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Experimental investigation on materials and lubricants for sliding-vane air compressors

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Abstract. Positive-displacement compressors and, among them, sliding-vane rotary machines are widely used in the compressed air sector. As in many other industrial fields, the efficient utilization of energy has become a major goal also in this sector. The aim of the present activity is the experimental investigation on the influence of two vanes materials (cast iron and aluminium with anodized surface) and of four commercial lubricants (characterized by different formulations and additives concentrations) on the performance of a mid-capacity sliding-vane rotary compressor in a number of operating pressures. The performance is identified by both the volume flow rate and the absorbed mechanical power, evaluated according to the international standard ISO 5167 and ISO 1217. The campaign indicates that the considered lubricants do not affect appreciably the volumetric flow rate. On the other hand, the specific lubricants determine a variation of about 1% of the mechanical power for both materials, while the specific material a variation between 0.9% and 2.6%. The best performance is achieved by aluminium vanes and a synthetic poly-α-olefin lubricant.

1. Introduction and test conditions

Positive-displacement air compressors are adopted widely in commercial and industrial applications. In these applications, compressed air may count for an appreciable fraction of the total energy use. Hence, increasing the efficiency of the compressors yields large benefits from many perspectives: energy, economic and environmental. With the scope of achieving such benefits, the present work investigates experimentally the influence of materials and of lubricants on the performances of sliding-vane rotary compressors (SVRC): the weight of vane and the lubricant properties affect directly the friction losses and, thus, the compressor efficiency. A commercial SVRC, whose features are reported in Table 1, is employed for the purpose and tested under diverse conditions.

Table 1. Properties of the sliding-vane rotary compressor.

Rated flow rate, l/min*	3500
Rated working pressure, bar-g	7.5
Rated power, kWe	22
Nominal rotor speed, RPM	1500

* Free air delivery as per ISO 1217:1996 annex "C"

Each test condition is characterized by:

- the material of the vanes: 2 options, cast iron and aluminium with anodized surface;
- the lubricant: 4 market oils characterized by diverse formulations and additives concentrations;
- the delivery pressure: 5 options, from 6.5 to 8.5 bar-g by a 0.5-step;
- the operating temperature of about 85°C;
- the nominal rotor speed of 1500 RPM.

The combination of all characteristics generates 40 test conditions. All conditions are repeated 10 times in at least 2 different days to verify repeatability and increase the confidentiality of the results, yielding an experimental campaign of 400 tests in total. The sequence of the tests is randomized to cancel the effect of any correlation among them. The considered performances are: (i) the standard volume flow rate of air and (ii) the absorbed mechanical power of the packaged compressors calculated accordingly to standard ISO 1217 and ISO 5167.

The present activity is a continuation of an industrial-academic collaboration that has defined and proved already a number of technical enhancements to reach higher efficiencies in sliding-vane rotary compressors [1,2]. To the knowledge of the authors, this work is the first experimental investigation of materials and lubricants for positive-displacement compressors. The next sections will define in details the materials as well as the lubricants, the experimental setup, the results and the conclusions.

2. Materials and lubricants

The two materials options are cast iron vanes (CIV) and aluminium alloy vanes with anodized surface (AlV). The main features of the chosen materials are listed in Table 2. The differences between them are well known: cast iron offers better mechanical properties than aluminium, it is readily machined and, additionally, the machined surfaces are resistant to sliding wear. Furthermore, cast iron has a high thermal conductivity, low modulus of elasticity and the ability to withstand thermal shock. For these reasons this material is often used for the vanes. On the other hand, aluminium has a lower density and its superficial properties can be easily improved via a finishing superficial treatment, such as anodization. This treatment consists in the growth of an oxide thin coat on the material surface by way of an irreversible electrochemical process. The anodization allows improving the superficial mechanical characteristics and the corrosion resistance. Additionally, it improves the superficial hardness and increases the affinity with lubricants. The AlV used in the experimental investigation are characterized by an oxide coat with a thickness of about 20 μm. Both CIV and AlV have been manufactured with similar roughness indices (reported in Table 2) in order to evaluate only the effect of weight reduction on the performance of the SVRC.

Table 2. Properties of the chosen vane materials.

Properties	**cast iron**	**aluminium alloy**
Superficial treatment	None	Anodization (20 μm)
Density, kg/m^3	7200	2700
Specific heat*, J/kg/K	460	920
Thermal conductivity at 100°C, W/m/K	48.5	180
Coefficient of expansion*, μm/m/K	11.7	24
Modulus of Elasticity, GPa	120	70
Weight of a single vane	175	65
Roughness index, R_a	0.38	0.36

*Between 20°C and 100°C

Almost all positive-displacement air compressors require an oil to cool, seal and lubricate internal components. A correct lubrication ensures the reliability of the equipment, preventing corrosion and wear, protecting internal metal parts, and contributes to reduce the energy consumption. The formulations and properties of the four lubricants considered here are reported in Table 3: the performances of ISO-VG 68 diester-based synthetic lubricant (A), usually employed on the SVRC, are compared against those of an ISO-VG 100 Poly-α-olefin synthetic lubricant (B) and two different ISO-VG 100 diester-based synthetic lubricants (C, D). The lubricant viscosity affects the performances of air compressors in several working conditions: for example, viscosity determines the ease with which the equipment can be started in low-temperature environment or it can be kept running at high-temperature conditions. The four lubricants have been selected considering the operating temperature, the speed at which vanes are moving with respect to the rotor and the stator, and the load upon the compressor components of typical conditions. Although the considered lubricants have similar viscosity at higher temperatures, they differ appreciably in formulation and in additives concentration: these properties influence the tribology of the compressor and, ultimately, air volume flow rate and the absorbed mechanical power. In the present work, however, the lubricant effects on durability of lubricants are not evaluated.

Table 2. Properties of lubricants from datasheet.

Properties	Test Method	**A**	**B**	**C**	**D**
Type	-	Synthetic	Synthetic	Synthetic	Synthetic
Base	-	Diester	Poly-α-olefin	Diester	Diester
Additives concentration	-	high	low	medium	none
Viscosity, cSt @ 40 °C	ASTM D7042	68	91	96	95
Viscosity, cSt @ 100 °C	ASTM D7042	10	14.8	10.7	9.2
Viscosity index	ASTM D2270/ISO 2909	120	170	96	63
Total acid number, mg KOH/g	ASTM D664	0.17	0.03	0.18	0.11
Density, kg/m^3	ASTM D7042/ISO 12185	951	849	957	954

3. Experimental setup

The experimental rig, shown in Figure 1, employs the necessary instrumentation to measure: temperatures and pressures of air along the compression, the delivered volume flow rate, temperatures and pressures of lubricant along the process, shaft torque and rotational speed. The experimental setup is design to evaluate the compressor performance while varying the delivery pressure. In particular, the mechanical power is calculated as product of shaft torque and rotational speed measured using a flange torque meter installed between the compressor and the electric motor. A Kistler 4504B1KB1N1 torque meter (Full Scale of 1000 Nm, Accuracy ±0.5% FS) is controlled by the evaluation instrument Kistler CoMo Torque Type 4700A. The air volume flow rate is firstly determined considering the standard ISO 5167, than converted in the Free Air Delivery (FAD) conditions according to standard ISO 1217. The electronic data acquisition is performed thought the National Instruments cDAQ-9178 wired to a personal computer. LabView Signal Express 2011® is used to carry out the measurements. The test rig allows the easily replacement of vanes and lubricant to set the desired test condition. During every lubricant replacement, the oil circuit is accurately cleaned to prevent contaminations.

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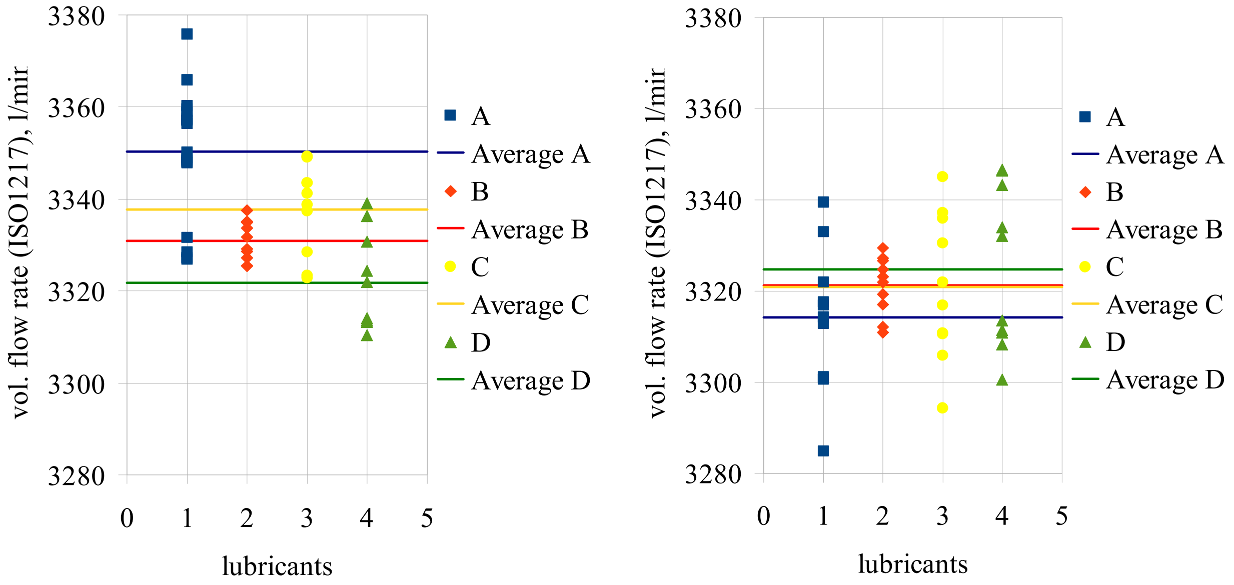
Figure 1. The test rig based on a mid-capacity sliding vane rotary compressor (top) and the acquisition system (bottom).

4. Results and discussion

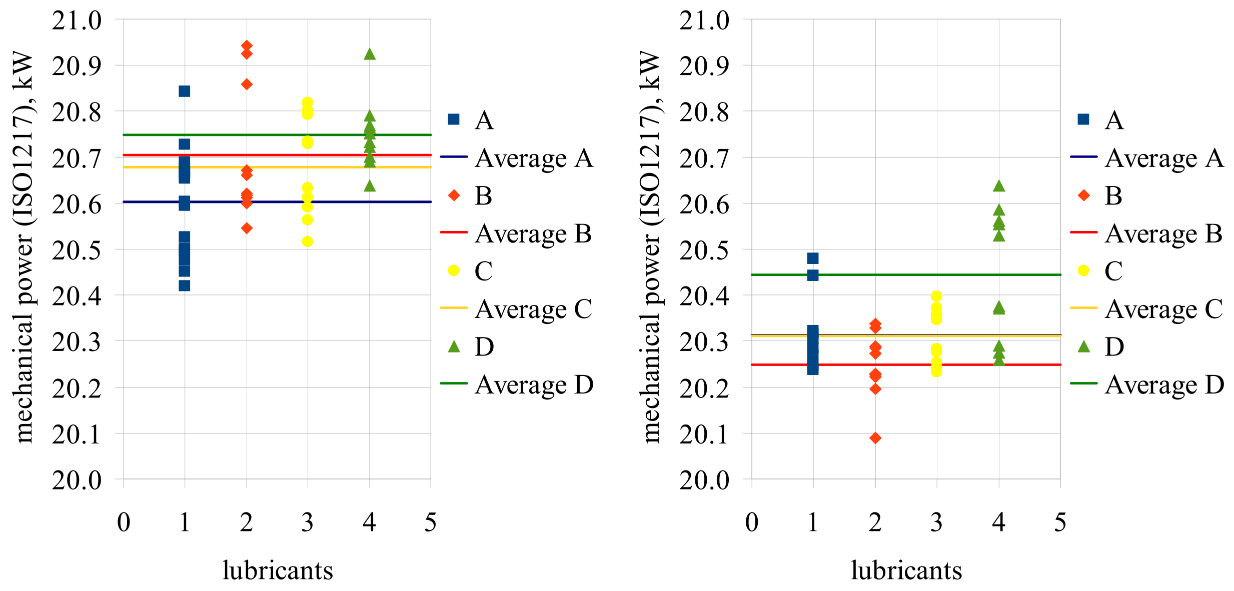
As mentioned, the purpose of this study is the investigation on the effect of 2 vane materials and 4 commercial lubricants on the performance of a sliding vane rotary compressor at 5 delivery pressures, from 6.5 to 8.5 bar-g by a 0.5-step. The test conditions are performed at the operating temperature of about 85°C and operating speed of 1500 RPM. A single test condition is repeated 10 times to verify the repeatability of the measurements and increase the confidentiality of the results. The averaged values of the empirical data over the 10 repeated tests are evaluated to verify the variation of the performances. Figures 2 and 3 are representative of the experimental approach: they illustrate the average values of the standard volumetric flow rate and the mechanical power, calculated according to the international standards ISO 1217 and ISO 5167, for each lubricant and vane material configuration at the pressure of 7.5 bar-g. The standard relative uncertainty on flow rate and mechanical power are around 2% and 1%, respectively, for each test As anticipated, each test conditions is repeated over 10 different times to verify the data repeatability and increase the confidentiality. Therefore the averaged values are employed in the next comparisons.

The experimental results reported in Figures 2a and 2b show that it is not possible to establish clearly a correlation between the volumetric flow rate and the lubricant with the adopted instrumentation: lubricants do not affect appreciably the volumetric flow rate, and the measured variations fall within the range of uncertainty of measurement. On the other hand, as shown in Figures 3a and 3b, when the mechanical power is considered, the effects of lubricants on the SVRC performance are more significant. In particular, when the lubricant A is used, the lowest mechanical power is achieved. This is due not only to the lower viscosity of lubricant A but probably also to its formulation. At the considered operating temperature of about 85°C, indeed, the viscosities of all lubricants are comparable and cannot justify the differences in mechanical power, which are due probably to the different formulations and additives concentration. In this regard, the lower additives concentration of lubricant D justifies the worst performance of this lubricant. As shown in Figures 3a and 3b, when ISO-VG 100 lubricants B, C and D are employed, an increase of the absorbed mechanical power can be noted, especially in the case of CIV. However, results show that the lubricant replacements determine only a slight variation (up to 1%) of the mechanical power for both the considered materials.



(a) Cast iron vane (CIV) **(b)** Cast iron vane (AlV).

Figure 2. Effect of lubricants on the volumetric flow rate of SVRC at 7.5 bar-g, 85 °C and 1500 RPM.



(a) Cast iron vane (CIV) **(b)** Cast iron vane (AlV).

Figure 3. Effect of lubricants on the mechanical power of SVRC at 7.5 bar-g, 85 °C and 1500 RPM.

The absorbed mechanical power decreases when AlV are used: the reduction of vane weight implies a reduction of the mechanical power on the order of 0.9-2.6%. The reduction of power consumption can be attributed not only to the lower density of the aluminium alloy but also to the improvement of its mechanical properties due to the superficial treatment. The chosen anodization allows to obtain a very high surface hardness, while the homogeneous surface finishing increases the affinity with the lubricant. Although the superficial treatment has a lower thickness comparing to conventional hard oxide coating, it resists very well to wear, improving the mechanical performance of AlV. As shown in the Figure 4, the performances of AlV are better than those of CIV in the range of the considered pressures: the reduction of the weight and the good surface finishing of the AlV determine an appreciable reduction of the adsorbed mechanical power. The maximum mechanical power reduction is achieved with the AlV and lubricant B. For both CIV and AlV the lubricant C is the only diester-based lubricant able to achieve the same performance of the Poly-α-olefin-based lubricant B. The good performances of the lubricant C are probably due to the use of some addictives (i.e. phosphorus, magnesium, etc.) in the formulation to improve the affinity between the lubricant and AlV surface. Results show that lubricant D offers the worst performance in the considered operating conditions: the lower viscosity index and, probably, the absence of additives justify the worse performances.

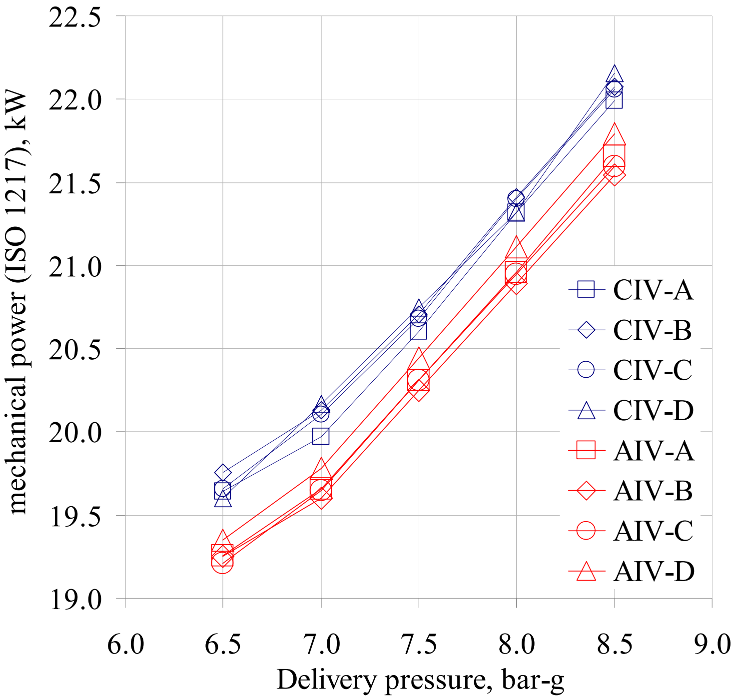


Figure 4. Comparison between the mechanical absorbed power profiles by varying materials (red and blue lines), lubricants (four markers) and delivery pressure at 85 °C and 1500 RPM.

Conclusions

This work investigates experimentally the performances of a commercial mid-capacity sliding-vane rotary compressor employing 2 kinds of materials for the vanes (cast iron referred to as CIV, and aluminium with anodized surface as AlV) and 4 different commercial oils (indicated as lubricant A to D) under 5 delivery pressures. All test conditions are replicated 10 times to verify the repeatability of the measurements and increase the confidentiality of the results. Volumetric flow rate and absorbed mechanical power for each test are calculated according to the international standards ISO 1217 and ISO 5167. The conclusions of the work are as follows.

- The considered vane materials and lubricants do not affect appreciably the volumetric flow rate, and the measured variations of performances fall within the range of the uncertainty of measurement. On the other hand, the effects of vane materials and lubricants on absorbed mechanical power are more significant: in the considered operating conditions, the lubricant replacement determines a slight variation of about 1% of the mechanical power for both the considered vanes materials.
- Lubricant A (ISO-VG 68) allows to reach the lowest mechanical power when cast iron vanes (CIV) are used. When lubricants B, C and D (all ISO-VG 100) are employed, an increase of the absorbed mechanical power can be noted, especially in the case of CIV. At the considered operating temperature of about 85°C the viscosities of all lubricants are comparable and cannot justify the slight differences in mechanical power. Performance are more probably influenced by the lubricant formulations and additive concentrations.
- The absorbed mechanical power decreases with aluminium vanes with anodized surface (AlV) by up to 2.6%. The reduction of power consumption can be attributed not only to the lower density of the aluminium alloy but also to the improvement of its mechanical properties due to the superficial treatment. The finishing surface of AlV allows to reach a good affinity with the lubricants. Results suggest that AlV is a proper solution for the energy optimization of SVRC.

The future work will focus on the evaluation of the effect of vane material and lubricants on a large-capacity 75 kW SVRC: in the future study the performance of AlV will be also investigated by varying the rotation speed of the compressor.

References

[1] Valenti G, Murgia S, Contaldi G and Valenti A 2014 *Case Studies in Thermal Engineering* Experimental evidence of the thermal effect of lubricating oil sprayed in sliding-vane air compressors **4** 113

[2] Valenti G, Colombo L, Murgia S, Lucchini A, Sampietro A, Capoferri A and Araneo L 2013 *Applied Thermal Engineering* Thermal effect of lubricating oil in positive-displacement air compressrs **51** 1055

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