that the correlation with pressures is better than with temperatures, and as discussed above, less dependent on the employed refrigerant. The fact of adding coefficients allows for a better fitting of the experimental results, however, different terms could lose significance.

The compressor consumption results of Cuevas & Lebrun, 2009 are not so many as the other two considered compressors, however the polynomials show slightly higher RMSE when fitted to those results. The authors have plotted the surface and it is very similar to the other MT-HT compressors. The origin for the errors could then be caused by a higher experimental uncertainty. Anyhow, all the proposed correlations, were able to describe those results with still high accuracy.

4. CONCLUSIONS

A thorough analysis of the energy consumption characteristics of scroll compressors have been performed. The study has included all scroll compressor results included in the AHRI reports corresponding to the AHRI Low-GWP Alternative Refrigerants Evaluation Program. The following main conclusions can be drawn from the performed study.

- The first conclusion is that when the compressor is measured in a wide range of operating conditions, inside its envelope, the compressor efficiency shows a complex shape, and it is clearly sensitive to the suction conditions (superheat). In contrast, the compressor consumption is a smooth surface when plotted versus the evaporation and condensation temperatures (or pressures), and it shows very little dependence on the superheat. Therefore, compressor consumption is much easier to characterize by fitting a polynomial than compressor efficiency.
- For scroll compressors it is not necessary to employ a 10 coefficients polynomial, as proposed in ANSI/AHRI 540, 2015, to characterize the compressor consumption. The much compact expression proposed by Shao et al., 2004 is accurate enough and requires many less test points to be fitted to.
- The authors have found that if the compressor consumption is correlated versus the condensation and evaporation pressures, the correlation results are better and moreover, it is more universal, being more independent of the employed refrigerant.
- The energy consumption of scroll compressors is a quite plane and smooth surface. A simple correlation with linear terms on the condensation and evaporation pressures together with a cross-term with their product, requires only 4 coefficients and provides a very simple and robust representation. If more accuracy is required, a 6 coefficients polynomial including a quadratic term for each pressure provides an excellent accuracy all across the compressor envelope.

Table 2: Correlations results

	Correlation 1			Correlation 2			Correlation 3				
Coeff	**Estimate**	**MRE (%)**	**RMSE (W)**	**Estimate**	**MRE (%)**	**RMSE (W)**	**Estimate**	**MRE (%)**	**RMSE (W)**	**Source**	**Fluid**
C0	7.650E-01	2.34	21.50	5.876E-01	1.54	13.44	1.364E+00	2.19	14.04	AHRI21	R404A
C1	-2.086E-03			1.100E-01			4.177E-04				
C2	8.803E-02			8.301E-02			2.082E-02				
C3	4.986E-03			-1.782E-02			-2.083E-04				
C4	-			-8.686E-05			-1.109E-02				
C5	-			7.071E-03			4.832E-04				
C0	6.718E-01	1.89	17.42	5.179E-01	1.29	9.40	1.165E+00	1.65	9.73	AHRI21	ARM31a
C1	1.598E-02			1.197E-01			3.626E-04				
C2	8.459E-02			8.342E-02			1.830E-02				
C3	5.617E-03			-2.242E-02			-1.556E-04				
C4	-			-2.473E-04			-8.665E-03				
C5	-			8.578E-03			4.503E-04				
C0	7.080E-01	2.61	18.41	5.574E-01	1.61	11.01	1.260E+00	1.85	11.98	AHRI21	D2Y65
C1	1.104E-03			1.028E-01			4.285E-04				
C2	8.712E-02			8.351E-02			1.873E-02				
C3	5.247E-03			-1.886E-02			-1.699E-04				
C4	-			-1.473E-04			-1.027E-02				
C5	-			7.683E-03			4.824E-04				
C0	6.125E-01	2.27	15.79	5.073E-01	1.50	9.04	1.164E+00	1.29	9.12	AHRI21	L40
C1	1.549E-02			1.149E-01			4.079E-04				
C2	9.143E-02			8.526E-02			1.627E-02				
C3	5.172E-03			-2.182E-02			-1.650E-04				
C4	-			-1.149E-04			-8.714E-03				
C5	-			8.141E-03			4.321E-04				
C0	6.063E-01	1.46	15.51	5.289E-01	0.91	8.89	1.306E+00	1.28	13.62	AHRI21	R32/R134a
C1	-5.939E-03			1.076E-01			5.739E-04				
C2	1.025E-01			8.770E-02			1.395E-02				
C3	4.996E-03			-2.107E-02			-2.337E-04				
C4	-			9.159E-05			-1.140E-02				
C5	-			7.826E-03			4.759E-04				
C0	2.758E-01	2.57	12.86	3.242E-01	0.72	4.95	7.719E-01	1.21	7.26	AHRI11	R410A
C1	-2.954E-02			-1.080E-02			4.470E-04				
C2	5.846E-02			4.813E-02			1.002E-03				
C3	4.317E-04			-2.900E-04			-7.612E-05				
C4	-			2.913E-04			-3.930E-03				
C5	-			-1.346E-04			-2.073E-05				
C0	4.033E-01	2.71	16.88	3.962E-01	3.19	12.53	7.952E-01	3.12	14.43	AHRI11	R32
C1	-4.484E-02			-1.635E-02			4.836E-04				
C2	5.235E-02			4.307E-02			6.100E-04				
C3	1.305E-03			-6.050E-04			-7.108E-05				
C4	-			3.195E-04			-6.163E-03				
C5	-			5.302E-04			6.753E-05				
C0	2.880E-01	4.95	17.94	3.566E-01	4.19	10.61	7.815E-01	4.62	13.00	AHRI11	DR5
C1	-3.288E-02			-1.259E-02			4.626E-04				
C2	5.778E-02			4.479E-02			-1.732E-03				
C3	6.835E-04			3.952E-05			-4.084E-05				
C4	-			4.213E-04			-2.703E-03				
C5	-			-2.444E-04			-3.607E-05				
C0	2.959E-01	2.29	10.48	3.021E-01	1.02	4.64	6.949E-01	1.25	6.33	AHRI11	L41a
C1	-3.105E-02			-7.373E-03			3.922E-04				
C2	5.503E-02			4.661E-02			1.556E-03				
C3	7.344E-04			-8.129E-04			-8.312E-05				
C4	-			2.678E-04			-4.315E-03				
C5	-			2.042E-04			2.430E-05				
C0	9.187E-02	3.16	60.75	1.779E-01	2.58	51.17	1.383E+00	3.05	54.48	Cuevas, Lebrun	R134a
C1	-3.761E-02			-2.548E-03			7.654E-04				
C2	1.549E-01			1.321E-01			-3.100E-02				
C3	-6.756E-04			-9.498E-04			-2.660E-04				
C4	-			5.152E-04			1.959E-02				
C5	-			-1.101E-03			-1.686E-04				

NOMENCLATURE

SH	Superheat (K)	$\eta_c = \dfrac{\dot{m} \cdot \Delta h_{is}}{\dot{W}_c}$	Compressor efficiency (%)
SC	Subcooling (K)	$\dot{m}$	Refrigerant mass flowrate (kg/s)
T_{suc}	Suction temperature (ºC)	$\Delta h_{is} = h_{2s} - h_1$	Enthalpy difference (isentropic compression) (kJ/kg)
T_{evap}	Evaporation temperature at dew point (ºC)	P_r	Pressure ratio (-)
T_{cond}	Condensation temperature at dew point (ºC)	$\dot{W}_c$	Compressor power input (kW)
P_{evap}	Evaporation pressure (bar)	MRE	Maximum Relative Error (%)
P_{cond}	Condensation pressure (bar)	$RMSE$	Root Mean Square Error

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